Flameless Heater Performance
Two and One Half Years of Operation

Presented by:
Great Southern Flameless, LLC
The World’s First Flameless Crude Heater

US Patent No. 8,128,399
(additional patents pending)
January 23, 2012 - Receipt of first Flameless Heater Order

October 1, 2012 - Delivery of Flameless Heater

February 27, 2013 - Lighting of pilots and Conventional Combustion

April 22, 2013 - Flameless Combustion

September, 2015 - 2-1/2 Years of Continuous Operation
NO$_x$ Reduction - SCR level NO$_x$ emissions without an SCR
CEMS DATA RECORDED OVER A 4 MONTH CONTINUOUS PERIOD

<table>
<thead>
<tr>
<th>Date</th>
<th>NOx, lb/MMBtu (HHV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/14/2014 16:58</td>
<td>0.0064</td>
</tr>
<tr>
<td>6/30/2014 16:58</td>
<td>0.0066</td>
</tr>
<tr>
<td>6/12/2014 8:58</td>
<td>0.0078</td>
</tr>
<tr>
<td>5/30/2014 0:58</td>
<td>0.0069</td>
</tr>
<tr>
<td>5/14/2014 8:58</td>
<td>0.0066</td>
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<tr>
<td>4/27/2014 8:58</td>
<td>0.0073</td>
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<tr>
<td>4/13/2014 16:58</td>
<td>0.0066</td>
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<tr>
<td>3/31/2014 8:58</td>
<td>0.0079</td>
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<tr>
<td>3/11/2014 16:58</td>
<td>0.0079</td>
</tr>
<tr>
<td>3/18/2014</td>
<td></td>
</tr>
</tbody>
</table>

Note: 0.01 lb/mmbtu = 8 ppmvcd
FLAMELESS HEATER PERFORMANCE DATA

- $\text{NO}_x$ Reduction - SCR level $\text{NO}_x$ emissions without an SCR
- Radiant Heat Flux
TYPICAL RULES DO NOT APPLY

- API 530 specification of 1.2:1 peak to average circumferential radiant heat flux ratio for a double fired coil
- GSF flameless heater circumferential factor is 1:1
- Typical industry longitudinal factor range is 1.1:1 and 1.4:1
- GSF flameless heater longitudinal factor is 1:1
- Benefit - reduced coil length/surface area and reduced coil cost
FLAMELESS HEATER PERFORMANCE DATA

- NO\textsubscript{x} Reduction - SCR level NO\textsubscript{x} emissions without an SCR
- Radiant Heat Flux
- Radiant Section Flue Gas Recirculation
RADIANT SECTION FLUE GAS RECIRCULATION

- CFD modeling indicates recirculation rate that is 4 times greater than a conventional heater due to:
  - Tangential firing
  - Momentum imparted by the fuel and air nozzles
- Flue gas velocity in non-recirculation zone is typical of a conventional heater, 3-6 ft/sec
- Recirculation zone is between the refractory wall and the tube face
GSF’S FLAMELESS HEATER DESIGN
PLAN VIEW
FLAMELESS HEATER PERFORMANCE DATA

- NO$_x$ Reduction - SCR level NO$_x$ emissions without an SCR
- Radiant Heat Flux
- Radiant Section Flue Gas Recirculation
- No Flame/Hot Gas Impingement
NO FLAME OR HOT GAS IMPINGEMENT

- Patented castable refractory dimple pattern pins rotating flue gas to the wall.

US Patent No. 8,128,399
(additional patents pending)
NO FLAME OR HOT GAS IMPINGEMENT

- Recirculation zone is designed for high volume of flue gas in rotation.
FLAMELESS HEATER PERFORMANCE DATA

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- Extended Run Length
EXTENDED RUN LENGTH

- No high localized flux rates to radiant tubes with GSF flameless technology
  - No flame impingement
  - No hot gas impingement
- No localized high tube metal temperatures
- Low fouling rates
- Unnecessary shut downs are expensive and pose safety hazards
FLAMELESS HEATER PERFORMANCE DATA

- NO\textsubscript{x} Reduction - SCR level NO\textsubscript{x} emissions without an SCR
- Radiant Heat Flux
- Radiant Section Flue Gas Recirculation
- No Flame/Hot Gas Impingement
- Extended Run Length
- Reduced Heater Size
Reduction in heater size due to:
- Longitudinal/circumferential factors
- Much higher average radiant section flux rates

<table>
<thead>
<tr>
<th>Model</th>
<th>Average Radiant Flux</th>
<th>Peak to Average Flux Ratio (Circumferential Factor)</th>
<th>API 530 Peak</th>
<th>Longitudinal Factor</th>
<th>Overall Peak Flux Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Single Fired Heater</td>
<td>10,000</td>
<td>1.8</td>
<td>18,000</td>
<td>1.33</td>
<td>24,000</td>
</tr>
<tr>
<td>GSF Flameless Double Fired Coil</td>
<td>21,000</td>
<td>1.0</td>
<td>21,000</td>
<td>1.0</td>
<td>21,000</td>
</tr>
</tbody>
</table>
FLAMELESS HEATER PERFORMANCE DATA

- NO\textsubscript{x} Reduction - SCR level NO\textsubscript{x} emissions without an SCR
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- No Flame/Hot Gas Impingement
- Extended Run Length
- Reduced Heater Size
- Reduced Radiant Coil Surface Area
REDUCTION IN REQUIRED RADIANT COIL SURFACE AREA

- 52% reduction of radiant coil surface area = 52% reduction in coil cost
- Reduction in process coil pressure drop
- Allows for increased mass velocities
- Higher mass velocities are important for thermally sensitive process fluids such as shale oil
NO\textsubscript{x} Reduction - SCR level NO\textsubscript{x} emissions without an SCR

Radiant Heat Flux

Radiant Section Flue Gas Recirculation

No Flame/Hot Gas Impingement

Extended Run Length

Reduced Heater Size

Reduced Radiant Coil Surface Area

Radiant Section Duty and Efficiency
RADIANT SECTION EFFICIENCY

- Typical radiant to convection section duty split for a conventional heater is 65% radiant/35% convection.
- The GSF flameless heater radiant to convection section duty split is approximately 95% radiant/5% convection.
- Flue gas temperature leaving the radiant section for a typical conventional heater is 1500-1600°F.
- Flue gas temp leaving the GSF flameless heater radiant section is approximately 1200°F.
- Approximately 11% increase in radiant efficiency over conventional heaters.
FLAMELESS HEATER PERFORMANCE DATA

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- No Flame/Hot Gas Impingement
- Extended Run Length
- Reduced Heater Size
- Reduced Radiant Coil Surface Area
- Radiant Section Duty and Efficiency
- Elimination of Filter/Coalescer
LARGE FUEL PORTS

- Fuel ports are approximately 3/8” diameter
- Eliminates fuel port plugging
- Eliminates need for fuel filter/coalescer
- Reduced maintenance cost
- Reduced capital cost
FLAMELESS HEATER PERFORMANCE DATA

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- Reduced Radiant Coil Surface Area
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- Reliability (Availability)
RELIABILITY (AVAILABILITY)

- No loss of combustion in 2-1/2 years of flameless operation
- Any and all trips have been associated with instrumentation nuisance trips
- Three different monitoring systems for loss of combustion:
  - Downstream thermocouples monitoring temperature rate of change
  - High Carbon Monoxide alarm
  - High unburned hydrocarbon shutdown
- Hot combustion air and fuel gas is all that is needed to continuously maintain combustion
FLAMELESS COMBUSTION MONITORING SYSTEM

- Recirculating flue gas flow
- Flameless fuel nozzle
- Air nozzles
- Conventional fuel nozzles
- Air nozzles
- Flameless combustion zone

Temperature rate of change combustion monitoring thermocouples group of 3 each level
FLAMELESS HEATER PERFORMANCE DATA

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- Extended Run Length
- Reduced Heater Size
- Reduced Radiant Coil Surface Area
- Radiant Section Duty and Efficiency
- Elimination of Filter/Coalescer
- Reliability (Availability)
- Scale Up
Design symmetry

Symmetry modules can be stacked or placed end to end to accommodate available real estate

(Note: not shipping modules but conceptual symmetry modules for scale up)
Scale Up

<table>
<thead>
<tr>
<th>Symmetry Modules</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10 MMBtu/ Hour</td>
</tr>
<tr>
<td>2</td>
<td>20 MMBtu/ Hour</td>
</tr>
<tr>
<td>3</td>
<td>30 MMBtu/ Hour</td>
</tr>
<tr>
<td>4</td>
<td>40 MMBtu/ Hour</td>
</tr>
<tr>
<td>8</td>
<td>80 MMBtu/ Hour</td>
</tr>
<tr>
<td>12</td>
<td>120 MMBtu/ Hour</td>
</tr>
<tr>
<td>24</td>
<td>240 MMBtu/ Hour</td>
</tr>
</tbody>
</table>
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- No Flame/Hot Gas Impingement
- Extended Run Length
- Reduced Heater Size
- Reduced Radiant Coil Surface Area
- Radiant Section Duty and Efficiency
- Elimination of Filter/Coalescer
- Reliability (Availability)
- Scale Up
- Economics
## COST COMPARISON

<table>
<thead>
<tr>
<th>Feature</th>
<th>GSF FLAMELESS DOUBLE FIRED</th>
<th>CONVENTIONAL DOUBLE FIRED</th>
<th>CONVENTIONAL DOUBLE FIRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heater And APH Cost, $*</td>
<td>3,103,000</td>
<td>4,152,365</td>
<td>4,152,365</td>
</tr>
<tr>
<td>SCR Cost, $</td>
<td>NA</td>
<td>NA</td>
<td>1,200,000</td>
</tr>
<tr>
<td>Total Cost, $</td>
<td>3,103,000</td>
<td>4,152,365</td>
<td>5,352,365</td>
</tr>
<tr>
<td>NOx, ppmvd</td>
<td>4-8</td>
<td>50-70</td>
<td>4-8</td>
</tr>
<tr>
<td>Filter/ Coalescer Required</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Flame/ Gas Impingement on Tubes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased Run Length</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Increased Tube Life</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Even Heat Transfer to Radiant Coil</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Burner-Burner Flame Interaction</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Multi-Burner Effect NOx Increase</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Basis: 60 MMBtu/hr, 850F Air Preheat

*Equipment Cost Only (not installed)*
SUMMARY

- NO\textsubscript{x} Reduction - SCR level NO\textsubscript{x} emissions without an SCR
- Radiant Heat Flux
- Radiant Section Flue Gas Recirculation
- No Flame/Hot Gas Impingement
- Extended Run Length
- Reduced Heater Size
- Reduced Radiant Coil Surface Area
- Radiant Section Duty and Efficiency
- Elimination of Filter/Coalescer
- Reliability (Availability)
- Scale Up
- Economics
GSF FLAMELESS TECHNOLOGY

- Safe
- Simple
- Reliable
- Saves $$
QUESTIONS

www.GreatSouthernGroup.com