DOE Webcast
GTI Super Boiler Technology
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WHO WE ARE

Gas Technology Institute

Leading U.S. research, development, and training organization serving the natural gas industry and energy markets

- An independent, 501c (3) not-for-profit

Serving the Energy Industry Since 1941

- Over 1,000 patents
- Nearly 500 products commercialized
Super Boiler Background

> U.S. industrial and commercial steam boilers
  – Consume over 6 quads of natural gas per year
  – Wide range of steam uses from process steam to space heating

> Installed base of steam boilers
  – Largely over 30 years old
  – Average efficiency 76%
  – Typical NOx emissions 85 ppmv
  – Significant potential for improved technology
Project Origin & Goals

> Super Boiler program
  - Started by DOE and gas industry in 1999
  - GTI team selected to carry out project

> Goals:
  - Maximum efficiency
  - NOx and CO less than 5 ppmv
  - Reduced footprint and weight
  - Cost-effectiveness
Natural gas combustion produces heat for steam generation, but also unwanted emissions (NOx, CO, VOC, PM)

Combustion at lower excess air improves energy efficiency

Minimizing NOx while achieving complete fuel burnout at low excess air was a huge challenge
Combustion: parallel approaches

> Single-stage
  - Commercially available NatCom burner
  - Internal staging and FGR

> Two-stage
  - Extension of GTI’s FIR burner technology
  - Staged premixed combustion with inter-stage heat removal
  - No FGR required
  - Requires special boiler design
Combustion: single-stage controls

> Operator interface via Hawk ICS touchscreen PLC control panel

> PLC control
– Fuel/air ratio control via individual drive motors with VFD trim
– FGR damper control from individual controller
– O$_2$ trim managed by in-situ O$_2$ sensor
– Separate combustion setups for heat recovery and bypass modes
Combustion: two-stage version*

> 80 HP lab boiler
- Staged burner with internal recirculation
- Interstage cooling pass
- No FGR required
- 3-5 ppmv NOx at 1-2% O₂

Combustion: two-stage field demo

> 300 HP field demonstration
  - Clement Pappas & Co. (Ontario CA)
  - Juice and beverage bottler
  - Steam used for pasteurization and cleaning
  - Steam demand = zero to 9,500 lb/h, highly variable
  - Scale-up included integral head design
  - Operates year-round 24/7
  - Started testing Feb 2008
Combustion: two-stage controls

- Operator interface via Hawk ICS touchscreen PLC control panel

- PLC control
  - Critical first stage fuel/air ratio control via fuel delta-P and windbox air delta-P
  - Control implemented via parallel positioning (PP) controllers with VFD trim
  - O$_2$ trim integrated into air split management
  - Separate setups for heat recovery and bypass modes
Heat Transfer: convective pass

Enhanced firetube heat transfer
- Fire-tubes with extruded aluminum inserts
- Heat transfer 18X higher than conventional tubes
- 2-pass boiler can deliver 4-pass performance with a smaller footprint
Heat Transfer: field demonstrations

> 300 HP field demonstration
  - Both AL and CA demos use finned firetube inserts in two-pass design
  - Flue gas cooled to 35°F above steam temperature
  - California Super Boiler: 38% lighter & 31% smaller footprint than conventional 300 HP boiler

[Diagram showing comparison of Standard CB 300HP boiler (123 sq ft) and 300HP Super Boiler (85 sq ft)]
HEAT RECOVERY

- Natural gas combustion produces about 18% water from oxidation of H in fuel
- Water vapor up the stack accounts for 10% of fuel energy input, or 65% of stack loss
- Key to higher energy efficiency is to recover both sensible and latent heat
Heat Recovery: general approach

> Flue gas heat recovery

- Remove sensible heat with two economizers
- Remove latent heat with Transport Membrane Condenser (TMC)
- Suitable for end users with high make-up water usage
Heat Recovery: TMC concept*

- Transport Membrane Condenser (TMC)
  - Nanoporous ceramic membrane tubes
  - Water vapor permeation via capillary condensation
  - Partial vacuum on shell side
  - Counter-flow configuration

* U.S. Patent No. 6,517,607, 2008 Chicago Innovation Award
Heat Recovery: expanded system*

> Applications with high condensate return
- Limited make-up water reduces TMC capacity
- Recycle water through humidifying air heater (HAH)
- Air humidification helps suppress NOx

*U.S. Patent No. 7,066,396
Heat Recovery: Alabama field demo
Heat Recovery: Alabama field demo

SUPER BOILER DEMONSTRATION
Specification Rubber Products, Inc. - Alabaster, Alabama
Last updated at 7/24/2007 10:24:11 AM

- Stack Gas:
  - Temp: 128 °F
  - Dew pt: 124 °F
  - O2 (dry): 5.4%

- Air to Boiler:
  - Temp: 93 °F
  - Dew pt: 56 °F

- Flue Gas to LPE:
  - Temp: 235 °F
  - Dew pt: 131 °F

- Steam to Process:
  - Output: 4533 lb/h
  - Pressure: 120 psig

- 300 HP Boiler:
  - Natural Gas:
    - Flow: 5736 scfh
  - Makeup Water:
    - Flow: 3230 lb/h
    - Temp: 76 °F

- Boiler Status:
  - Heat Recovery ON
  - Fuel-steam efficiency: 93.8%
  - Total operating time: 5568 hrs
Heat Recovery: TMC hardware

> Down-flow “Version 1.0”
  - Cylindrical shell design
  - Tube bundles (17” x 4”), 99 tubes/bundle
  - Water on shell side with bottom inlet for natural counter-flow
  - Flue gas cooled to <160°F
  - Shell-side vacuum 3 psid
  - Flue gas pressure drop <4 in WC
Heat Recovery: California field demo

- Clement Pappas & Co. in Ontario CA
  - Heat recovery system (HRS) similar to Alabama site
  - HRS mounted above boiler
1\textsuperscript{st} and 2\textsuperscript{nd} Generation Membrane Bundles
TMC Version 2.1 in Duct

Warm water to deaerator

Warm moist flue gas in

Cooler
Dryer flue gas out

Cool feed water in
Heat Recovery: improved TMC design

- Upflow “Version 2.0”
  - Modular design
  - 25-HP tube bundle modules
  - Water inside tubes with staged downward flow
  - Above-boiler mounting
  - Easier assembly and service
  - More compact
  - Less ductwork
Heat Recovery: Utah field demo

> Retrofit of Existing 200 hp 150 Psig Firetube Boiler
  - TMC “Version 2.0” retrofit to standard 200 HP CB boiler
  - No condensate return/ no HAH
  - Low-cost integrated LPE panel
  - Integrated boiler/HR controls
Latest Improvements

> TMC Version 2.1
  - CFD modeling and full-scale lab tests revealed ability to reduce passes from 4 to 3
  - 25% savings in number of modules
  - TMC module capacity increased to 33 HP

> Air heater
  - Field data showed that HAH efficiency results could be achieved with non-humidifying air heater
  - 80% lower capital cost
  - Simpler controls
Proposed Heat Recovery Retrofit for 250 hp 150 psig CB Boiler

> Schematic
Required Support Equipment

- Makeup tank/ deaerator
  - Receives hot water from LPE
  - Two-stage level control
  - Need stable inputs (MUW, condensate return)
- Softened or de-mineralized water
- Water filter for TMC
- Structural supports/access platforms as needed
## Evaluation of TMC HRS Retrofit to 250 hp Boiler

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<thead>
<tr>
<th>Present Boiler</th>
<th>Retrofit with TMC HRS</th>
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<tbody>
<tr>
<td>&gt; Fuel: 902,000 therms/yr.</td>
<td>&gt; Fuel: 786,500 therms/yr</td>
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<tr>
<td>&gt; Water: 2,000,000 gallons/yr</td>
<td>&gt; Water: 1,600,000 gallons/yr</td>
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<tr>
<td>&gt; Stack Temperature: 407°F</td>
<td>&gt; Stack Temperature: 130°F</td>
</tr>
<tr>
<td>&gt; Efficiency: 82%</td>
<td>&gt; Efficiency: 94%</td>
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<tr>
<td>&gt; Savings: 115,500 therms/yr</td>
<td>&gt; Fuel Savings: $138,600/yr based on $1.20/therm</td>
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<td>&gt; Water Savings: $11,700/yr based on $2.20/750 gal’s</td>
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