



Super Boiler

> **Gas Technology Institute
Cleaver-Brooks Inc.**

May 2008

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 2000
 - GTI team selected to carry out project
- > Goals:
 - Maximum efficiency
 - NOx and CO less than 5 ppmv
 - Reduced footprint and weight
 - Cost-effectiveness



Project Moves Forward

- > Define program
 - Industrial Advisory Group
 - Cleaver-Brooks as manufacturing partner
 - Other participants: Media & Process Technology, PNNL, gas utilities
- > First-generation Super Boiler
 - Platform
 - Combustion
 - Heat transfer
 - Heat recovery
 - Controls



COMBUSTION

- ❖ Natural gas combustion produces heat for steam generation, but also unwanted emissions (NO_x, CO, VOC, PM)
- ❖ Combustion at lower excess air improves energy efficiency
- ❖ Minimizing NO_x while achieving complete fuel burnout at low excess air is a challenge



Combustion: parallel approaches

- > Single-stage
 - Commercially available NatCom burner
 - Internal staging and FGR
- > Two-stage
 - Extension of FIR burner technology
 - Staged premixed combustion with interstage heat removal
 - No FGR required
 - Requires special boiler design

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Combustion: single-stage field demo

- > 300 HP field demonstration
 - Specification Rubber Products (Alabaster, AL)
 - Makes rubber gaskets for the water works industry
 - Steam-heated vulcanizing presses
 - Steam demand = steady 3000-4000 lb/h
 - Operates year-round 24/5
 - Started operation July 2006



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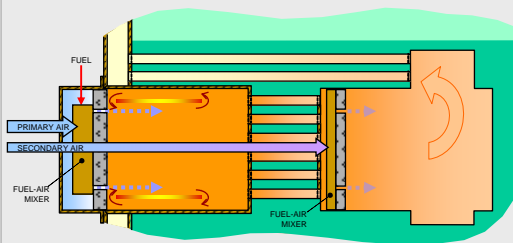
Combustion: single-stage controls



- > 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
 - O₂ trim managed by in-situ O₂ sensor
 - Separate combustion setups for heat recovery and bypass modes

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Combustion: two-stage version*



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



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* U.S. Patent No. 6,289,851 (Sept 2001)

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



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Combustion: two-stage controls

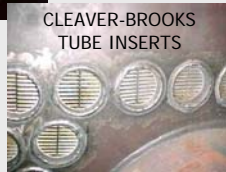


- > Operator interface via Hawk ICS touchscreen PLC control panel
- > PLC control
 - Critical first stage fuel/air ratio control via fuel delta-P and windbox air delta-P
 - Control implemented via parallel positioning (PP) controllers with VFD trim
 - O₂ trim integrated into air split management
 - Separate setups for heat recovery and bypass modes

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Heat Transfer: convective pass

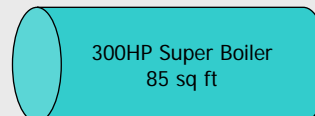
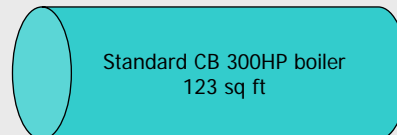
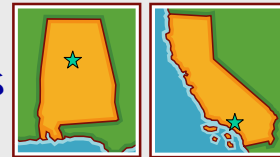
- > Enhanced firetube heat transfer
 - Firetubes with extruded aluminum inserts
 - Heat transfer 18X higher than rifled tubes
 - 2-pass boiler can deliver 4-pass performance in smaller size



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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



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HEAT RECOVERY

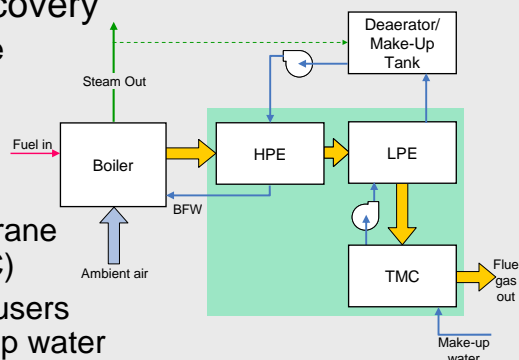
- ❖ Natural gas combustion produces about 18% water from oxidation of H in fuel
- ❖ Water vapor up the stack accounts for 10% of fuel energy input, or 65% of stack loss
- ❖ Key to higher energy efficiency is to recover both sensible *and* latent heat

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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

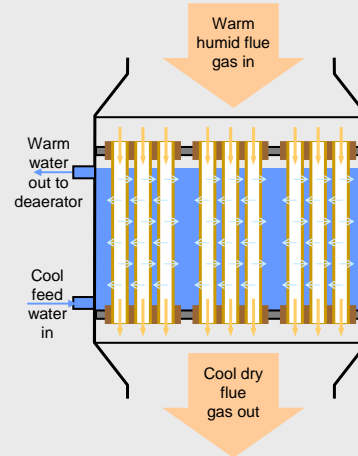


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Heat Recovery: TMC concept*

> Transport Membrane Condenser (TMC)

- Nanoporous ceramic membrane tubes
- Water vapor permeation via capillary condensation
- Partial vacuum on shell side
- Counterflow configuration



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* U.S. Patent No. 6,517,607

Heat Recovery: TMC hardware

> Downflow "Version 1.0"

- Cylindrical shell design
- Media & Process tube bundles (17" x 4" diam), 99 tubes ea
- Water on shell side with bottom inlet for natural counterflow
- Flue gas cooled to <math><160^{\circ}\text{F}</math>
- Shell-side vacuum 3 psid
- Flue gas pressure drop <math><4</math> inwc

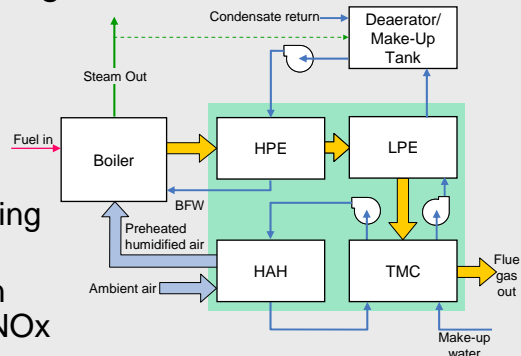


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Heat Recovery: expanded system*

> Applications with high condensate return

- Limited make-up water reduces TMC capacity
- Recycle water through humidifying air heater (HAH)
- Air humidification helps suppress NOx



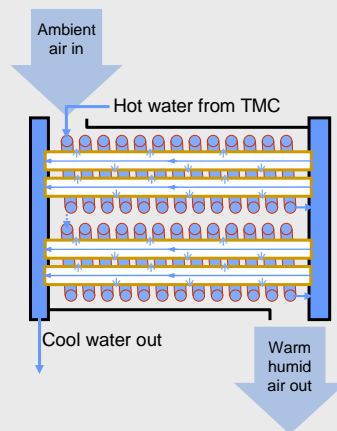
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*U.S. Patent No. 7,066,396

Heat Recovery: HAH concept

> Humidifying Air Heater (HAH)

- Cools TMC outlet water for recycle
- Heat exchanger coils transfer heat
- Nanoporous tubes transfer additional heat through evaporation
- Air is heated and humidified, water is cooled and sent back to TMC



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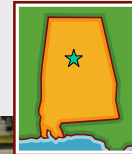
Heat Recovery: HAH hardware

- > Compact design
 - Inlet & outlet water distribution panels
 - Media & Process tube bundles (34" x 3" diam), 36 tubes ea
 - Separate PVC air duct for each bundle
 - Copper coil heat exchanger surrounds each bundle
 - Air-side pressure drop 1.5 inwc



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Heat Recovery: Alabama field demo



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Heat Recovery: Alabama field demo



> TMC design & operation

- 304SS shell with aluminum tube sheets
- 94 membrane bundles
- Venturi vacuum pump driven by compressed air
- Low-NPSH water outlet pumps



> TMC control

- Water level
- Vacuum
- Startup and shutdown

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Heat Recovery: Alabama field demo



> HAH design & operation

- 30 tube bundles
- Separate PVC air duct for each bundle
- Mounted on boiler air inlet
- Fiber air filter

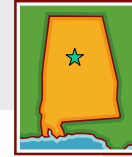


> HAH control

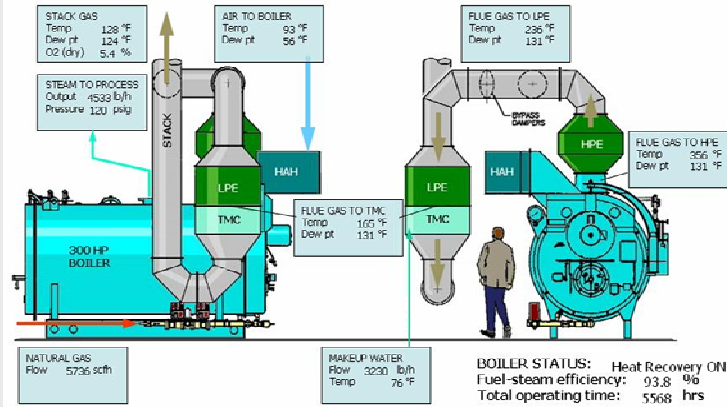
- Water flow
- Water pressure
- Startup and shutdown

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Heat Recovery: Alabama field demo



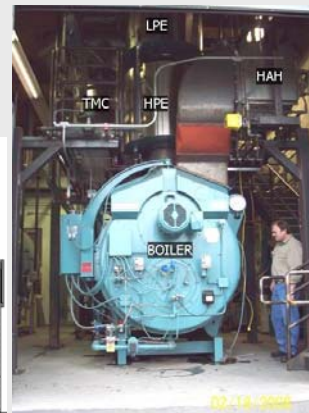
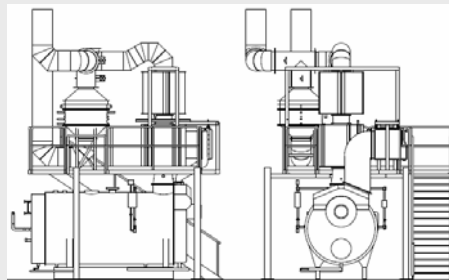
SUPER BOILER DEMONSTRATION
Specification Rubber Products, Inc. - Alabaster, Alabama
Last updated at
7/24/2007 10:24:11 AM



Heat Recovery: California field demo

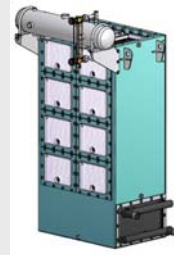


- > Clement Pappas & Co. in Ontario CA
 - Heat recovery system (HRS) similar to Alabama site
 - HRS mounted above boiler



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



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Heat Recovery: Utah field demo

- > Third Dimension Inc. in West Jordan UT
 - 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



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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



Acknowledgment

- > Thanks to DOE ITP, GRI, Southern California Gas, GTI-SMP, UTD NFP, California Energy Commission, California Air Resources Board, South Coast Air Quality Management District, Cleaver-Brooks, and the three host sites for the financial support of this project.

