Type RX Ultra-low NOx Burner

Innovative Clean Air Technology

S.T. Johnson Company

Celebrating a Century of Innovation
INNOVATIVE CLEAN AIR TECHNOLOGY

DEMONSTRATION OF AN ULTRA LO-NOx BURNER ON A FIRETUBE BOILER

A JOINT EFFORT BY:
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WITH SUPPORT FROM:
CALIFORNIA DAIRIES INC, TIPTON CA
MOEHLMAN BOILER TECHNOLOGY, FRESNO CA
RELIABLE EMISSIONS MEASUREMENTS, FRESNO CA

WITH MATCHING GRANT FUNDS FROM:
CALIFORNIA AIR RESOURCES BOARD
INNOVATIVE CLEAN AIR TECHNOLOGY GRANT PROGRAM
The Benefits and Costs of Ultra-low NOx Emissions

Benefits:
- Smog reduction
- Acid rain reduction
- Healthier air

Costs:
- Low efficiency
- High capital cost
- High operating cost
- More maintenance
- Safety
CURRENT & PROPOSED METHODS EMPLOYED TO ACHIEVE SUB 9ppm NOx

**CURRENT:**

- MASSIVE FGR BURNERS
- PREMIX POROUS MATRIX BURNERS
- POST COMBUSTION TREATMENT

**PROPOSED (Series RX Burner):**

- MOLECULAR MODIFICATION DURING COMBUSTION PROCESS
- COUPLED w/ STAGED COMBUSTION & MODERATE FGR
MASSIVE FGR BURNERS

**FEATURES**

- CAN USE FGR FLOWS AS HIGH AS 40% OF THE TOTAL STACK EFFLUENT
- SOME SYSTEMS OPERATE VERY CLOSE TO THE LIMITS OF FLAMABILITY
- SOME SYSTEMS OPERATE WITH VERY RAPID MIXING, VERY CLOSE TO STOICHIOMETRY.

**CON’S**

- HIGH ELECTRICAL USAGE (FGR fan HP doubled compared to RX system)
- LOW TEMPERATURE, TRANSLUCENT, FLAME REDUCES HEAT TRANSFER & EFFICIENCY.
- COMBUSTION INSTABILITY
- CAN’T CHANGE FIRING RATE FAST ENOUGH TO FOLLOW CHANGING LOAD DEMANDS
PREMIX POROUS MATRIX BURNERS

FEATURES

• REQUIRES DELICATE, EXPENSIVE, POROUS MATRIX MATERIALS

• REQUIRES EXCESS AIR LEVELS AS HIGH AS 65% TO OBTAIN NOx <9ppm

• REQUIRES FILTERED AIR.
  (Matrix materials can easily become fouled)

CON’S

• HIGH ELECTRICAL USAGE DUE TO EXCESS AIR & HIGH PRESSURE DROP THROUGH SYSTEM (Fan HP >50% more than RX System)

• REDUCED EFFICIENCY DUE TO EXCESS AIR. (73% vs. 82%)

• DURABILITY OF MATRIX MATERIALS IS LIMITED

• MATRIX FAILURE CAN LEAD TO PROPERTY DAMAGE AND PERSONNEL INJURY

• LIMITED TURNDOWN RATIO
  (MAX FUEL INPUT/MIN FUEL INPUT)
  (3:1 vs. 5.5:1 for Series RX)
POST COMBUSTION TREATMENT

FEATURES

• SCR SYSTEMS UTILIZE EXOTIC CATALYST MATERIAL.
  (TEMPERATURES (500-850F)
  (90+% NOx REMOVAL)

• SNCR SYSTEMS OPERATE @ HIGH TEMPERATURES (1700-2100F)
  (50% NOx REMOVAL)

• CAN USE SODIUM HYDROXIDE, UREA, OR AMMONIA INJECTION.

CON’S

• HIGH UPFRONT & OPERATIONAL COSTS.

• CAN RESULT IN CHEMICAL WASTE STREAMS (e.g. SODIUM NITRATE, AMMONIA)

• REQUIRES ELABORATE SENSORS/CONTROL SYSTEM TO METER THE PROPER INJECTION VOLUMES.
RX Technology Goals: Minimize the Costs and Maximize the Benefits of Ultra-low NOx Technology

- Increase efficiency
- Lower the cost to industry
- Improve reliability
- Improve safety
Increase Efficiency

- The RX burner operates optimally with 3% $O_2$ in the stack. Matrix burners typically operate with $O_2 > 9\%$ resulting in efficiencies at approximately 73%. RX efficiency is approximately 82%.
- By optimizing the combustion process we minimize FGR requirements. Producing less NOX requires less NOx suppression.
- Utilizing multiple stabilized flame zones improves turndown performance, typically 5.5:1 or better. Some existing designs only operate @ 3:1, or less.
Lower Cost to Industry

• Simple durable refractory and steel construction results in:
  - Lower initial cost
  - Lower maintenance costs

• Lower operating cost
  - Less stack losses due to low excess air and low FGR requirements
  - Lower fan costs
  - Eliminates the need for chemicals & catalysts
COST/ TON NOx REMOVED

NEW BOILER SYSTEMS

- POST COMBUSTION
  $24,500

- MASSIVE FGR
  $3,676

- POROUS MATRIX
  $2,787

- RX TECHNOLOGY
  $258

INITIAL & OPERATING COST
COST / TON NOx REMOVED

BOILER RETROFITS

- POST COMBUSTION
  $24500

- MASSIVE FGR
  $4568

- POROUS MATRIX
  $4177

- RX TECHNOLOGY
  $889

INITIAL & OPERATING COST
Improve Reliability

- Proven durable construction over an 11 month field test.
- Good flame radiation for reliable flame detection and a high radiant heat transfer rate.
- No small orifices to get plugged with particulate matter in the combustion air.
- No ceramic fiber or metallic material to degrade.
Improve Safety

- RX provides good stability with a stable anchored flame at all firing rates and during transition. No flame retention problems.
- Multiple flame zones promote smooth modulation of load without instabilities, noise and flashback.
- Multiple flames zones also reduce the likelihood of destructive acoustic coupling. (Combustion harmonics or vibrations can be destructive to equipment)
- No requirement for an active control system. (O₂ trim or vibration detectors)
OVER 200 REACTIONS INVOLVING 20 DIFFERENT SPECIES OCCUR DURING THE COMBUSTION PROCESS

THE MOST USEFUL COMPONENTS FOR OUR PROCESS ARE:

PARTIALLY OXIDIZED FUEL
(CHi, CO & SOOT)

AMINES SPECIES
(NHi)

THESE COMPONENTS ARE FORMED IN THE COMBUSTION PROCESS IN A REDUCING ATMOSPHERE. Stoichiometry < .6
COMBUSTION MODIFICATION

• **NOx FORMATION**

\[
\begin{align*}
N + O & \rightarrow NO \\
N + OH & \rightarrow NO + H
\end{align*}
\]

• **NOx REDUCTION**

\[
\begin{align*}
CH + NO & \leftrightarrow HCN + O_2 \text{ (Reversible)} \\
CH_2 + NO & \leftrightarrow HCN + OH \text{ (Reversible)} \\
C + NO & \leftrightarrow CN + O_2 \\
NH_i + NO & \rightarrow N_2 + H_2O
\end{align*}
\]

THESE NOx REDUCTANTS ARE FORMED BY PARTIAL COMBUSTION IN A REDUCING ATMOSPHERE.

THE INTERMEDIATE SPECIES, HCN & CN, ARE CONVERTED TO N2, CO2 & H2O IN THE FINAL BURNOUT ZONE.
PROMPT NOx

- Rapid Formation <1ms.
- Little affect from temperature.
- Presence of CHi & HCN during initial combustion can contribute to prompt NOx formation in an oxidizing environment, but will inhibit NOx formation in a reducing environment.
- Presence of C & NHi in initial combustion process reduces the formation of prompt NOx.
- Reactor combustion is controlled to a stoichiometry <0.6 and a temperature <2400F.
PROMPT NOx
Type RX Cross-sectional View

- RICH FUEL STREAM
- LEAN FUEL STREAM
- REDUCING ATMOSPHERE
- RICH MIX
- LEAN MIX
- (4) LEAN MIXERS
- AIR INLET
Rich Reactor produces hydrogen, CO and NOx reducing nitrogenous species.
Combines with the Lean Combustion products in the lower temperature Burnout Zone.
Results in stable combustion with low NOx emissions and good CO burnout.
Fuel Modification “Rich Reactor”

- Stabilizes combustion through early recirculation of hot products to the reactants.
- Controls the production of prompt NOx and the reduction of nitrogenous species (e.g. HCN, CN, NHx, NOx) back to molecular nitrogen.
- Converts natural gas to mainly HCl, NH, CO and soot which all have a reducing affect on NOx molecules.
- Good flame radiation for reliable flame detection using standard flame detection equipment.
The Lean Reaction Zone

- Lean premixed flames minimize NOx:
  - Excess air suppresses thermal NOx production
- Stabilized and continuously ignited by gases directed from the Rich Reactor.
- Excess oxygen promotes final CO burnout.
- Flames quickly transfer heat to the furnace section with no negative quenching effect, because the lean premix flames have little CO or HC content.
- High exit velocity generates gas recirculation zones near the face of the burner.
NOx Formation vs. Stoichiometry

- Fuel Rich
- Fuel Lean

Relative NOx Formation
The Final Burnout Reaction Zone

- Products of the Rich and Lean Reactors combine for good CO burnout.
- Amine species, CO and soot exiting the Rich Reactor reduce thermal NOx produced in the burnout reaction zone for very low final levels.
- The relatively low temperature of the burnout zone inhibits thermal NOx production.
- 10-25% FGR is introduced to further reduce Burnout temperature if NOx requirement <20ppm.
- Soot burns to produce a strong radiation for good radiant heat transfer.
The Result: Single Digit NOx

- Sub-20 ppm NOx without FGR.
- Single digit NOx with 15 to 25% FGR.
- Suitable for all firetube boiler applications.
- Adaptable to watertube boiler applications.
TYPICAL COMPONENTS

- Fuel valves
- Servos
- Lean Jet
- Reactor

Fuel valves & Servos
TYPICAL COMPONENTS

REACTOR PORT

LEAN JETS
Existing 30ppm LO-NOx System

Induced FGR
### Existing Emissions & Goals

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<thead>
<tr>
<th>Emission</th>
<th>Existing</th>
<th>Proposed</th>
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<tr>
<td>NOx ppm@3% O2</td>
<td>25.3</td>
<td>5 - 6</td>
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<tr>
<td>CO ppm@ 3% O2</td>
<td>70.2</td>
<td>&lt;50</td>
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<tr>
<td>Stack O2, %</td>
<td>6.2</td>
<td>2.5 – 3.2</td>
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Reduce NOx by 75%
Reduce O2 by 48 - 60%

Reducing O2 from 6% to 3% saves this customer 273 CFH of nat gas
A Look Down the Furnace

- Rich Flame
- Lean Flames (x4)
- FGR
- Burnout Zone
## THE NUMBERS

<table>
<thead>
<tr>
<th></th>
<th>MIN</th>
<th>INT 1</th>
<th>INT 2</th>
<th>MAX</th>
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<tbody>
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<td>INPUT CFH</td>
<td>3721</td>
<td>5187</td>
<td>10707</td>
<td>20190</td>
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<td>O2 %</td>
<td>3.5</td>
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<tr>
<td>CO PPM @ 3% O2</td>
<td>75</td>
<td>45</td>
<td>20</td>
<td>0</td>
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<tr>
<td>NOx @ 3% O2</td>
<td>6.0</td>
<td>5.1</td>
<td>5.0</td>
<td>6.2</td>
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Affect of FGR

NOx ppm vs % FGR
Summary of the Technology

- The RX burner brings NOx suppression and NOx reduction technology together in a single design.
- Generates several reaction zones in which NOx control is balanced with important combustion characteristics such as low CO and HC emissions, low noise and high stability.
- Features simple yet durable construction for a lower initial cost and a lower cost of ownership.
- Provides conventional burner performance with single-digit NOx emissions.
Any Problems?

- You bet!
- After 10 months of tracking emissions data -
- The initial source test was not passed.
- The reason -
- Faulty feedback drive on the air damper servomotor.
Have the Goals Been Met?

- Several prototypes and nearly $900,000 has validated the technology.
- Laboratory-proven at 25HP, 100HP & 300HP.
- Field-proven at 500 HP, in constant operation since May 2003:
  - Emissions goals met
  - Good stability with low noise levels
  - Optimum performance found between 2 and 3% O₂
  - 5.5:1 turndown ratio with smooth modulation
  - Good structural integrity
- Lower cost relative to other technologies.
THE AFTERMATH

• This project has led to a 20 year licensing agreement to utilize the technology in the production of sub 15ppm & sub 9ppm industrial combustion systems.
• The product received an honorable mention award at the 2004 AHR Expo for most innovative product.
• Several systems have been purchased; the first has been installed in the San Diego area and is scheduled for commissioning in April 2004.
• Development of smaller, sub 20ppm & sub 15ppm, systems is currently being considered.
Thank you

California Air Resources Board