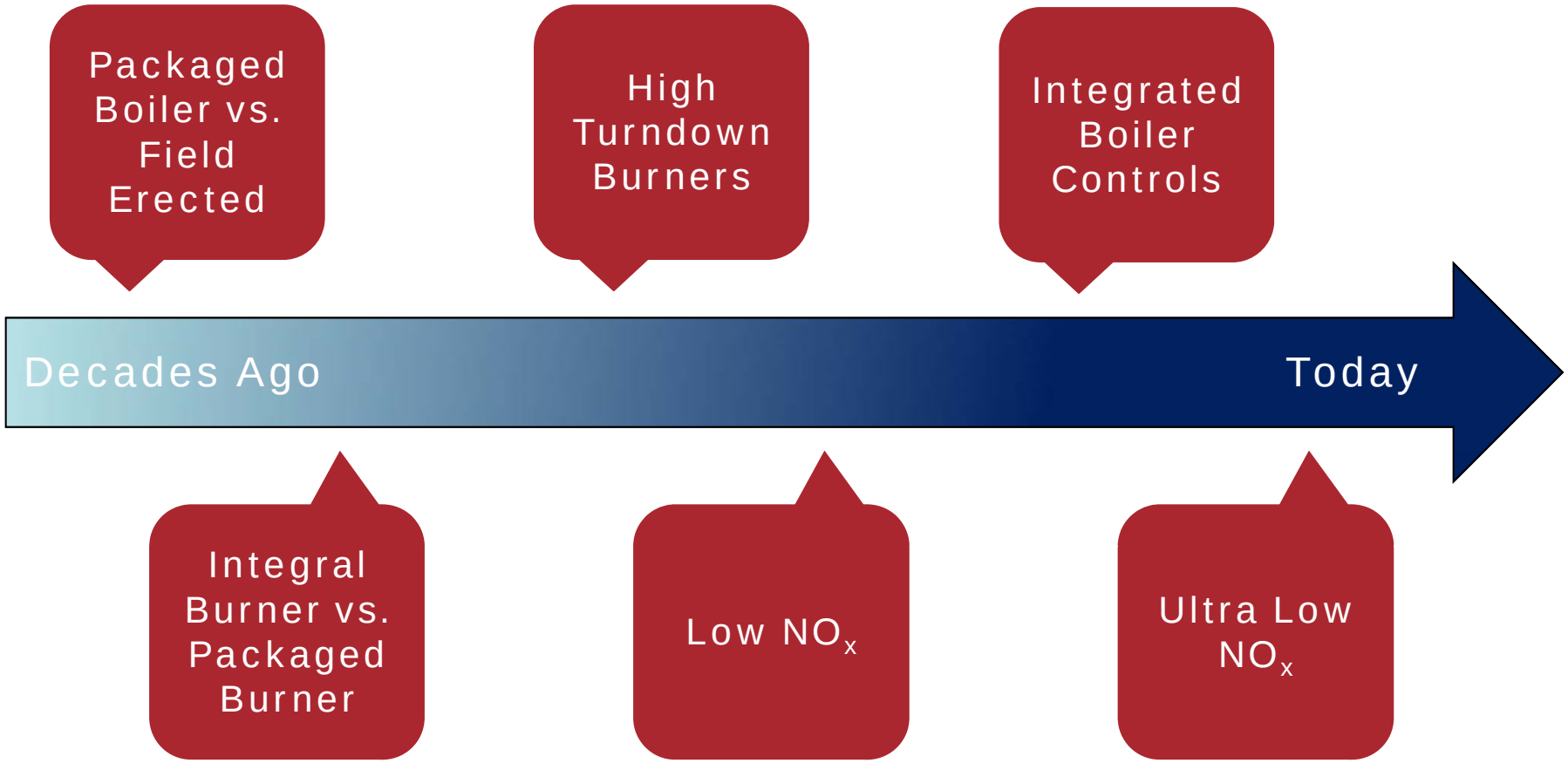
Advanced Firetube Design Breakthroughs

Cleaver-Brooks CBEX Firetube Boilers

Slow Development In Firetube Technology Breakthroughs



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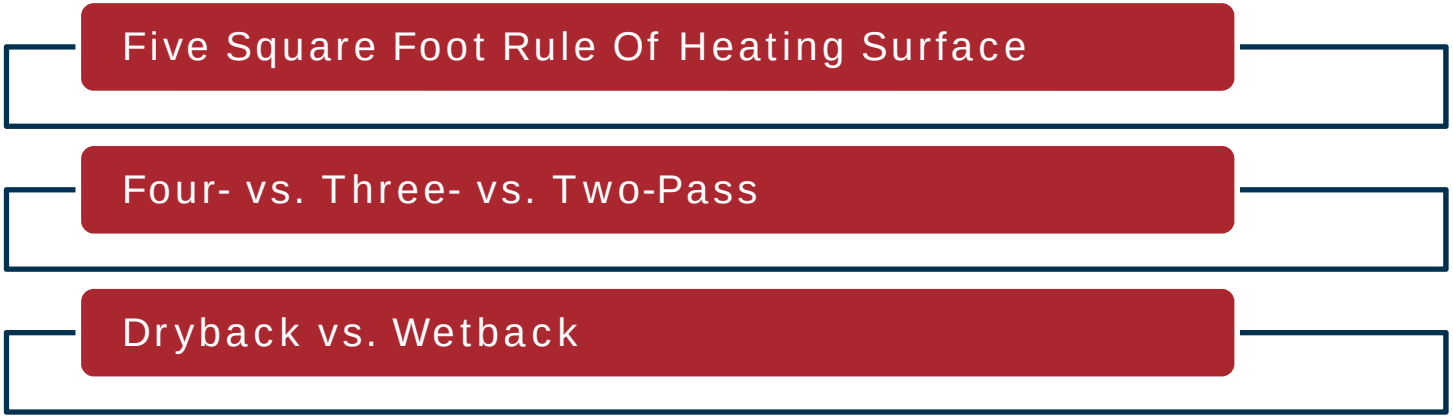
- "Rules Of Thumb" Philosophy



- Unavailable Sophisticated Modeling
  - Sophisticated modeling did not exist or was not financially feasible
  - Relied on trial and error from the field or R&D lab

New Sophisticated Design Techniques

Computational Fluid Dynamic Modeling

- Computer software solves conservation equations
- Visualizations created showing distribution of key parameters
- Changes made to model, testing improvements
- Provides for design optimization

Finite Element Analysis

- Breakdown of complex engineering problems into finite elements
- Finite elements broken down to sets of linear equations
- Equations solved using matrix algebra
- Used for predictive performance and evaluating new concepts

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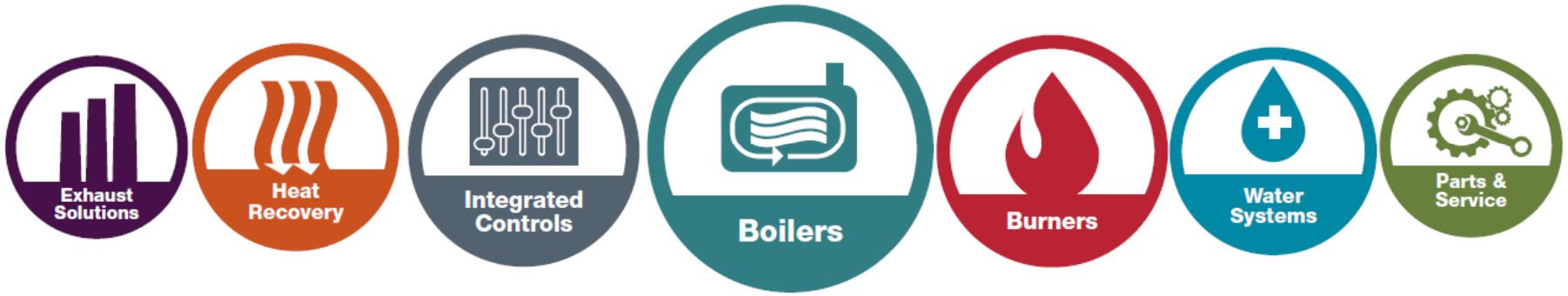
The Benefit Of Modeling Integrated Components

- By modeling the boiler, burner, heat recovery, and other components together, more accurate calculations for the values of velocity, temperature, chemical species, and other properties are determined from the boundary conditions



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CBEX – The Most Advanced Firetube Ever Built

Primary

- Higher Efficiency
- Lowest Possible Emissions

Secondary

- Smaller Footprint / Less Weight
- Quicker Steam-Up
- Extended Pressure Vessel Life

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Cleaver-Brooks Uses New Technology To Advance Firetube Design

- Key elements of advancement to create the CBEX – the most advanced firetube design

1. Heat Transfer Of The Tubes
2. Furnace Geometry
3. Combustion Performance

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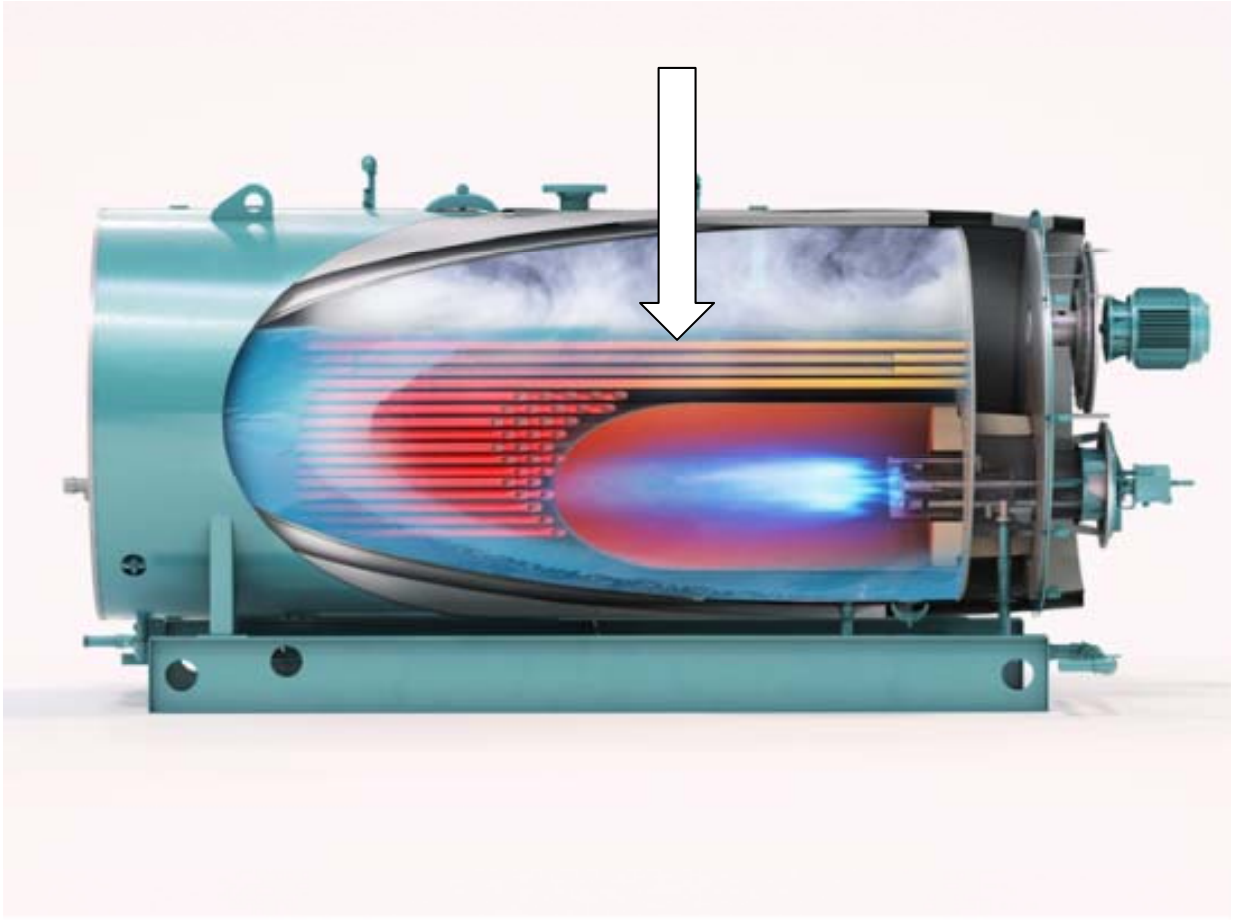
1. Heat Transfer Of The Tubes



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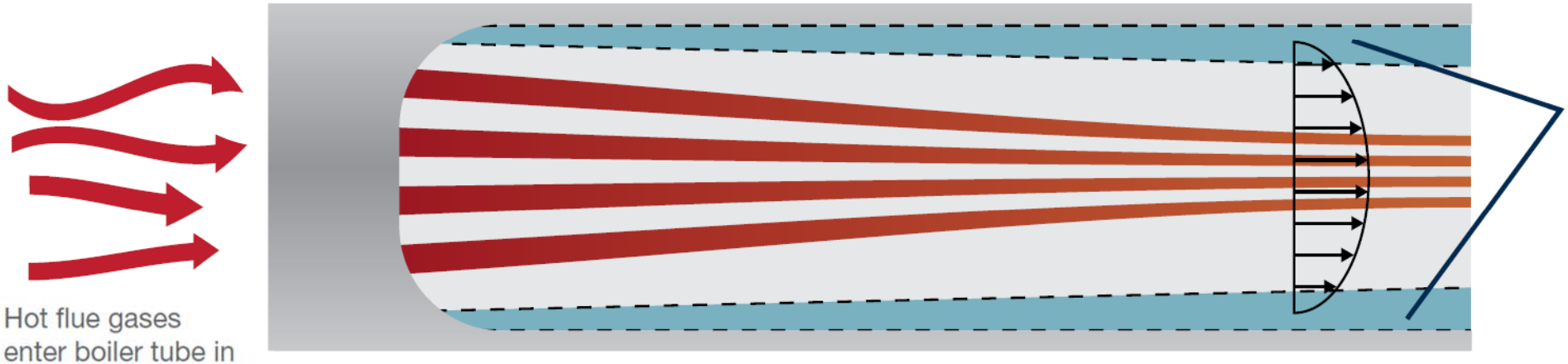
1. Heat Transfer Of The Tubes
The Fundamentals

Typical Boiler Tube

Boundary layer forms along tube walls, retarding heat transfer.



Hot flue gases enter boiler tube in turbulent pattern but quickly change to a laminar, or straight, flow

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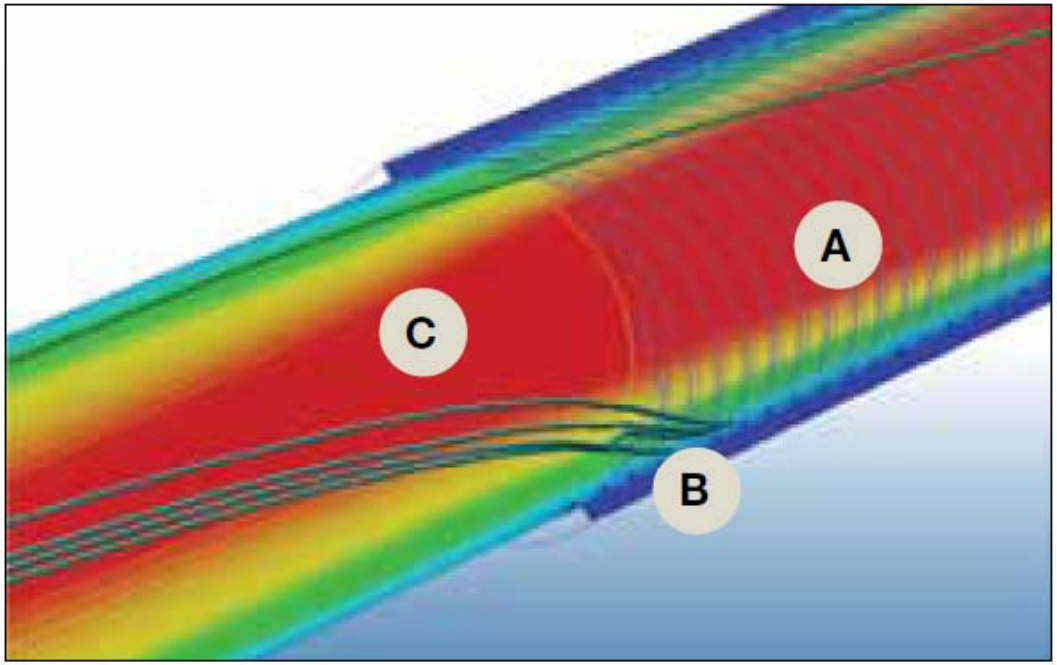
1. Heat Transfer Of The Tubes

Cleaver-Brooks Advanced Heat Transfer Tubes



CFD model of an advanced heat transfer tube.

A. The number of ribs, angle of the ribs, and height and width of the ribs have been optimized for peak tube performance.

B. Improved tube profile utilizes 100% of the tube diameter for heat transfer.

C. Increased surface area and a complex boundary layer separation reattachment phenomenon result in better heat transfer.

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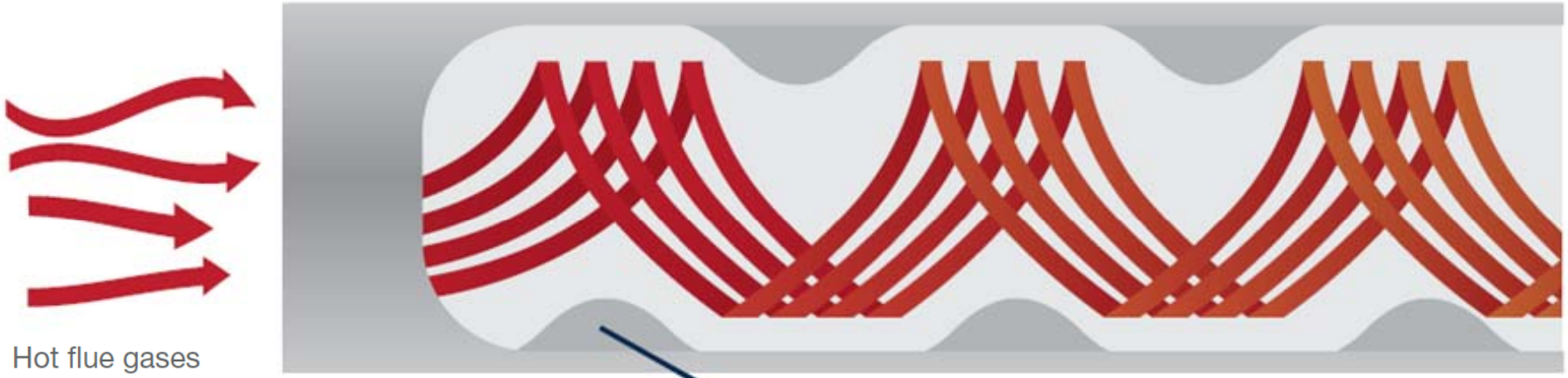
1. Heat Transfer Of The Tubes

An Optimized Heat Transfer Tube

Cleaver-Brooks Advanced Heat Transfer Tube

+85% more heat transfer



Hot flue gases enter boiler tube in turbulent pattern and remain turbulent

Precisely designed ribs keep hot flue gases in turbulent flow throughout the tube profile

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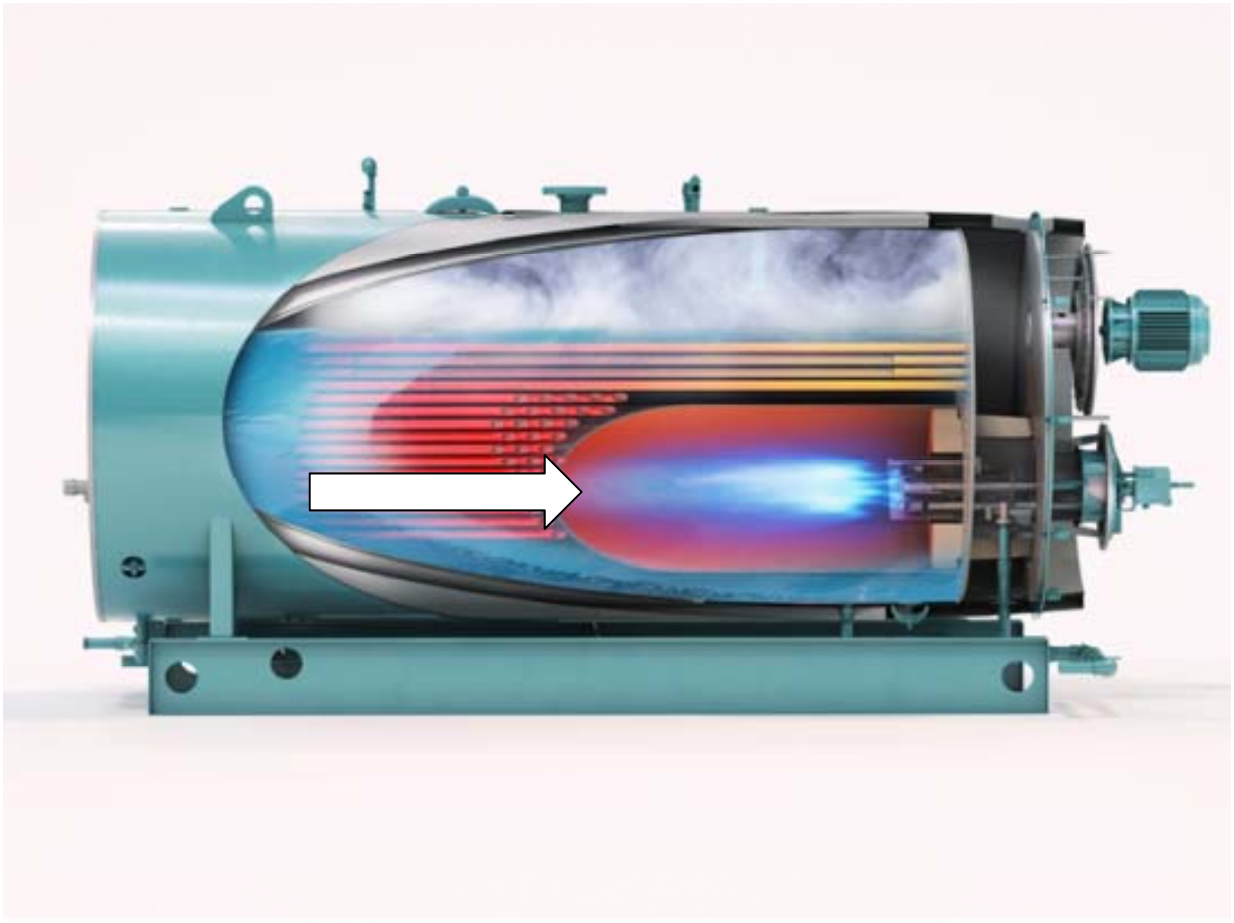
2. Furnace Geometry



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2. Furnace Geometry
Important Considerations

- Balance of high heat transfer of the radiant zone while minimizing pressure
- Lower and more uniform flame temperature and flame stability in the furnace
- Reduce heat release rates of the furnace
  - Current firetube average is 150,000 BTU/hr/cubic feet

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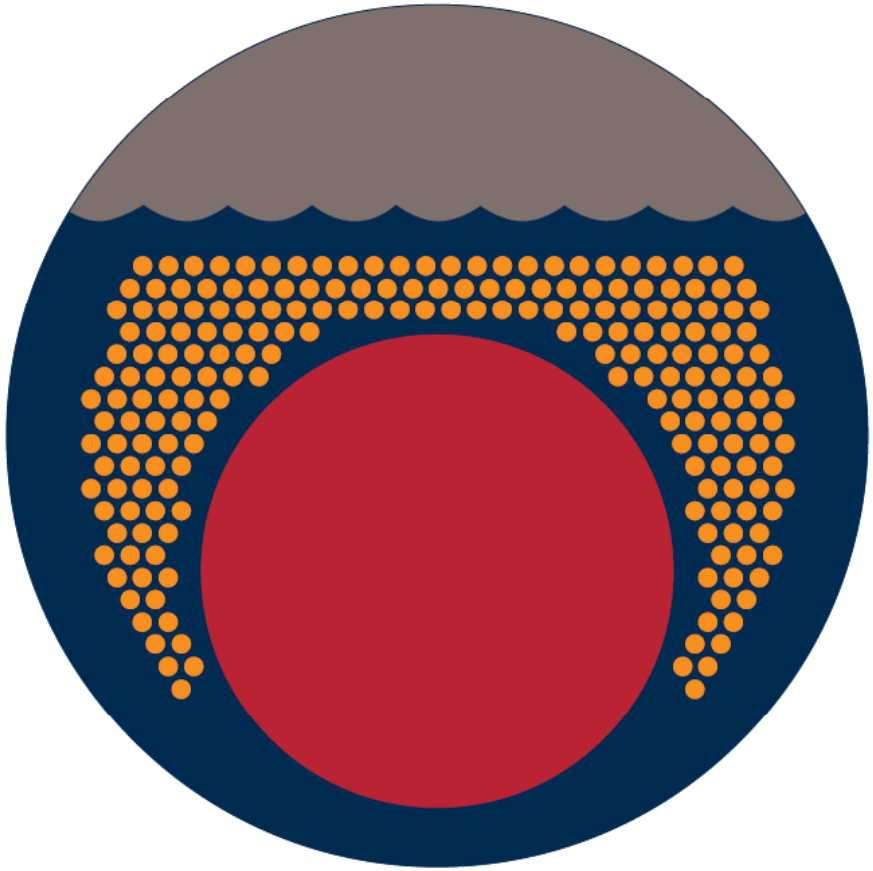
2. Furnace Geometry

Cleaver-Brooks Answer To Furnace Optimization



- Maximized the heat transfer with the lowest possible pressure drop
- Lower heat release rate enables a more uniform flame temperature
- Reduced furnace heat release rates to 125,000 BTU/hr/cubic feet

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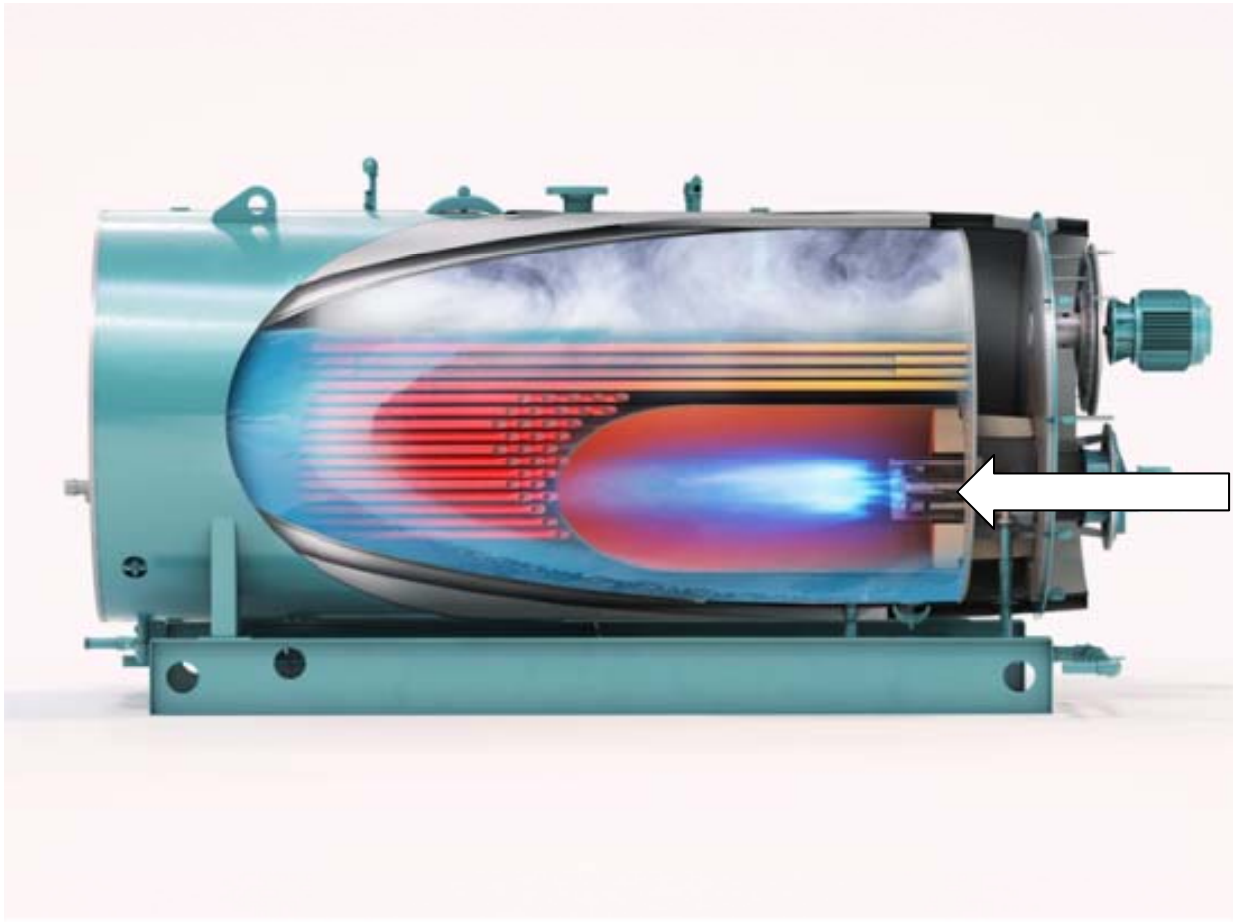
3. Combustion Performance



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Excess Air Is An Important Factor

- Some excess air needed to reduce unwanted emissions and surface fouling
- Controlling excess air reduces flame instability
- Too much excess air causes a decrease in efficiency
- An ideal balance calls for a 15% excess air level

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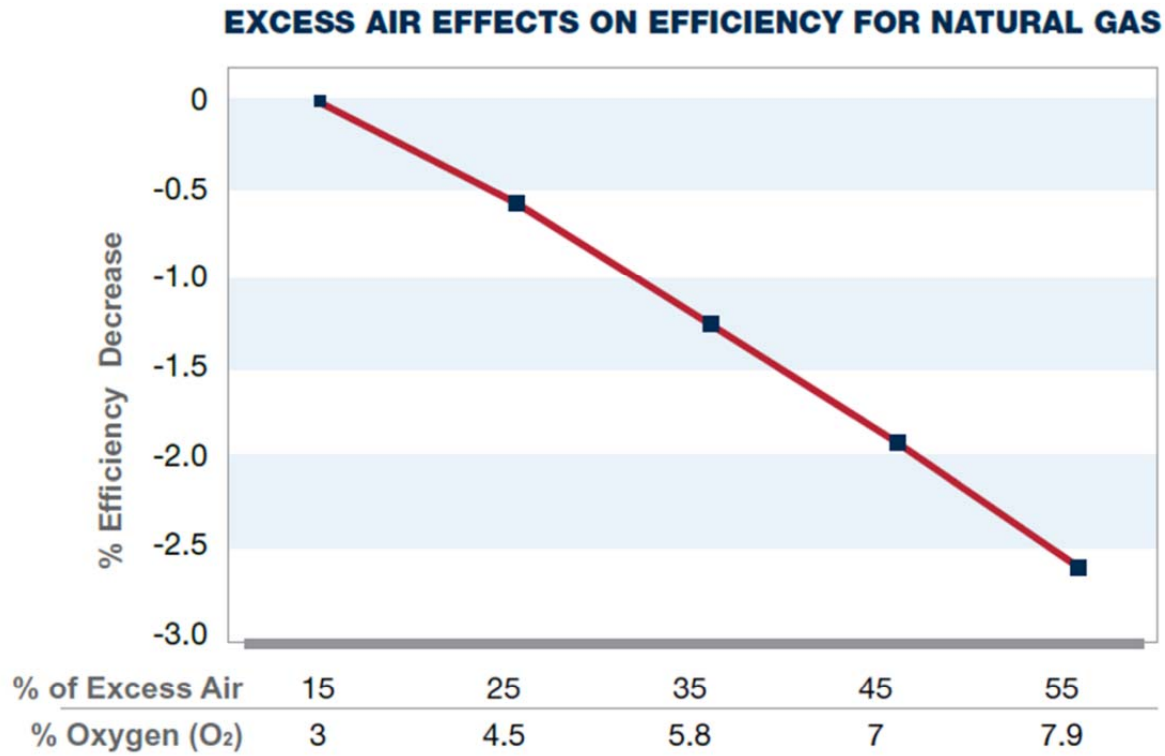
3. Combustion Performance

As Excess Air Increases, Efficiency Decreases



EXCESS AIR VS EXCESS OXYGEN (O_2)

The terms excess air and excess oxygen are commonly used to define combustion. They can be used synonymously but have different units of measurements. The percentage of excess air is the amount of air above the stoichiometric requirement for complete combustion. The excess oxygen is the amount of oxygen in the incoming air not used during combustion and is related to percentage excess air. For example, 15% excess air equals 3% oxygen while firing natural gas.

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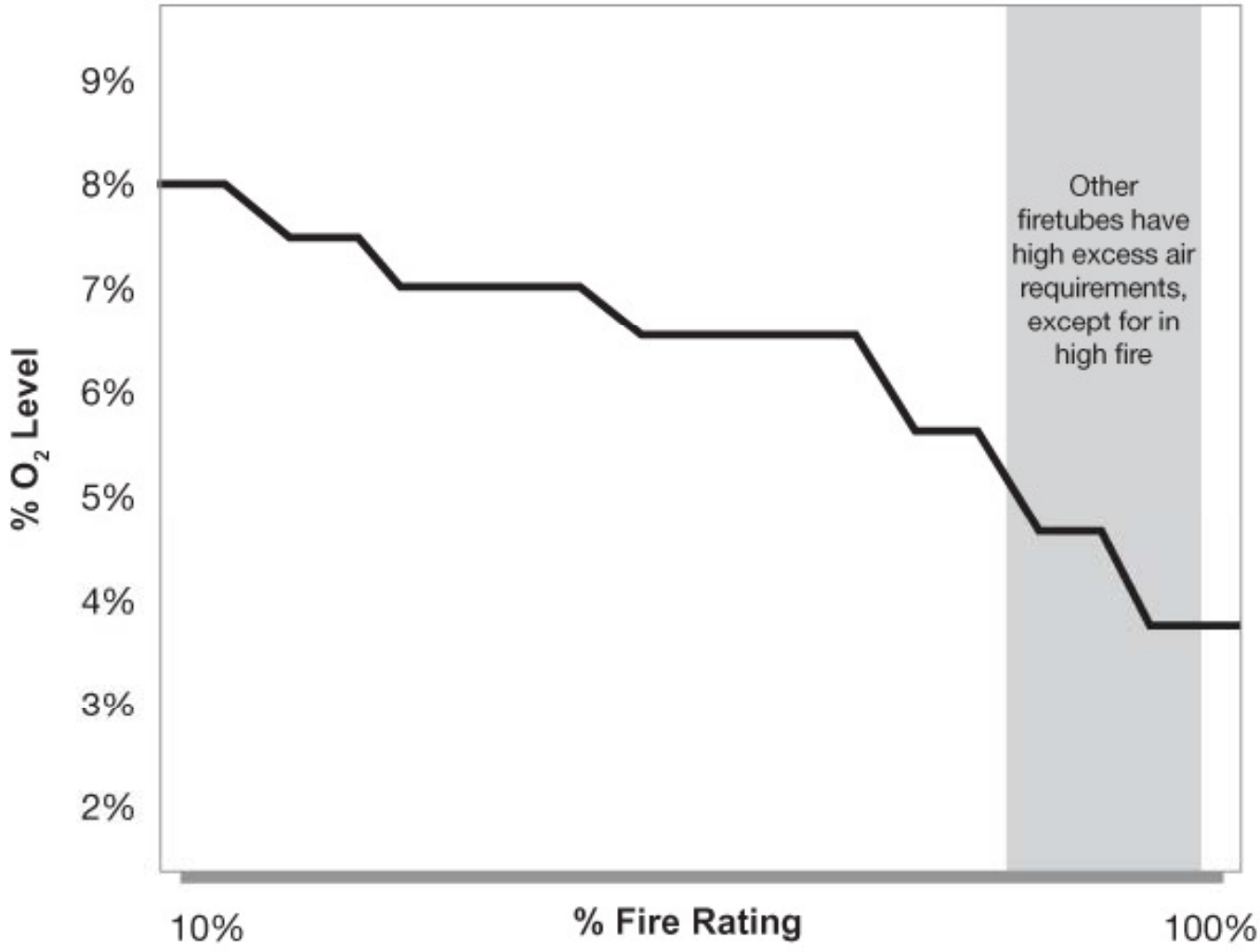
Excess Air Increases As The Firing Rate Decreases



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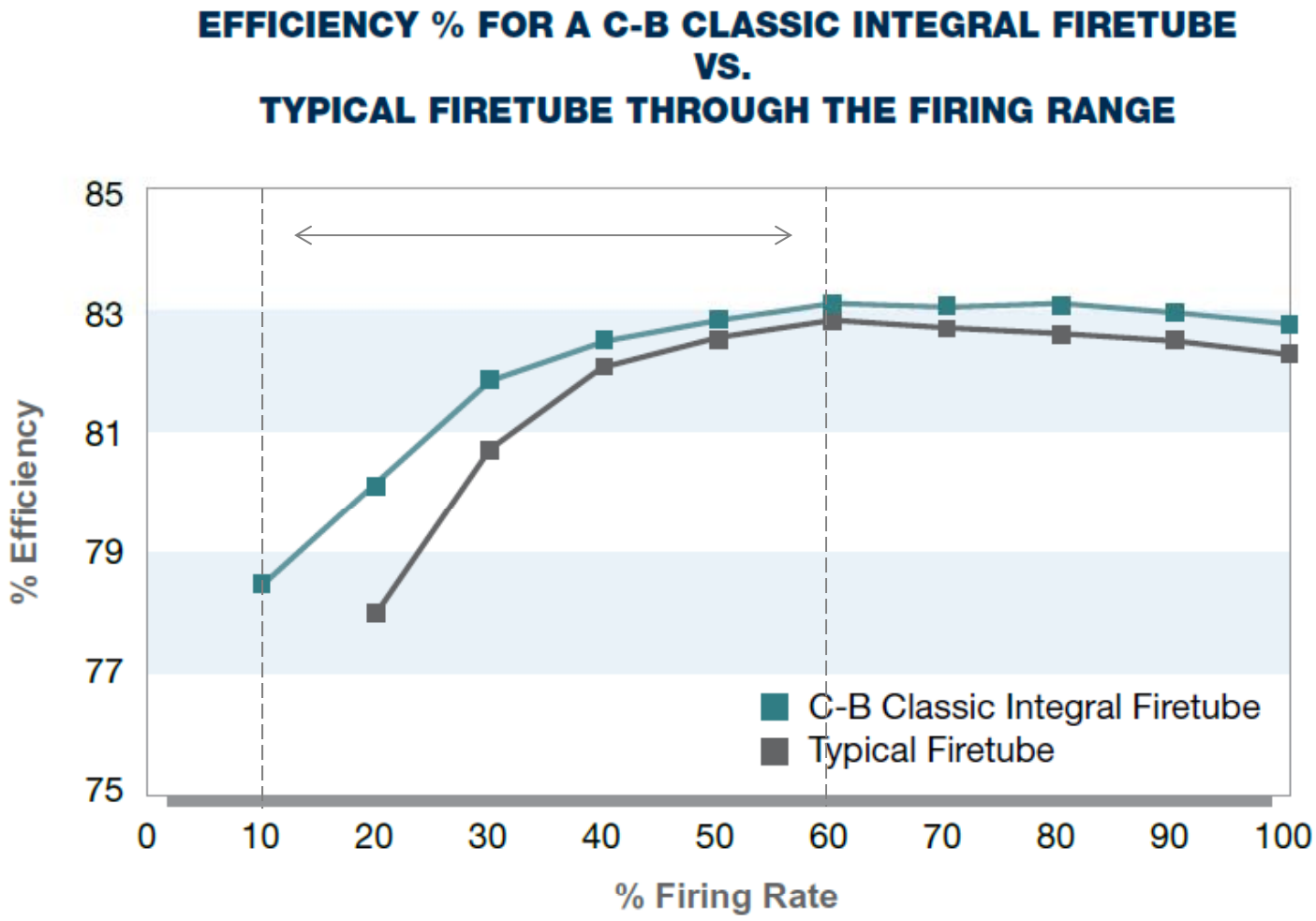
Efficiency Drops Dramatically At Lower Firing Rates



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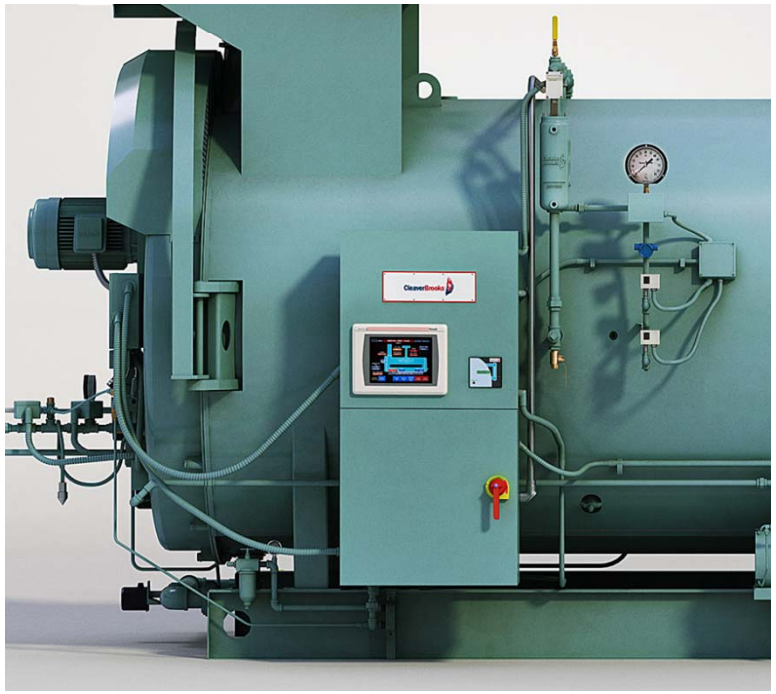
The Integrated Package

By integrating the burner and controls, combined with the optimization of the furnace, superior combustion can be achieved



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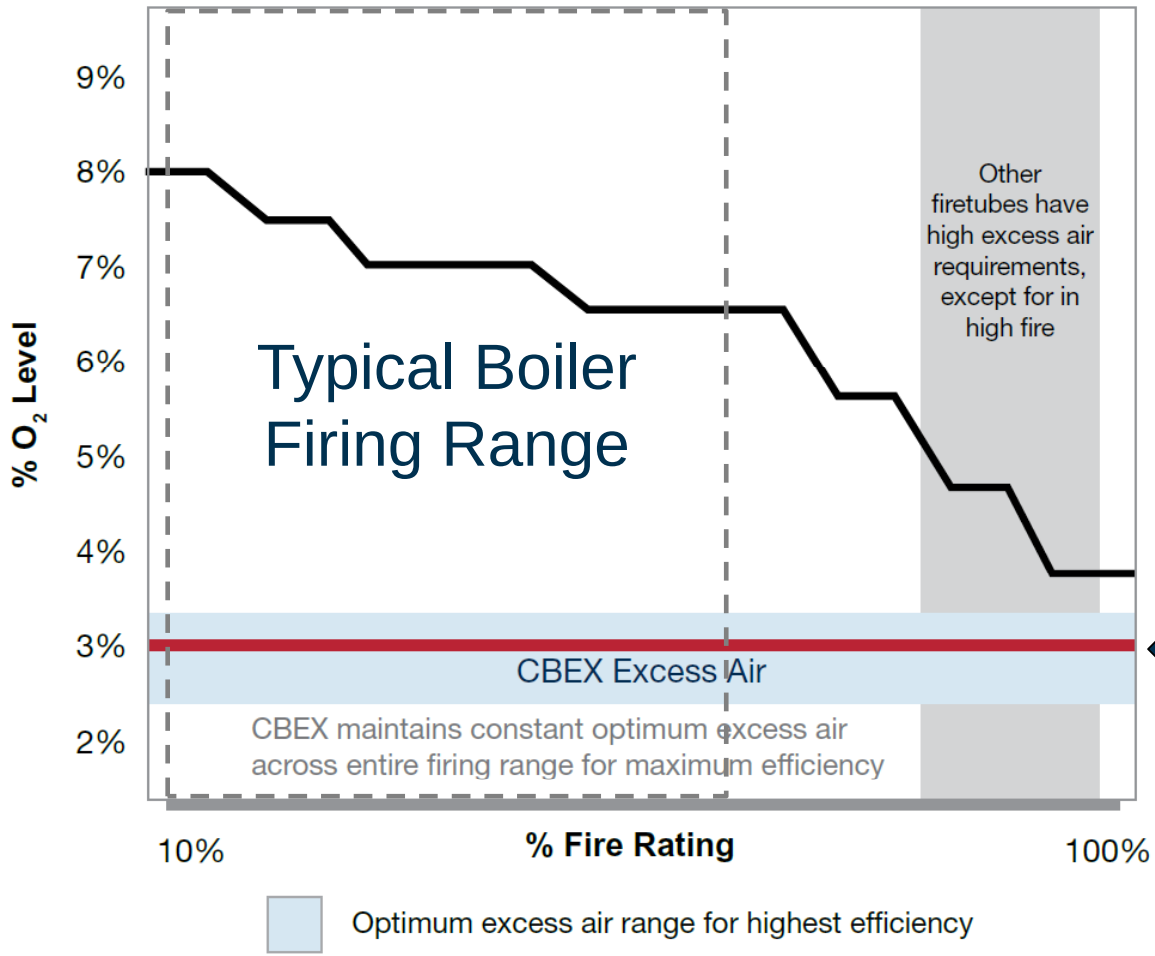
The Highest Operating Efficiency Of Any Firetube



10:1 turndown while maintaining 3% O_2 across the firing range

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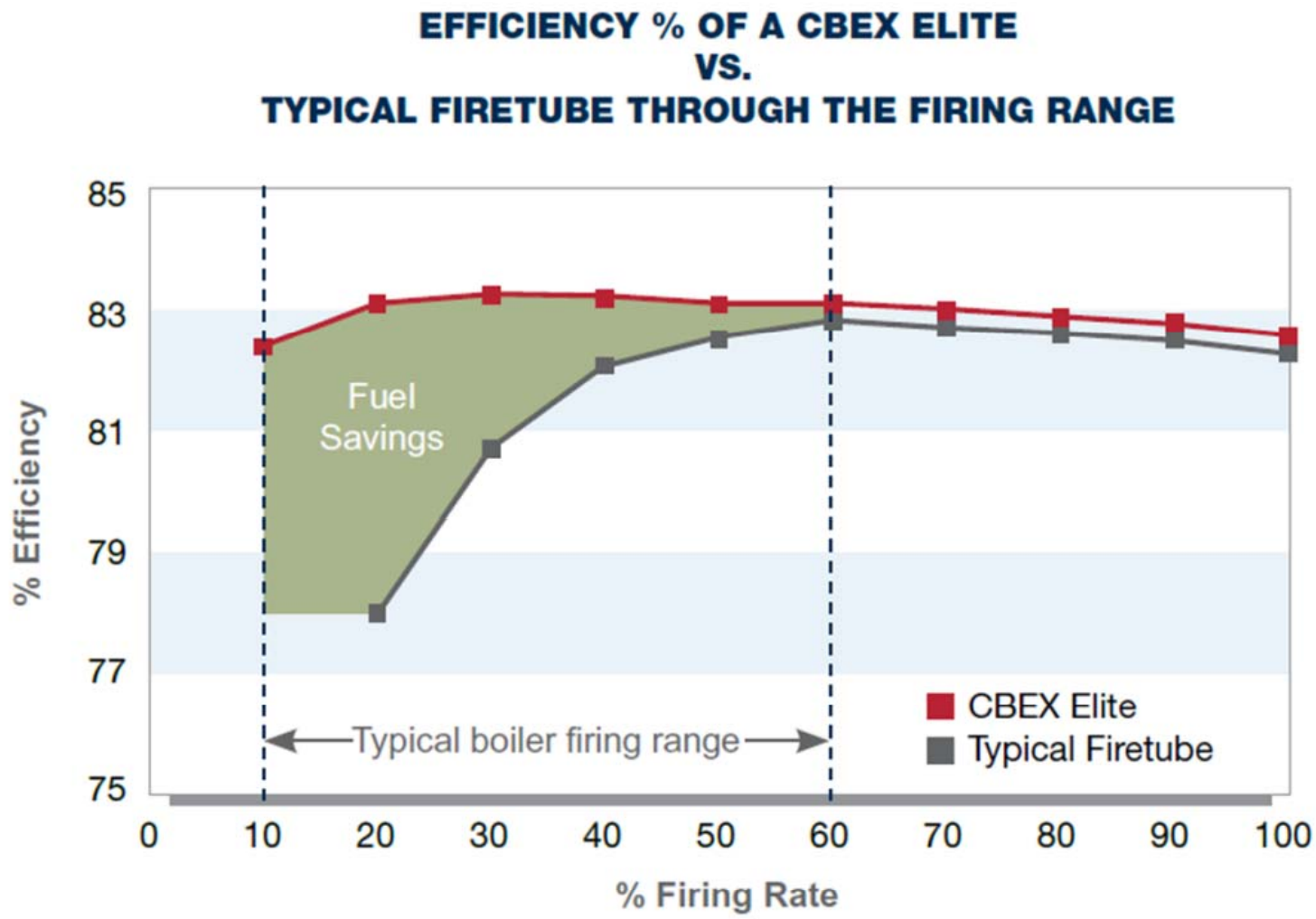
Higher Efficiency Over The Entire Firing Range



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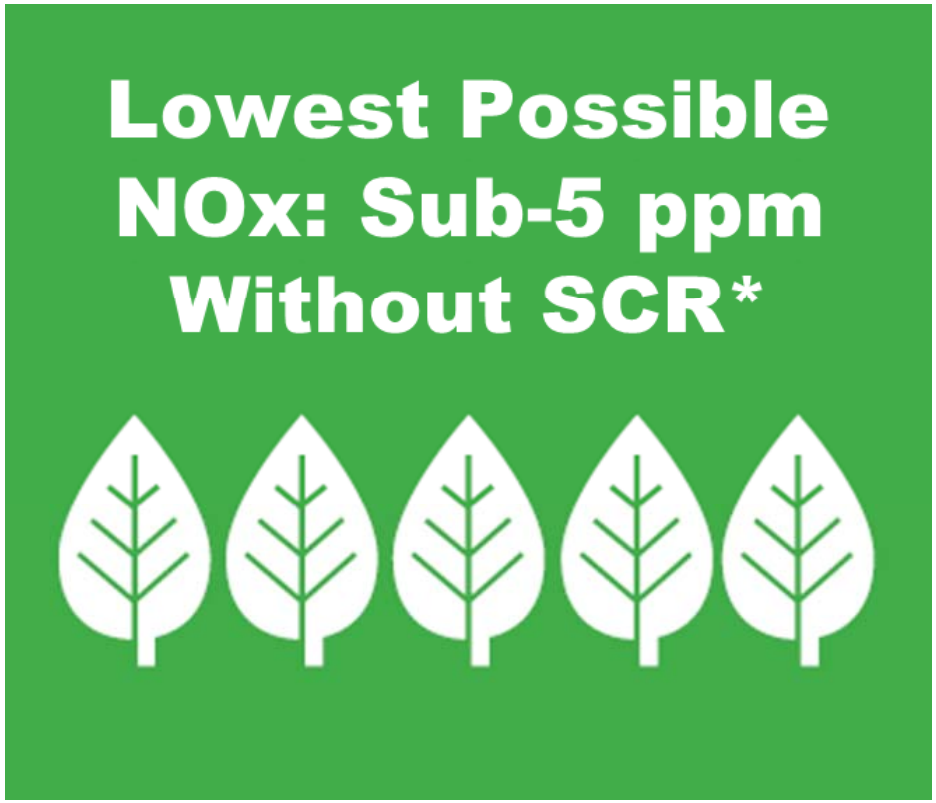
Optimized Combustion Results In Lower NOx



- Optimized furnace provides lower heat release and near-perfect combustion
- Combined with the Hawk, emissions are reduced to unprecedented levels
- Prior to the CBEX, sub-5 ppm NOx without SCR had never been achieved

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** Select models*

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CBEX Firetube Boiler Line

CBEX ELITE

CBEX PREMIUM

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CBEX ELITE

Delivering the best efficiency and emissions control in the world.

- Best operating efficiency of any firetube ever built
- Completely integrated boiler, burner, controls, and heat recovery system
- Minimum excess air across the operating range
- Ultra-low NOx emissions without SCR
- Can meet 10 ppm CO emissions requirements (at 30 ppm NOx)
- 15% reduction in footprint vs. traditional designs

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CBEX ELITE

Delivering the best efficiency and emissions control in the world.

100–1,200 HP

Exclusive Cleaver-Brooks integral burner

Integral burner design now available with 50% more capacity

Air-cooled integral front head

Can meet 5 ppm NOx emissions requirements without SCR (select models)

Can meet 10 ppm CO emissions requirements (at 30 ppm NOx)

1,300–2,200 HP

System-matched Cleaver-Brooks packaged burner

Maintains a small footprint in large capacities

Affordable alternative to industrial watertube boilers

Can meet 9 ppm NOx emissions requirements

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CBEX PREMIUM

Get EX advantages with a packaged burner.

- EX technology in a high-value solution
- Completely integrated boiler and burner system
- High-efficiency, next generation firetube
- Can meet 9 ppm NOx and low emissions requirements
- Smaller footprint than traditional firetubes

100–1,200 HP

High-quality, Cleaver-Brooks packaged burner

Available up to 1,200 HP with a traditional, packaged burner

Add available heat recovery and controls for a completely integrated package

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How Can You Find Out More?

- The following tools can be found on the Cleaver-Brooks Website:
  - CBEX Elite & Premium Product Brochures
  - CBEX Technology – Boiler Heating Square Footage
  - CBEX Technology – Burner Efficiency and Firing Rate
  - CBEX Technology – Excess Air and Boiler Efficiency
  - CBEX Technology – Advanced Tube Design
  - CBEX Dimensions & Ratings Chart
  - CBEX Boiler Book
  - CBEX Elite & Premium Specifications
  - CBEX Elite & Premium Technical Drawings
  - CBEX Case Studies

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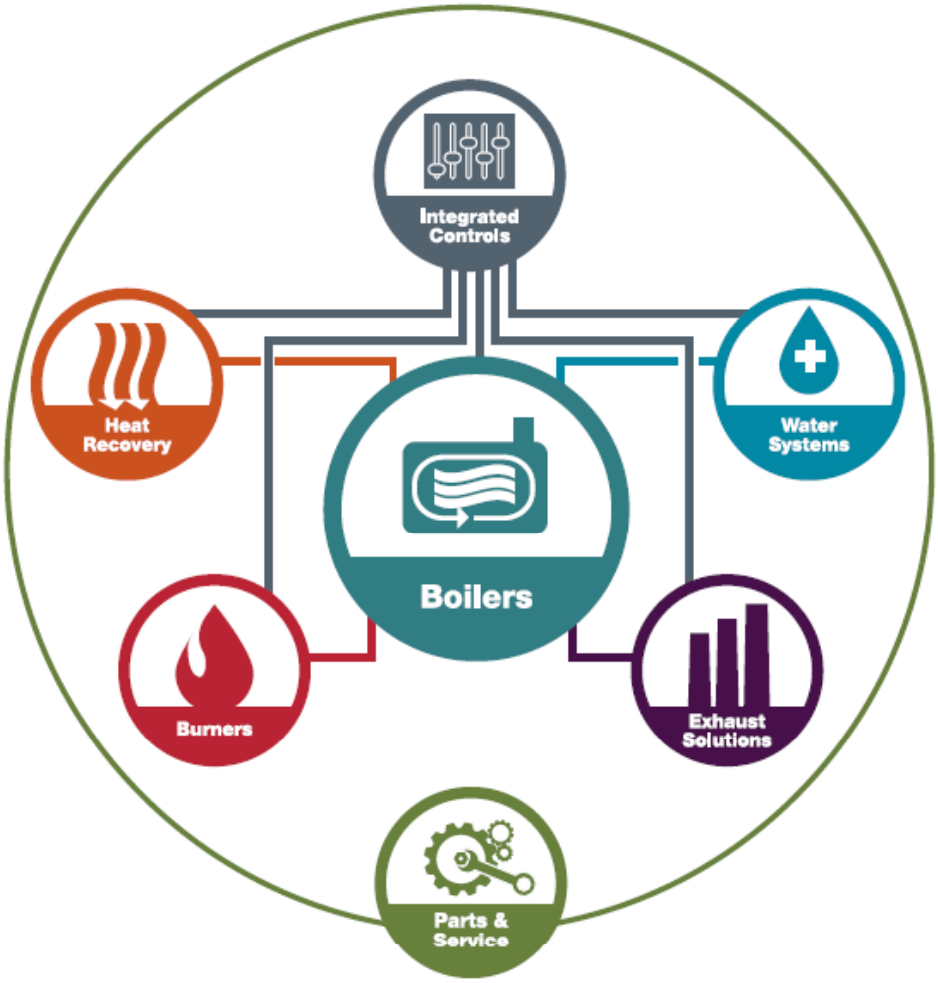
Total Integration Goes Far Beyond Boilers



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