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1800	1900	1939	1946	2011
10 sq. ft. of boiler heating surface originates based on "physical" size of boiler.	"Double Rated" 5 sq. ft. of heating surface boilers are built.	The Navy begins building 2–3 sq. ft. of heating surface boilers. Trend of smaller boilers begins, but boilers have a shortened lifespan.	ABMA recommends 5 sq. ft. of heating surface for firetube boilers as the standard to prevent shortened boiler life.	Cleaver-Brooks designs firetube boiler utilizing advanced heat transfer tubes and optimized furnace with less than 5 sq. ft. of heating surface. Superior performance proves firetube boilers can be properly designed with lower heating surface requirements.

The technology behind the CBEX:

EXPLORING THE MYTH OF BOILER HEATING SQUARE FOOTAGE

In 1800, the number of boiler horsepower denoted the actual "physical" size of the boiler. One rated horsepower was defined as 10 sq. ft. of boiler heating surface. This was based on a "standard" coal-fired steam piston engine that required 30 lb/hr of water evaporated from 100ºF to steam at 70 psi saturated to generate one net horsepower of shaft power. This equated to a performance of less than 8% efficiency (one horsepower or 2,546 BTU/hr output when divided by one boiler horsepower or 33,475 BTU/hr input equals 7.6%). This inefficient 10 sq. ft. rule stayed in effect until a century later, when oil combustion boilers began to be built as "double rated," or 5 sq. ft. per boiler horsepower. During World War II, the U.S. Navy had requirements for firetube boilers smaller than the "double rated" boilers being built utilizing the 5 sq. ft. standard, and the trend towards smaller boilers and less heating surface began.

The Navy commissioned boilers designed utilizing 2–3 sq. ft. of heating surface per boiler horsepower. These boilers had a limited life due to the overheating of the rear tube sheets—for the Navy this was fine, as the space constraints were more important than the life cycle of the boiler. However, conventional users would not accept such a short life. After the war ended, several boiler manufacturers, including Cleaver-Brooks, worked with the American Boiler Manufacturers Association (ABMA) to study the failures of boilers and recommend a standard for heating surface area per boiler horsepower. With only experience from the field to rely on, they recommended 5 sq. ft. of heating surface per boiler horsepower. This is where the 5 sq. ft. engineering rule originated.

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BOILER HEATING SQUARE FOOTAGE

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In 2011, Cleaver-Brooks R&D engineers set out to design a revolutionary firetube boiler from the ground up, not letting any "rules of thumb" go unchallenged. Utilizing the latest in Computational Fluid Dynamics (CFD) modeling and finite element analysis, they studied two key areas of boiler heat transfer: the boiler tube design and the furnace geometry.

They focused on addressing the issue of traditional plain tubes utilizing a fraction of their heat transfer surface because of boundary layers caused by the laminar, or straight, flow of the gases through the tube. The boundary layers create a barrier for heat transfer, requiring more tube length, or square footage of heating surface, to accomplish the required heat transfer. By designing a tube with a proprietary rib system inside, engineers were able to develop a tube that utilizes 100% of its heating surface and transfers 85% more heat through the tube than a traditional bare firetube. Thus, fewer tubes, or less square footage of heating surface, are required to accomplish the required amount of heat transfer.

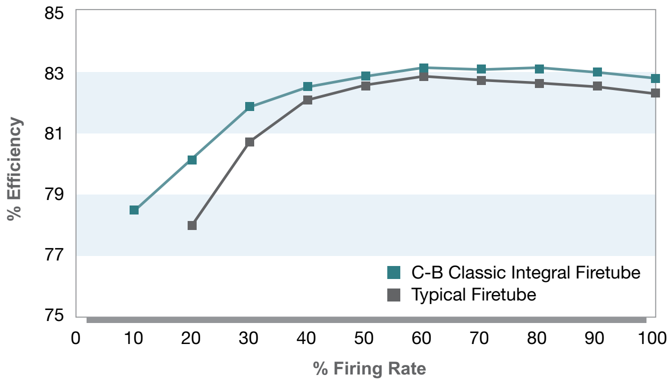
With the tubes now transferring more heat with less heating surface, space was afforded to the engineers to evaluate the size and geometry of the furnace, where 60%–70% of the boiler's heat transfer takes place. With advanced CFD modeling and finite element analysis, engineers were able to optimize the geometry of the furnace to maximize the heat transfer while achieving the ideal balance of high heat transfer with the lowest pressure drop.

Balancing the heat transfer with the pressure drop was important because of the lessons that had been learned in the field with boilers with less heating surface per square foot overheating, specifically the rear tube sheet attachment. The optimized furnace has a heat release rate of 125,000 BTU/hr/cubic foot compared to a boiler industry average of 150,000. The low heat release rate keeps flue gas temperature lower and reduces thermal expansion. A lower flue gas turnaround temperature at the end of the furnace reduces temperature gradient of the tubesheet. This, combined with the reduced thermal expansion of the furnace, increases the tubesheet and tube attachment's life, leading to longer pressure vessel life. The engineers had created a boiler that has a longer pressure vessel life than boilers that maintain at least 5 sq. ft. of heating surface per horsepower, with a boiler design that defies the century-old "rule of thumb." In addition to the extended life, the boiler has a smaller footprint and lower shipping cost.

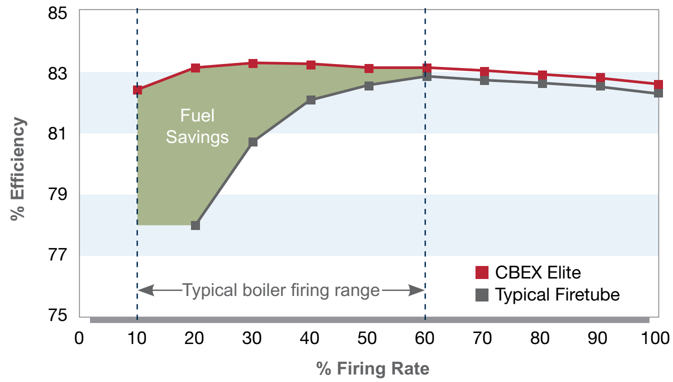
The technology behind the CBEX:

DISCOVER HOW TO SAVE FUEL WITH TURNDOWN AND HIGH EFFICIENCY ACROSS THE FIRING RANGE

EFFICIENCY % FOR A C-B CLASSIC INTEGRAL FIRETUBE VS. TYPICAL FIRETUBE THROUGH THE FIRING RANGE



EFFICIENCY % OF A CBEX ELITE VS. TYPICAL FIRETUBE THROUGH THE FIRING RANGE



Efficiency curves based on natural gas firing at 125 psig steam at 30 ppm NOx. Efficiencies do not reflect secondary heat recovery options.

The typical boiler plant has boiler capacity larger than what would normally be required to run their given process. This is due to redundancy requirements, changes in long-term plant demand, new efficiencies in the process, or any number of other factors. Often, over-sizing of boiler equipment is incorporated into the original design. The over-capacity paired with the changing requirements for steam or hot water at a given time in the process means boilers have to move through their firing ranges to meet demand, most of the time operating at 60% or less of their full firing range (capacity).

This leaves two important factors to consider: boiler turndown and boiler efficiency throughout the firing range. All burners have a specific turndown, ranging from 4:1 to 10:1 or higher, depending on the burner design. As the demand for steam or hot water decreases, the boiler's burner "turns down" to try to only meet the required demand. If a burner only has 4:1 turndown, that means it can only operate at 25% of firing capacity (100%/4=25%). As the process's demand continues to decrease, the firing rate must decrease. However, if the demand falls under the minimum turndown, the boiler will quickly meet the minimum process demands and then "cycle off" until more demand is needed. A boiler cycle consists of a firing interval, a post-purge, an idle period, a pre-purge, and a return to firing—causing valuable energy to be wasted.

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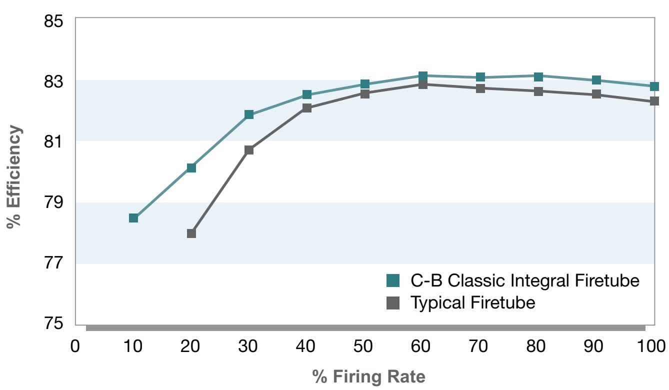
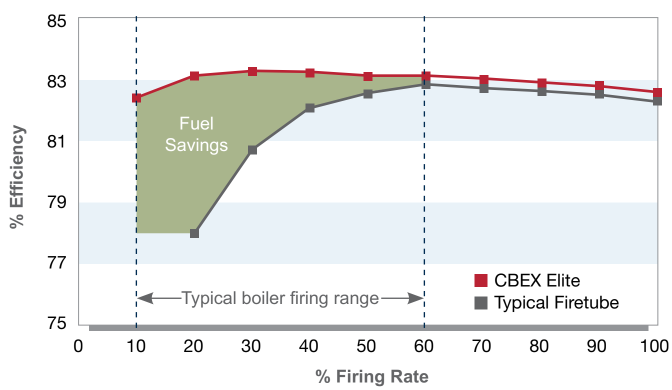
BOILER EFFICIENCY AND FIRING RATE

**EFFICIENCY % FOR A C-B CLASSIC INTEGRAL FIRETUBE
VS.
TYPICAL FIRETUBE THROUGH THE FIRING RANGE**



**EFFICIENCY % OF A CBEX ELITE
VS.
TYPICAL FIRETUBE THROUGH THE FIRING RANGE**



Recognizing this, in 1990, Cleaver-Brooks engineers made 10:1 turndown standard in its classic line of firetube boilers, featuring the industry's benchmark integral burner. With 10:1 turndown, a boiler can "turn down" to 10% of capacity without cycling, preventing needless energy losses.

The efficiencies of boilers change as you go up and down the firing range—often falling off dramatically as the boiler enters the lower end of the firing range. If boilers are operating at 60% of capacity, this decrease in efficiency leads to lower operating efficiencies and increased fuel expense. While the classic Cleaver-Brooks line of integral firetubes prevents energy loss from cycling, the boilers still have reduced "thermal efficiency" in the lower firing ranges, albeit higher than other firetubes.

In 2011, Cleaver-Brooks engineers were challenged with pushing firetube boiler technology further. Taking advantage of advancements of Computational Fluid Dynamics (CFD) modeling and finite element analysis, engineers began the process of designing a new firetube boiler from the ground up. Engineers focused on three areas: 1) optimizing the heat transfer of the firetubes with a proprietary heat transfer tube, 2) using the space created from improving the tubes to geometrically optimize the shape of the furnace for more robust combustion, and 3) integrating the burner and controls for peak performance.

Their efforts paid off. The new CBEX Elite firetube boiler achieves extremely high efficiency throughout the boiler's entire 10:1 turndown range.* Specifically, as the boiler turns down to 60% or below, the efficiencies remain high all the way down to the 10% firing range, not decreasing like other firetube boilers. With the advanced CBEX firetube boiler's 10:1 turndown combined with unprecedented high efficiencies across the turndown range, operators will recognize tremendous fuel savings while operating below the 60% firing rate and throughout the boilers entire firing range.

*10:1 turndown available on CBEX models larger than 200 BHP.

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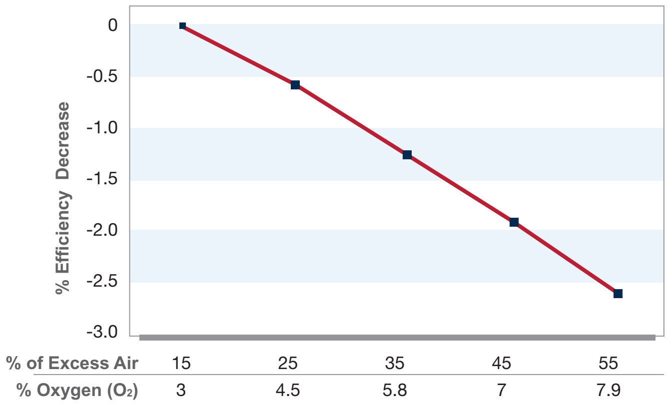
EXCESS AIR EFFECTS ON EFFICIENCY FOR NATURAL GAS



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.

The technology behind the CBEX:

THE IMPACT OF EXCESS AIR ON EFFICIENCY

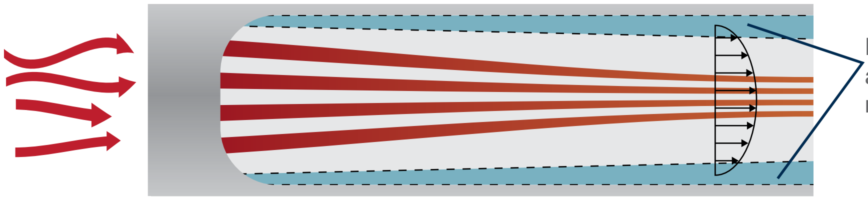
In theory, to have the most efficient combustion in any combustion process, the quantity of fuel and air would be in a perfect ratio to provide perfect combustion with no unused fuel or air. This type of theoretical perfect combustion is called stoichiometric combustion. In practice, however, for safety and maintenance needs, additional air beyond the theoretical “perfect ratio” needs to be added to the combustion process—this is referred to as “excess air.” With boiler combustion, if some excess air is not added to the combustion process, unburned fuel, soot, smoke, and carbon monoxide exhaust will create additional emissions and surface fouling. From a safety standpoint, properly controlling excess air reduces flame instability and other boiler hazards. Even though excess air is needed from a practical standpoint, too much excess air can lower boiler efficiency. So a balance must be found between providing the optimal amount of excess air to achieve ideal combustion and prevent combustion problems associated with too little excess air, while not providing too much excess air to reduce boiler efficiency. Research has shown that 15% excess air is the optimal amount of excess air to introduce into the boiler combustion process. While some boilers have been able to achieve 15% excess air at the top end of a boiler’s firing range, the challenge presents itself at the lower end of the firing range, or below 60% of the boiler’s maximum capacity. In general, most boilers tend to increase excess air requirements as the firing rate of the boiler decreases, leading to lower efficiency at the lower end of the firing range. To complicate matters, most boilers operate on the lower end of the firing range—so selecting a boiler that has low excess air throughout the firing range is important. This will ensure that you are always operating at high efficiencies.

PUBLISHED BOILER EFFICIENCY AND EXCESS AIR

Most manufacturers will publish boiler efficiencies with either corrected levels of excess air or efficiencies only at the top end of the boiler capacity. This makes the boiler efficiency appear higher than it actually is. For a more accurate efficiency, ask for boiler efficiencies with actual excess air levels given throughout a 10:1 turndown range.

Typical Boiler Tube

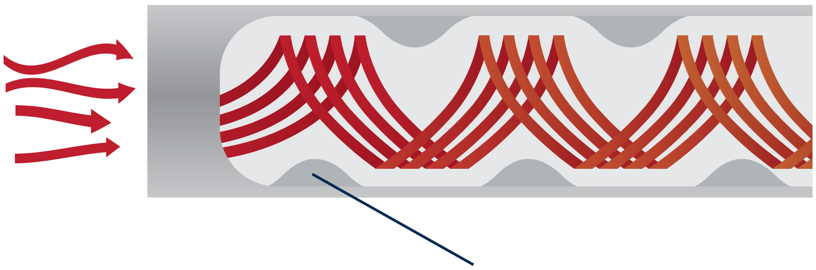
Hot flue gases enter boiler tube in turbulent pattern but quickly change to a laminar, or straight, flow



Boundary layer forms along tube walls, retarding heat transfer

Cleaver-Brooks Advanced Heat Transfer Tube

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



+85% more heat transfer

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

The technology behind the CBEX:

ADVANCED HEAT TRANSFER TUBES

In a firetube boiler, the hot flue gases travel through the boiler tubes and transfer heat to the water through the surface of the tube. The greatest heat transfer occurs when the hottest gases come in contact with the surface of the tube for the greatest amount of time.

In a traditional bare tube used in the majority of boiler designs, the hot combustion gases enter the tubes in a turbulent flow pattern. This initial turbulent pattern produces good heat transfer initially, but the hot flue gas pattern quickly changes to a laminar flow, or a straight parallel flow of gases. With the gases traveling in this straight pattern, a boundary layer forms along the tube walls, increasing with the distance of the tube. This layer serves as a barrier, retarding heat transfer. As a result, a bare tube only utilizes a fraction of its diameter for heat transfer, which equates to a lot of wasted space.

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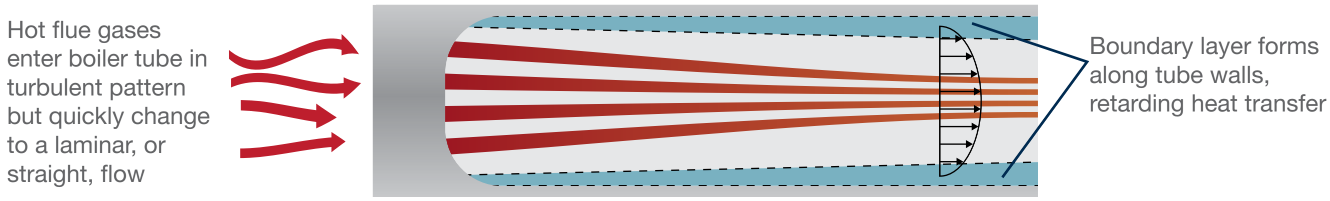
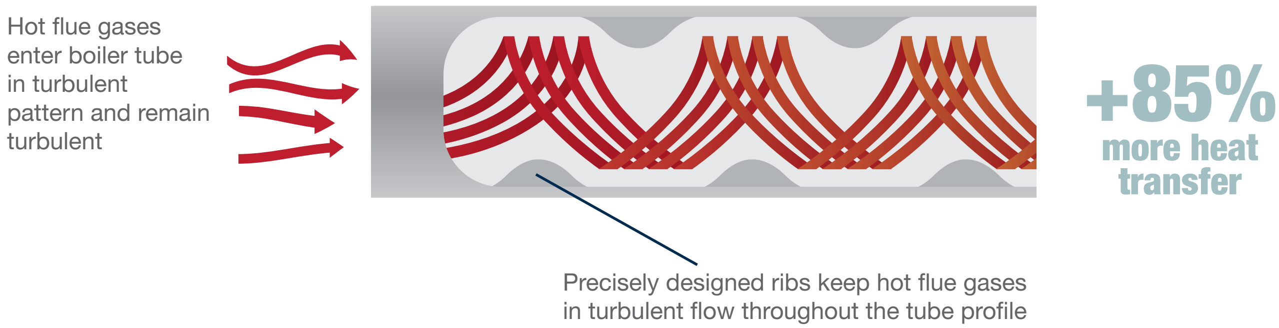
ADVANCED TUBE DESIGN

Typical Boiler Tube



Cleaver-Brooks Advanced Heat Transfer Tube



Because 30% to 40% of the boiler's heat transfer takes place in the tubes, it is important to generate as much heat transfer as possible within the tubes. Knowing that the laminar flow of the flue gases causes poor heat transfer, as described above, over the past 10+ years engineers have been looking at ways to create turbulence of the flue gases throughout the length of the tube to increase heat transfer and decrease the formation of boundary layers. By adding helical ribs or embossed spiral patterns to the inside of the tube, engineers were able to create more turbulence of the hot flue gases and thereby create more heat transfer. But more could still be done.

Using Computational Fluid Dynamics (CFD), finite element analysis, and mathematical modeling, Cleaver-Brooks engineers began to improve the tube profile. Coupling the modeling technology with their extensive knowledge of boiler systems, Cleaver-Brooks engineers dedicated countless hours to spiral tube engineering to perfect heat transfer within the proprietary spiral tube. To obtain the right cross section for optimal tube performance, the engineering team continuously made changes to the number of ribs, the angle of the ribs, and the height and width of the ribs. They would then analyze the calculations, continuing to refine the geometry to achieve the optimal result.

In the end, the advanced heat transfer spiral tube for the CBEX utilizes 100% of the tube diameter and increases heat transfer by 85% compared to a traditional bare tube. This proprietary tube is the only one to achieve these remarkable results.