Low Emissions and High Efficiency; A Dichotomy?

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Through empirical engineering practices it has been observed and proven that simply applying any burner to a boiler does not result in the most energy efficient unit and certainly not one which will be emitting low amounts of nitrous oxides (NOx) and other pollutants. On the contrary, facing the challenge of the 21st century to generate steam or hot water with high fuel efficiency, and low or ultra-low NOx emissions to reduce smog in the air, requires advanced engineering practices using sophisticated technical and modeling tools. Burner design can no longer be made independently of the furnace to which it is installed. It must integrate the furnace effects and provide a means of adapting combustion aerodynamics to match the furnace's geometry. This trend is therefore leading to a total integration of the boiler, burner and controls; forming a compact, energy efficient and low emitting steam/hot water package.

Today, the leaders in the boiler industry are following a technological path similar to that of the gas turbine industry; using computational fluid dynamics (CFD) principles to shape the best, most efficient design result.

Likened to the gas turbine, the modern boiler furnace design, with its constraints of volumetric heat generation, requires a high level of temperature uniformity obtained by fast and efficient mixing of the fuel and air to achieve extremely low NOx emissions.

In the final analysis, it is the mixing power of the properly designed burner working in conjunction with the existing or properly designed furnace which results in natural gas NOx emission levels ranging anywhere from 60 to < 9PPM without reducing the boiler's overall fuel to steam or water efficiency.

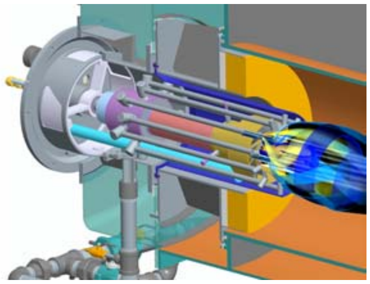
Two (2) examples of this advanced technology being applied to the packaged firetube boiler can be found in Cleaver-Brook's most recent boiler designs, the ***Promethean model 4WI and Criterion model ICB.***

Burner and Furnace Compatibility

With these boiler designs, optimum combustion and heat transfer begins with the fuel and air delivery system and progresses to the firing head where the proper amounts of fuel and air are united to form a highly combustible mix. A combustible mix which is achieved through the mixing power of the fuel and air caused by the summation of their respective pressure drops and inter-linking of the spontaneous combustion process wherein all of the inert combustible products are volatized within the main flame body or the immediate periphery.

The aerodynamically shaped flame with an optimum length to diameter ratio matching the furnace, results in the highest combustion efficiency and lowest emissions with minimal amounts of excess air, zero CO, particulate and, NOx levels to less than 9 PPM when burning natural gas.

To accomplish this, the burner is designed to incorporate a high injection velocity; blending the volatile molecules of fuel and air into a homogeneous mixture at the point of ignition. This mixing power and resultant high combustion efficiency then combines with the properly designed Furnace to deliver the maximum fuel-to-steam or fuel-to-water efficiency.



Since the mixing rate and its specific distribution determines the temperature and chemical species developed within a given furnace, the configuration of the burner, relative to the geometry and flow pattern in the furnace, exerts a significant influence on the amount of heat absorbed, and the formation of noxious emissions such as NOx, CO and particulate.

Lowering Emissions
Minimizing emissions coming out of boiler stacks is becoming a greater issue, and must be incorporated into the burner design as private industry and government officials become increasingly aware of the harmful effects which can result from excessive exposure. One of the most critical pollutants to be controlled during the combustion process is oxides of nitrogen (NOx) because in the presence of sunlight and other volatile organic compounds (VOC) they will form harmful ozone or smog.

Promethean Model 4WI Cut-a-way

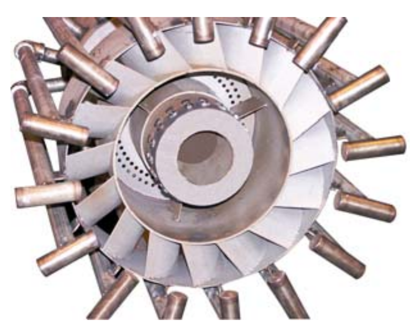
Criterion Model 4WG Cut-a-way

Reducing emission formation during the combustion process requires not only excellent burner design, but as stated previously, the proper mating of the burner to the furnace into which it is firing. Flame shaping and temperature control throughout the entire firing range is critical in reducing NOx formation, and can only be realized if proper thermal and fluid dynamic principles are incorporated in the design. Principles resulting in maximum tangential and axial fluxes along with the ultimate length to diameter ratio of the flame within the furnace are critical as these are the main determinants for flame temperature control, no carbon monoxide or hydra-carbon formation and, combustion stability.

The Promethean and Criterion line of firetube boilers with low NOx burners using flue gas re-circulation *(FGR), offer options affording a range of NOx maximums depending on specific requirements. Available in 75, 60, 30, 15 to <9 PPM when burning natural gas and 75 PPM with #2 oil (0.02% FBN), these steam and hot water packages provide flexible alternatives; meeting an array of needs.

*By using combustion air to draw 4th pass flue gas (FGR) into the combustion mix, the flame temperature is reduced to a level which limits the propagation of nitrous oxides without quenching it or reducing overall efficiency.

In the Ultra-low NOx design (15 - <9 PPM), induced flue gas re-circulation is also applied; however, the gaseous fuel and air is introduced using three independent areas of supply. The first area is located within the inner core tube, assuring positive flame stabilization independent of burner load. The second



area is used to inject fuel and air into a swirling flow generated by the fixed angle blades within the outer swirler. The third area is through specially designed burner nozzles which deliver and connect the

fuel stages to blend with the axial and swirl air supplies. The result is NOx levels less than 9 PPM when firing natural gas. This compares to 100-120 PPM in standard, uncontrolled burner technology.

The next step in achieving optimum fuel to steam/water efficiency, and clean combustion involves the furnace into which the flame is enveloped, and the convection heat transfer area which is exposed to the mass flow of post combustion gases and combustion air.

With the Promethean and Criterion designs, the furnaces are enlarged and engineered to optimize the radiant heat transfer area, releasing a minimum of 35% of the burner's input as radiant energy; the most effective heat transfer method in a boiler by a power of four (4) when compared to the other means including conductive and convective heat transfer surfaces.

The large, highly engineered furnace following the design constants as determined by Stefan-Boltzmann, combine the heat transfer dynamics of radiation, convection, conduction and emissivity to maximize heat transfer while lowering heat release per cubic foot of furnace area. This lower heat release limits excessive furnace film temperatures which impede heat energy from entering the water backed contact surfaces around the furnace, weakening the metal and reducing efficiency.

Heat Transfer Coefficient Dictates Surface Area

While in the modern day firetube boiler which has been designed for high efficiency and low emissions, the furnace is of extreme importance for capturing radiant energy, the convection section of the boiler plays an equally important role. It is the combination of these two areas of heat transfer, which if optimized, reduce fuel consumption and boiler size without compromising pressure vessel integrity. The key lies in how the total package is designed and controlled.

Promethean Model 4WI

For the most part, firetube boilers today are designed with five (5) square feet of heating surface per boiler horsepower. This standard essentially evolved as a way to improve efficiency and most importantly, add to boiler life expectancy.

Cleaver-Brooks, using advanced CFD modeling, deviated from this standard with its model *ICB firetube boiler, using a lesser amount of heating surface per boiler horsepower, delivering efficiencies at or above most firetubes with the standard five (5). This, without compromising pressure vessel integrity.

The reason for the ICB's excellent performance, is the boiler/burner matching working in conjunction with optimal fluid dynamics, enhancing the overall heat transfer coefficient (U) in the furnace and convection zones.

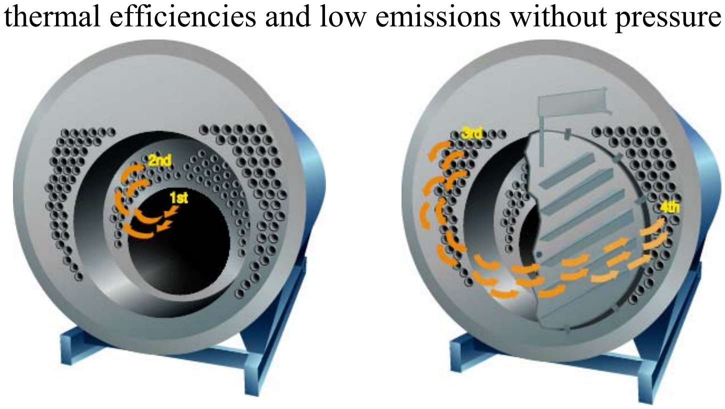
The high U value in the ICB is accomplished through a combination of the following:

- Proper residence time in the furnace resulting in a minimum of 35% radiant heat absorbtion.
  Designing for the critical Reynolds number; achieving the optimum ratio between inertia and viscous forces of the post combustion gasses to result in maximum turbulent action and heat transfer.
- Multiple passes including three (3) passes in the convection zones.
- Maintaining critical mass flow velocities through the radiant and convection areas.
- Excellent contact of the hot flue gasses to the water backed surfaces of the tubes.
- Proper feedwater introduction enhancing thermal circulation and overall heat transfer within acceptable and proven Reynolds number standards .

Criterion Model ICB

Given these dynamics; necessary to enhance the overall heat transfer coefficient within the exchanger, the heat is quickly absorbed and moved into the water where it is converted to hot water or steam for heating or process applications.

This quick movement of energy reduces temperature gradients across the surfaces, keeping them relatively constant, cool, and free of inordinate stresses. The result is high thermal efficiencies and low emissions without pressure vessel compromise.



Left: ICB view of 2nd pass – Right: ICS Rear Access Way

* The Criterion model ICB is truly unique. Its designed to incorporate the key features and benefits of both a wet-back and dry-back boiler. The key is in the revolutionary inter-cooled rear turnaround chamber and access way providing complete accessibility to the 2nd pass tube area. Couple this with the Cleaver-Brooks Profire gun burner and optimized heat exchanger and you have a totally engineered package delivering high efficiencies, low emissions and maintenance ease.