

An Industry

COMMITMENT

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CLEAVER  **BROOKS**

In the world of steam and hot water generation today, we find consultants, design engineers, clients and customers concerning themselves primarily with four (4) main issues which drive their decision making when considering choices for commercial/industrial heating and process applications. The issues are:

- ▲ *Energy conservation*
- ▲ *Emission reduction*
- ▲ *Reliability*
- ▲ *Safety*

This dynamic has forced responsible manufacturers of combustion and heat transfer equipment to re-evaluate their product offerings, redesigning them to meet these demands for the retrofitable aftermarket or, designing completely new packages to deliver the desired results for new installations, replacements and expansions... This may seem an easy task at first, but in reality, the engineering know how for success is considerable, requiring years of experience from both the theoretical and empirical perspectives.

For instance, to be notably effective when it comes to energy conservation and emission reduction, it is important to consider the energy conversion unit as a complete burner/boiler package, incorporating the unique characteristics of the combustor (burner) along with the thermodynamic characteristics of the furnace into which the chemistry of combustion takes place. The two work in tandem, along with the controls, and all must be designed and configured as a synergistic package in order to maximize performance and optimize long term results.

This technical paper, some of which is a summary of writings and discussions with Dr. Normand Brais, Sr. VP and world renown combustion specialist from Cleaver-Brooks Advanced Technologies Group, delves into the key issues and what can be done from an overall design standpoint to save energy and the environment while positively impacting reliability and safe operation...

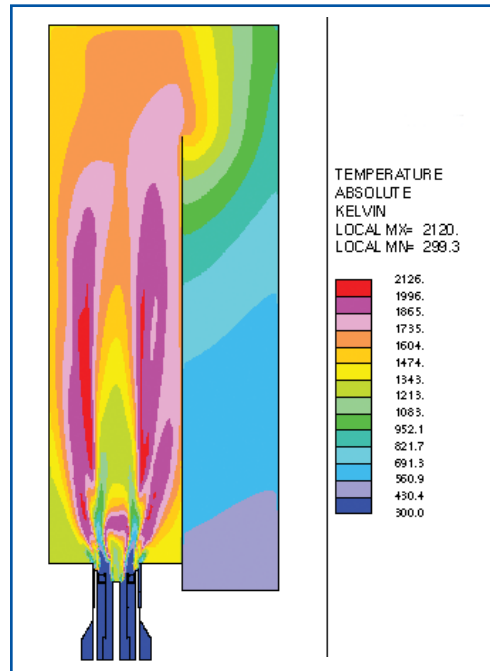
Overview

Engineers, boiler owners and operators have long observed that the combustion chamber or furnace geometry and construction greatly affect burner performance. It has been proven many times that the same burner installed in different boilers will not produce the same results. The universal burner that fits all is a technical utopia that has long plagued the boiler industry.

Facing the challenge of the 21st century to generate steam and hot water efficiently, reliably and safely with ultra-low emissions, requires using engineering practices incorporating a more advanced technical toolbox than employed in the past. Burner design can no longer be made independently from the furnace in which it is to be installed. To the contrary; it must integrate the furnace effects and provide a means of adapting combustion aerodynamics to match the furnace. This trend will lead to a total integration of the boiler, burner and controls, resulting in high efficiency and low contaminant emitting steam/hot water generating systems.

It is very likely that the boiler industry will be following a technological path similar to that of the gas turbine industry. In gas turbine engines, the constraints of volumetric heat generation are significantly higher than in current boilers. Yet, the high level of temperature uniformity obtained by fast and efficient mixing

CFD – Furnace Temperature Profiling



allows for extremely low NOx emissions even without Flue Gas Recirculation (FGR). The achievements of the aircraft and gas turbine industries are largely due to the use of advanced test facilities and computer simulations involving Computational Fluid Dynamics (CFD) which essentially correlates fluid mass flows and velocities with temperature profiles and gradients, (accurately) predicting and modeling thermodynamic outcomes.

It is not the intent of this paper to elaborate on computer simulation, but rather to try to demystify the fundamental physics of burners and combustion chamber interaction. Also, this paper will explain a technically innovative strategy on how to achieve sub-9 ppm NOx emissions when burning natural gas with less than 25 PPM CO in various furnaces including smaller or more confined ones. The paper will also address the continual need for reliability of the total boiler package and the need to keep safety at the forefront of any development work.

Efficiency Begins with the Burner

Whether it is a pre-mix or a nozzle-mix/diffusion type flame, the very first function of a burner is to insure that the fuel is evenly mixed with air so that it burns completely within a confined combustion chamber volume. The lower the excess air required for complete combustion in a given volume, the more efficient the burner. The efficiency of a burner can in fact be defined as an inverse function of the amount of excess air required to achieve complete combustion in a given flame volume.

Air & fuel pressure drop combine for efficient mixing and shaping

For a nozzle-mix burner, the mixing power required to obtain the desired mixing rate is the sum of the combustion airflow pressure drop and the fuel flow pressure drop. On the air side, the burner dissipates some fan horsepower to affect mixing. On the fuel side, gas pressure multiplied by volumetric flow through the gas injectors provides another source of mixing power. These air and fuel pressure drops at a given volumetric flow rate provide the potential mixing power for a burner to accomplish its task of mixing the two streams. The volumetric heat generation of the flame of any burner is a function of this quantity; the larger it is, the smaller the resulting flame is.

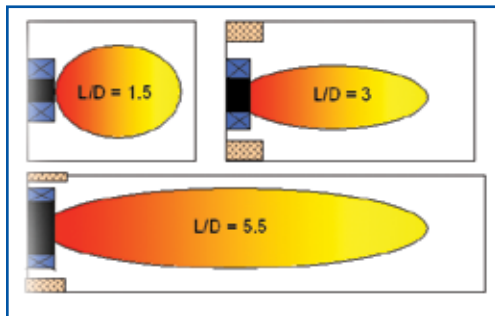
An example of the potential mixing power can be explained by referring to a 350 MMBTU/hr (8365 HP) natural gas burner running at full load with 12 psig of gas pressure and 8 inches of air pressure drop.

Although the gas flow is a considerable order of magnitude less than the air flow when comparing volumes in square feet per minute, the natural gas mixing power still represents more than 75% of the total mixing power. Additionally, the air mixing-power requires spending fan electrical horsepower while the gas mixing power source is essentially free. Designing for low gas pressure at the burner is a waste of that potential mixing source and resultant burning efficiency.

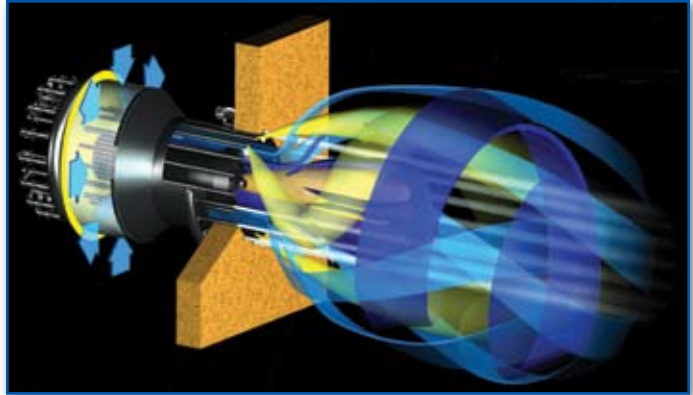
Stabilizing and Shaping the Flame to Match the Furnace

As a second function, a burner must be able to ignite and generate a stable flame that, most importantly, fits the furnace geometry.

Flame stabilization is generally performed without much difficulty by a bluff effect and/or a critical swirl effect occurring at the mixing point of fuel and air. Flame shape can be described by its length-to-maximum diameter ratio and is determined by the aerodynamics of the air and fuel injection pattern. The swirl, defined as the ratio of tangential momentum to axial momentum fluxes, added to the other injected fluid streams, is the key controlling parameter for flame shaping.



To achieve good practical results, it is imperative that the burner-generated flame be compatible with furnace geometrical constraints. This is most critical in water-cooled furnaces such as boilers and especially in packaged boilers. If flame impingement occurs on cold surfaces, carbon monoxide and other by-products of incomplete



combustion will be produced at the point of impingement and, in large proportions, produce severe furnace vibrations upon violent re-ignition of these by-products.

Besides this condition being an energy waste and pollution contributor, **safety** is also compromised by this lack of proper matching; meaning the situation should be avoided at all cost.

The Dynamics of NOx Generation in Boiler Combustion

Considering that NOx is massively formed in areas where flame temperatures exceed 2800°F, and



that boiler furnaces are designed to operate at average outlet temperatures ranging from 1800 to 2400°F, NO_x formation is simply the result of poor temperature uniformity within the furnace and more particularly, within the flame zone.

Unfortunately, most burners today are still being designed independently from the furnace.

The primary reason being many boiler manufacturers are operating separately from the burner manufacturer of choice.

This separation, if not bridged by collaborative design engineering and testing between the two parties, will lead to inadequate design of the burner and its required compatibility with a given furnaces' aerodynamics. This condition then leads to inadequate mixing rates not only between the air and the fuel, but also with the products of combustion inside the furnace.

If on the other hand, compatibility is assured, temperature peaks are reduced and cold spots are minimized, thus reducing both NO_x and CO emissions. Furthermore, the improved mixing uniformity results in a significant reduction of the flame size and of the peak heat fluxes on the boilers' heat transfer surfaces. Consequently, ultra low emission performances can be achieved in much smaller furnaces

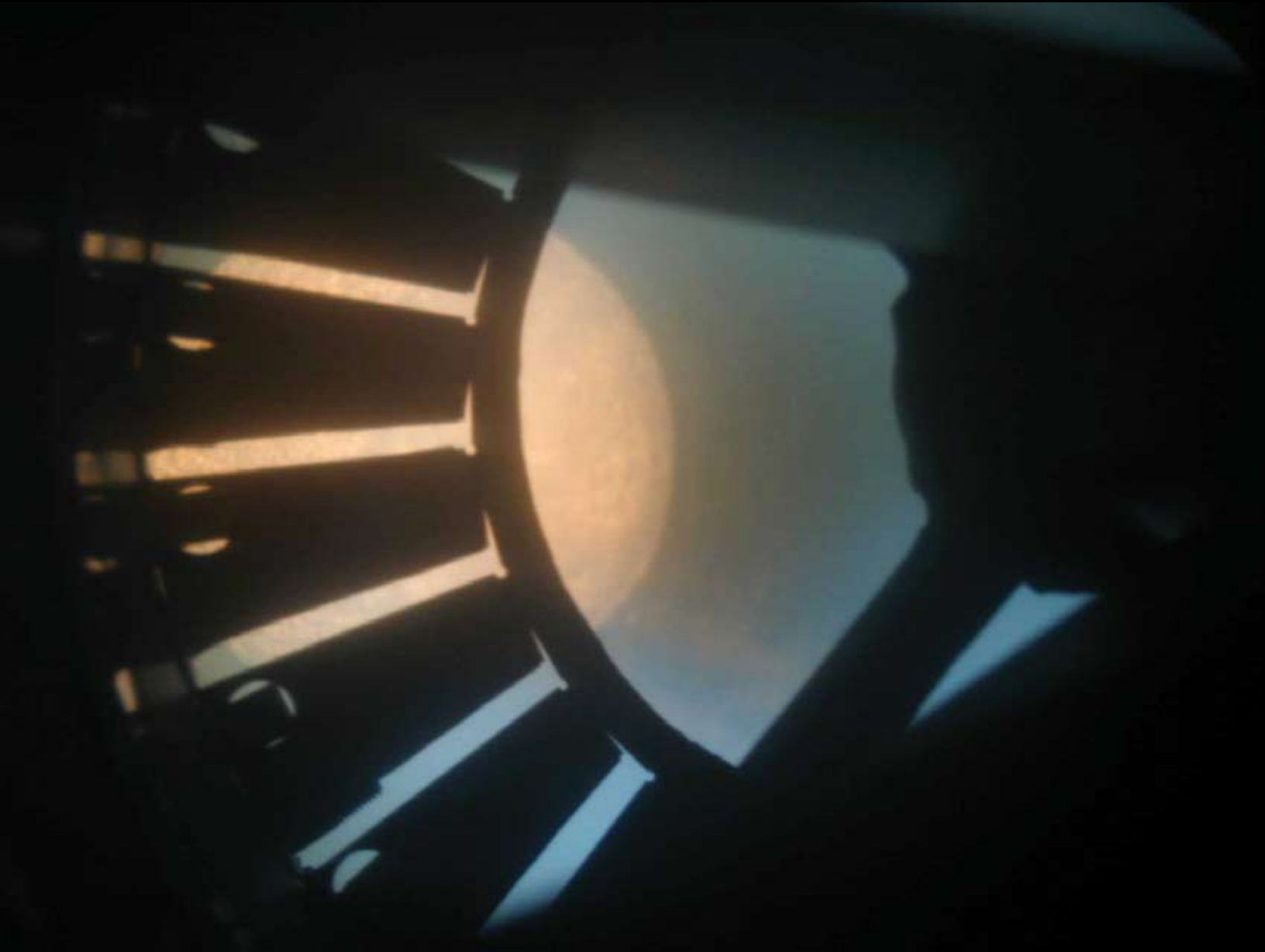
with less thermal stress for better longevity and **reliability** of the boiler proper. This integral design philosophy has already proven successful in other combustion applications such as gas turbines and car engines with their multiple valve designs.

Reducing NO_x and Other Pollutants

Since the mixing rate and its specific distribution determines the temperature and chemical species concentration within a given furnace, the design and configuration of the burners in relation to the geometry and flow pattern in the combustion chamber has a significant influence on NO_x, CO and Particulate formation.

The emission of pollutants is intimately linked with furnace configuration and distribution of heat dissipation. It is obvious that reducing pollutants successfully in a given furnace requires that the burner configuration be sufficiently adaptable to properly match the furnace flow and temperature characteristics.

To achieve Ultra-Low NO_x emissions (<9 PPM), the burner mixing power must not only provide enough mixing between air and fuel to obtain complete combustion, it must also provide enough mixing power per unit furnace volume to evenly mix the inert combustion products within that radiant chamber.



Poor combustion results in pollutant generation.

NOx and CO formation is simply the result of poor temperature uniformity within the furnace

NOx formation is triggered in areas where local furnace temperatures exceed 2800°F and CO formation results mainly from low temperature zones well below 1400°F. Since most boiler furnaces are designed to operate at average outlet temperatures ranging from 1800°F to 2400°F, NOx and CO formation is simply the result of poor temperature uniformity within the furnace, particularly within the flame zone.

A perfectly mixed combustion zone would result in negligible NOx formation that could theoretically be close to zero even without the use of FGR; however, such perfect mixing would require a level of mixing power per unit furnace volume that would be cost prohibitive for many boiler applications. Additionally, even an imperfectly mixed furnace with temperatures within 1300°F to



2900°F would still result in very low emissions for both CO and NOx.

Finding the Optimum Solution for Emission Control

Balancing the benefits of high mixing technology and uniform temperatures with the realities of cost containment and practicality has led to the use of FGR as an additional inert mass released into the combustion zone, reducing the peak temperature of the flame; lowering NOx production.

The major drawback of FGR is that it can also reduce the temperature of colder zones in the furnace, increasing CO emissions. Another factor of FGR use is its dilution effect on the fuel-oxidant, increasing flame size. At a certain FGR rate, this can cause flame impingement and induce furnace vibrations and rumbling.

To reach ultra-low NOx levels (<9 PPM) with FGR alone, the amount of FGR typically used by low mixing power burners is in the 30 to 40% FGR range. Under these conditions, the bulk of the flame zone is approaching the lower flammability limit of methane, the major component of natural gas. Under extremely lean conditions, combustion becomes radically unstable especially with rapidly varying flame modulation rates working in conjunction with standard commercial control systems. In these situations, only extremely slow firing rate changes



can be achieved without adversely affecting reliability and/or safety.

Other important factors to consider with FGR is that it has led to many burner manufacturers requesting that the boiler manufacturer increase the size of their furnaces to fit the new ultra low

NOx burner. This recent trend in boiler design is detrimental not only for the obvious, elevated material cost and footprint, but also for the boilers' convection bank pressure drop since furnace size is often increased, compressing the boilers' convection section. The result is a boiler with higher draft losses; increasing fan horsepower requirements.

Another possible downside to FGR is that due to the larger furnace volume, more burner mixing power will be required to obtain the same temperature uniformity, the driving factor being the mixing horsepower per unit of furnace volume. Higher

FGR rates will impact the required fan horsepower, driving up electrical cost.

Lastly, FGR in the 30-40% range may result in considerably higher burner windbox temperatures which can adversely impact mechanical devices located in the vicinity of the hot recirculation gases and, if super heaters are a part of the package, impact their output as well.

Integrated Design and Technologies Provide the Key

With advanced design tools such as Computational Fluid dynamics (CFD), an integrated boiler+burner manufacturer can build a combination of burner and combustion chamber that displays an unrivaled temperature homogeneity compared to what was accomplished in the past.

Typically with the right burner design and matching, 20-25% FGR results in low NOx

As explained above, by narrowing the temperature extremes within the furnace, very little FGR becomes necessary to reduce the peak temperature(s) to achieve less than 9 ppm NOx.

Typically with the right burner design and matching, levels as low

as 20 to 25% FGR have proven to be sufficient to reach the desired emission level on Cleaver-Brooks integral packages. This, because the lowest temperatures are reduced as a consequence of better homogeneity with virtually no unburned fuel and very little of its precursor (CO). Carbon monoxide emissions between 0 and 10 ppm across the range were easily demonstrated with this design strategy.

Another point worth noting, is that flame volume becomes much smaller when homogeneous mixing is achieved. Thus, the combustion chamber can be made much shorter than before, and because of this, the next generation of low emission boilers will exhibit a much smaller footprint with firetube boiler efficiencies approaching or exceeding 90%.

The key for achieving high efficiency and low emissions besides proper design and mating of the burner

involve the overall design of the heat exchanger proper. This begins with maximizing the effective emissivity ratio in the furnace; attaining the highest achievable Reynolds numbers (ratio of flue gas inertia forces to viscous forces) within the (fireside) convective section of the vessel. Concurrently, it is essential the external circulation on the fluid side of the shell be designed to enhance proper hydraulics, optimizing pressure/density differentials to achieve the highest degree of flow/exchange possible.

Secondly, the total package (burner/ boiler) must include the proper devices or system to automatically and safely control, monitor and communicate the operation of the boiler package from prepurge to post purge and shutdown.

PLC Based Controls Enhance Efficiency, Reliability and Safety

In this day of advanced electronics, design and specifying engineers are turning more and more to a PLC based platform for burner/ boiler management and control as it provides the greatest flexibility and almost limitless opportunities for expansion, upgrading, and very importantly, Communications. All this, while playing a collateral role in emission reduction, and a direct role in improving efficiency, reliability and safety within the boiler operation.



9



One example of this direction, is the Cleaver-Brooks Hawk ICS, an integrated boiler control system incorporating burner management along with an array of other features to satisfy the varied needs within the marketplace, including the (4) drivers mentioned above.

PLC Control and Energy/ Emission Reduction

Achieving proper burner/boiler design and integration though extremely important in achieving an efficient low emitting boiler, is compromised if the optimum control scheme is omitted from the conceptualized package. This, because the advanced controls available today using electronics as opposed to electro-mechanical sensing and actuation, are infinitely



more sensitive, responding to load changes far more rapidly; limiting over/under shooting while repeatedly maintaining setpoint. This saves energy and as such, reduces emissions.

Using PLC platforms, the control scheme can also integrate variable speed drives (VSD), oxygen trim systems and actuators for controlling fuel and air (parallel positioning); reducing electrical demand while adjusting for atmospheric changes which adversely affect fuel/air ratios, and/or, eliminating linkages which if not maintained and adjusted, can also lead to improper fuel/air ratios and wasted fuel.

PLC Control and Reliability

The essence of PLC control today, and having it part of the overall boiler control scheme, is achieving the added benefit of optimum information gathering and communication flexibility.

With ever rising fuel costs, pressures to reduce noxious emissions, and the extremely high cost for unexpected outages, it becomes imperative for the boiler owner to have the ability to closely monitor and track the boiler's operation, communicating conditions on a moments notice. PLC based packages afford this capability, amassing volumes of data which can be trended on spreadsheets for developing predictive maintenance procedures



Trending and documenting energy use.

or, highlighted for important cost impact areas involving energy use and emission variances.

Further enhancing these awareness benefits, PLC based technology allows for the instant communication of this information via pager, phone, local terminal, BMS or, over the world wide web; improving equipment uptime while improving the overall cost of operation for the entire plant or facility.

PLC Control and Safety

Boiler manufacturers for over 100 years have recognized the importance of producing a safe unit, manufacturing their products under rigid ASME Codes and controlling them in accordance with 3rd party standards such as UL, cUL, NFPA, CSD-1, and various insurance companies who assume property risk on behalf of the client.

Though these standards have enhanced the safe operation of thousands of units throughout the years, accidents still occur despite the tireless efforts on the part of manufacturers to produce and provide the most safe and reliable boiler possible. It is here where PLC based controls, taking advantage of modern day technologies, can further assist in the effort.

Using the PLC based platform, the overall boiler management system can integrate the best in burner

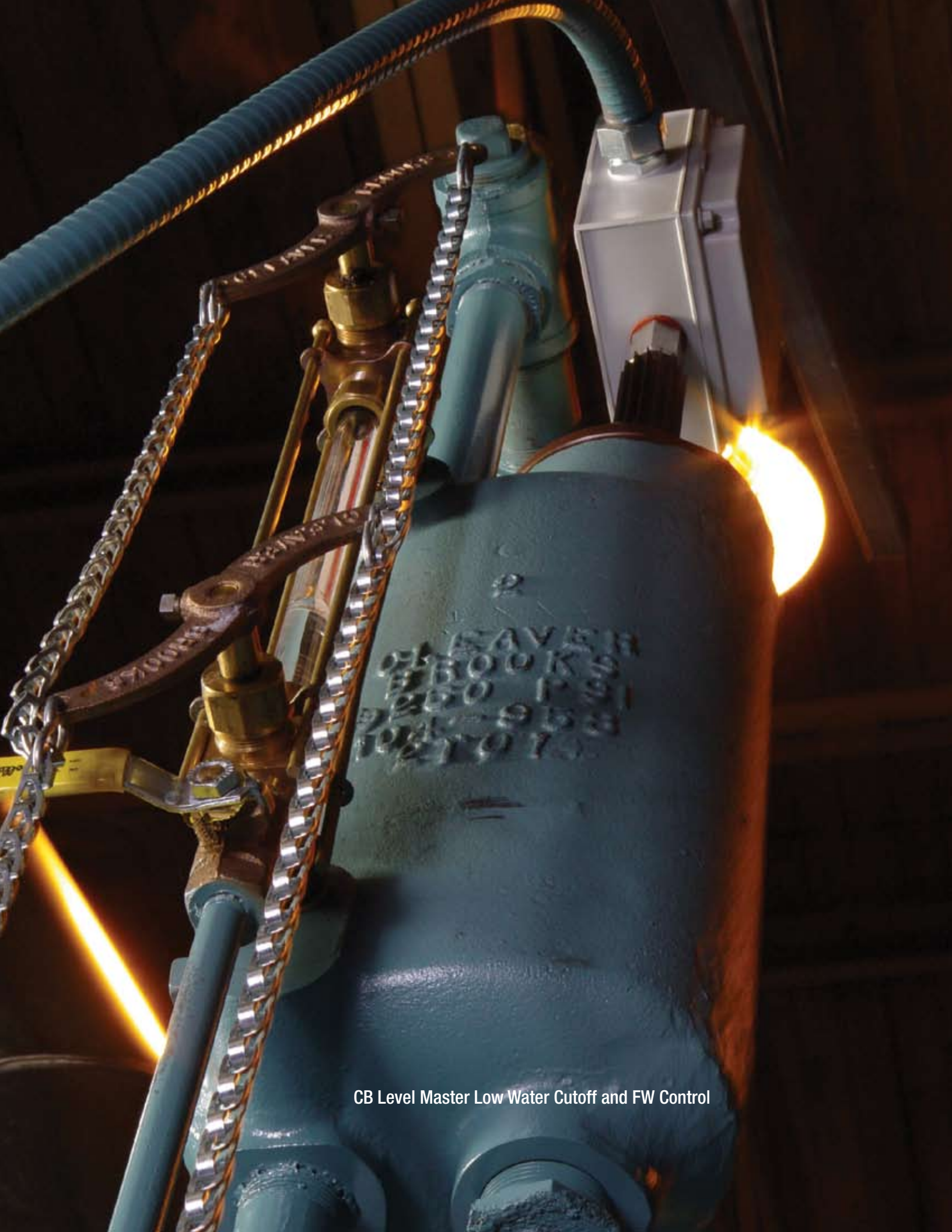
management control, assuring the user maximum safety from pre-ignition interlock checking through pre-purge, trial for pilot, proof of main flame and post purge following load satisfaction. All this while continually



checking itself hundreds of times a minute and looking for any faults triggered by the boilers' safety circuit.

Additionally, the PLC based platform allows incorporation of other safety devices in addition to the burner management control. An example of this is the C-B Level Master, a revolutionary low water cutoff and pump control which uses magnetostrictive technology in conjunction with solid state and microprocessor integration to sense and control level.

With most boiler **occurrences** happening because of unexpected low water conditions, the new technology provides continuous information on precise water level during standby



CB Level Master Low Water Cutoff and FW Control

and operation, alarming when it is too high or alarming when it is too low before turning the burner off. It will also remind the operator to blow the column down, advising if it was done properly, logging results and any faults to an alarm history with date and time stamping.

Total Commitment Leads to Ultimate Success

There are many things which responsible and dedicated boiler manufacturers can do to assist users of steam and hot water generators to achieve their desire for equipment which will conserve energy and the environment, operating reliably and safely for years to come. Several ways have been presented in this paper.



Training programs lead to safe, reliable operation



Another way, not discussed, but which needs to be mentioned, is supplying the various users of steam and hot water generating equipment with the **training programs** and the tools they need to safely and reliably operate the equipment with optimum long term results. These programs should be dynamic and flexible in nature, fitting an array of needs, and be readily accessed to meet expanding demand...

In the final analysis, all the solutions start with the manufacturers' commitment and steadfast dedication to the business, applying research and development dollars and other resources toward the creation of new products and programs; stretching the envelope to accomplish the objectives with a constant eye on the customer and his ever changing needs.



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