

Combustion Control Guidelines

**For
Multiple-Burner
Boilers**

December 2001

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FOREWORD

This publication has been prepared by the American Boiler Manufacturers Association (ABMA) to provide concerned parties, whether boiler owners, suppliers, or designing/consulting engineers, with current minimum industry practices and application guidelines for boiler combustion controls. This publication was prepared by the ABMA Burner Group, under the supervision of the ABMA Technical Committee and appropriate ABMA product/market groups. The guidelines for multiple-burner boiler combustion controls contained herein are a consensus of the ABMA member companies based on their collective experience with the equipment that they provide to the boiler market.

The ABMA believes that the lack of a national comprehensive combustion control recommendation represents a significant void in the industry's existing safety guidelines. The ABMA hopes that the recommendations contained herein will be incorporated as part of future industry standards. The various NFPA, UL and ASME standards have become the accepted industry standards for owners and manufacturers of equipment for boilers. However, these documents do not currently provide owners and designers with detailed recommendations for boiler combustion controls.

The contents of this publication are offered as guidance only. The American Boiler Manufacturers Association does not assume responsibility or liability for consequences arising from the implementation or failure to implement the guidance contained herein. The contents of this guide should not be construed as an endorsement by the ABMA of any product or manufacturer.

This guide is intended as a supplement to the other sources of information that are available on this topic. Information furnished by specific equipment manufacturers and/or designing engineers must also be consulted regarding individual combustion controls applications. This information is intended as a guideline of acceptable industry practices, but may not represent the best current practice. It is not a substitute for experience and sound engineering principles.

ABSTRACT

Traditional combustion controls packages are relatively simple and effective for responding to a variable process steam or hot water load. However, simultaneous technological advances on two fronts (low NO_x burner operation, and digital controller standardization) have complicated the task of selecting and implementing new combustion controls for new or retrofit boiler applications.

Low NO_x burners typically incorporate different fuel and air mixing patterns that lead to reduced boiler emissions. Additionally, these applications may incorporate controlled variables that are not present in traditional burner packages. The required band of control for a low NO_x combustion control application can be narrower than that of a traditional burner application. As regional NO_x requirements continue to trend lower, the required band of control for low NO_x combustion control systems also narrows. With this requirement for a narrow band of control, coupled with additional controlled combustion variables, more precision/repeatability is required from the combustion controls system.

Advances in digital controller technology have made it possible for the controller hardware to enhance the overall boiler performance, while also adding new safety features.

The boiler owner is ultimately responsible for the safe and reliable long-term operation of his boiler. There are five primary factors that the owner or his representative must control for a successful long-term boiler combustion control application. These are:

- Proper selection and engineering of the control scheme
- Proper selection of the controller hardware, final control elements, and field measuring devices
- Proper commissioning
- Proper operation (including operator training and staffing)
- Proper maintenance

The member companies of the ABMA feel that this publication will enhance the understanding of boiler owners and system designers in the complicated and dynamic field of combustion controls.

Combustion Control Guidelines **for** **Multiple-Burner Boilers**

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1 Introduction

1.1 Purpose and Scope of this Publication

This guideline was written by the American Boiler Manufacturers Association (ABMA) to provide boiler owners and operators, as well as consulting or design engineers and contractors, and other interested parties with current minimum industry guidelines to enhance the safety and reliability of the combustion controls for industrial and utility boilers. The paper focuses on gas and/or liquid fired boilers, and covers the design of the two predominant combustion control schemes (Parallel Positioning, & Metering) and the applicability of each. Also, it includes minimum recommended features for the hardware required for a combustion controls application. The paper discusses the proper commissioning of a new combustion control application, and the importance of maintenance, operator training and adequate operator staffing. An example of the system design and commissioning cycle for a hypothetical metering control system is also offered.

The specific goals of this guideline are to:

- Provide concerned parties with an understanding of the requirements for safe and reliable combustion controls so that they can be properly specified for new and retrofit applications.
- Provide concerned parties with an understanding that combustion controls are a “system”. This system incorporates the control scheme (suitable for the requirements of the application), the actual controller, the final control elements, the field measurement devices, the startup/commissioning and the subsequent operation and maintenance. The safe and reliable implementation of a combustion controls application on a multiple-burner boiler requires thoughtful attention to all of these elements of the control system.
- Provide concerned parties with the understanding that lower boiler emissions requirements drive the need for additional combustion control precision. This need for added precision and attention to detail applies to the design, selection, installation, operation and maintenance of new or retrofit combustion control applications.
- Provide specific guidelines regarding the design and selection of components for combustion control systems.

The member companies of the ABMA feel that this publication will enhance the understanding of boiler owners and operators in the complicated and dynamic field of boiler combustion controls.

1.2 History of the ABMA

The ABMA, founded in 1888, is a voluntary, non-profit corporation with headquarters in Arlington, Virginia. The only national association representing commercial, industrial and utility and other power-generating boiler manufacturers, fuel burning system manufacturers, boiler-related product/service suppliers and end-users, ABMA is committed to lead and strengthen the boiler industry, and is dedicated to safety, technical, environmental and commercial advancement. ABMA's commitment is to improving and growing the market for member company products and services. The mission of the ABMA is:

to promote the common business interests of the industry; to improve its services to the public; to be proactive with government in matters affecting the industry; to promote the safe, economical, and environmentally-friendly use of the products and services of the industry; and to carry out other activities recognized as lawful for such organizations.

The members of ABMA provide a wide variety of expertise in the area of combustion and boiler-burner operation. Drawing upon this expertise, this guideline was established to help boiler owners and operators educate themselves on boiler combustion controls.

1.3 Understanding the Role of Combustion Controls for multiple-burner boilers

For most industrial and utility boilers, steam is an internally generated utility that is critical to the processes or power generation of the facility. However, it is not uncommon for plant personnel and management to consider the steam only when failures cripple production, or capital appropriations are considered. Boiler combustion controls are one of the critical links that can keep the steam flowing in a safe and reliable manner.

In the early history of steam generation, combustion was controlled by how quickly an operator could shovel coal into the furnace. Obviously, combustion controls in the modern boiler plant have evolved significantly since then. The very active role of the boiler operator has given way to more sophisticated modern control hardware. The boiler operator now plays a more passive role. The introduction and acceptance of the Distributed Control System (DCS) for plant wide control is one of the latest steps toward the modern boiler control room. However, the evolution of combustion control hardware has not, and should not, lead to the extinction or obsolescence of more traditional and simple

combustion control schemes; nor does it lessen the necessity for cognizant and trained operators. The result of the continuing evolution in combustion control hardware is that the plant or design engineer now has a wide variety of possible combustion control solutions at his or her disposal for new or retrofit applications.

Combustion controls serve the vital role of metering fuel and combustion air flow in preset quantities to satisfy a load demand. A burner's exact fuel and air flow requirement as a function of boiler demand signal is typically established during commissioning and routine maintenance tune-ups. The combustion controls are required to automatically respond to a variable load demand within the boiler's designed range of operation, and to reliably and repeatedly deliver the appropriate amount of fuel and air for safe and efficient combustion.

Typically, process operations result in a variable steam demand. The magnitude of change in steam demand ranges from a few percent for near steady state operations to full boiler load swings for some batch plant operations. As process demand for steam increases and draws more steam from the boiler drum or header, the steam pressure in the boiler drum will decrease. Conversely, as demand for steam decreases, less steam is drawn from the system, and the steam pressure increases. The primary function of the boiler combustion control system is to sense and then safely, reliably, and automatically respond to deviations from the steam pressure set point. As drum pressure decreases with increased steam demand, the combustion controls must automatically increase the air flow and fuel flow through the burners to transfer more heat into the boiler, and return the steam pressure to set point. The converse is again true as steam demand decreases. In utility boilers, both simple and supercritical types with controlled superheat and reheat, steam temperature also becomes a controlling factor.

For plants where multiple boilers feed a common steam header, a plant master steam pressure controller is used to base load and modulate different boilers in the plant while maintaining the steam header pressure. The functionality of the plant master controller is detailed in this paper.

The "band of control" for a burner is the magnitude of acceptable deviation of one or more controlled combustion variables relative to fuel flow. For example, throughout a burner's designed range of operation, there is a target combustion air flow relative to a given fuel input. The magnitude of relative air flow deviation from set point at a given fuel flow that does not adversely affect burner stability, burner emissions, or the onset of incomplete combustion is the combustion air "band of control".

1.4 Low NOx Applications

Traditional burner/boiler packages have an allowable band of control wide enough to absorb most inherent system flow deviations. Systems that are designed for low NOx operation incorporate different air/fuel mixing patterns that lead to lower emissions. In addition, low NOx burners may require the control of additional variables, and thus introduce additional bands of control, not required with traditional designs. More combustion control precision (narrower bands of control) may be necessary for acceptable operation within the required emission limits.

Technology that affects NOx reduction in modern low NOx burners continues to evolve. However, common NOx control techniques are to reduce the flame temperature and delay (or stage) the mixture of combustion air with the fuel being fired. A primary NOx formation mechanism (thermal NOx) is highly temperature dependent. Commonly, thermal NOx is controlled by reducing the flame temperature through dilution. Oxygen depleted boiler flue gas is recirculated through the burners back into the furnace. The additional volume of inert gas in the furnace cools the flame thus slowing NOx formation rates. This practice is called flue gas recirculation (FGR).

Recirculated flue gas can either be induced through the forced draft fan for small boilers or for larger units it can be bulk mixed with the combustion air in a mixing plenum in the ducting to the burners, using a dedicated FGR fan. Either way, FGR presents an additional system variable that must be controlled within its allowable band of control. Other NOx reduction techniques that do not incorporate FGR are also popular. Throughout this paper, FGR flow is referred to as one of the controlled variables for a combustion control application. Since not all low NOx applications utilize FGR, the descriptions and recommendations given for FGR control should be assumed to be prefaced with the “if applicable” qualifier.

The consequence of “sloppy” combustion controls on low NOx applications can range from NOx non-compliance to burner instability, incomplete combustion, or loss of flame. As regional NOx requirements continue to trend lower, the required band of control for low NOx systems narrows even further. With the requirement for a narrowed band of control, and additional controlled combustion variables, more precision is required of the combustion controls. This adds more importance to the responsibility of the concerned parties to properly control the combustion process.

2 Overview of Combustion Controls

2.1 Typical Control Schemes for Multiple-Burner Boilers

There are two major control philosophies that are used to control the combustion of gas, coal or liquid fired boilers. Positioning control systems control combustion by modulating the position of the final control elements, and inferring a resultant fuel flow. Metering control systems actually measure the controlled variable's flow rate, and modulate the final control elements as required to achieve the target flow rate. Many older existing power boilers use positioning control, but in general, most multi-burner boilers use full metering control due to repeatability and efficiency gains.

2.1.1 Positioning Control

Positioning control systems regulate fuel and air flow to boiler by “positioning” each of the individual final control elements as a function of the firing rate demand. Theoretically, one can always repeat a desired fluid flow rate by repeating the position of the final control element, when provided with consistent and repeatable upstream fluid properties and downstream conditions. This is the basic operating premise of all positioning control applications.

Natural deviations in supply side variables will affect flow to the burner, resulting in excursions from the as-commissioned air/fuel ratios. These natural deviations will exist to some extent for metering as well as positioning applications, and will impact the respective performance of each to a degree determined by the magnitude of the deviation and the sophistication of the specific controls package.

2.1.2 Metering Control

Metering control systems measure the controlled variable's flow rate such as air and fuel, and modulate the final control elements as required to achieve the target flow rate. Deviations in supply pressure and temperature are compensated for automatically to some extent by the system.

When properly designed, commissioned, and maintained, metering combustion controls can provide safe and reliable control for standard as well as low NO_x applications. Metering controls are superior to positioning systems when it comes to operational versatility and response to deviations in fuel supply properties. Separate control loops are used to control the flow of the combustion air and the fuels in metering systems. The boiler demand signal is the set point that is used

in both the fuel and air flow controllers. Measured fuel flow is the process variable for the fuel flow controller, and measured air flow is the process variable for the air flow controller. Accuracy, repeatability, and reliability in field measurement devices and transmitters are critical in metering applications. Since the fuel flow and air flow control loops operate independently of each other, some form of fuel and air cross limits are required to prevent excursions beyond the system's band of control. Traditional cross limited, metering combustion control applications vary the set point to the air and fuel flow controllers based on the measured flows. For example, the set point to the air flow controller will be the higher between the boiler demand signal and the measured fuel flow. The result is that the measured fuel flow sets the minimum set point that will be provided to the air flow controller. Similarly, the set point to the fuel flow controller will be the lower between the boiler demand signal and the measured air flow. The result of this cross limit is that the measured air flow sets the maximum set point that will be provided to the fuel flow controller. Before going into the respective high or low select block, it is common practice for a gain and bias to be applied to the fuel and air flow signals. The gain and bias is used to provide a dead band that prevents the set point from switching back and forth.

One drawback of traditional cross limits on low NO_x applications with a narrow band of control is that the air / fuel ratio is only protected against fuel rich excursions. Traditional cross limits will do nothing to prevent excursions that drive the air / fuel ratio too far in the fuel lean direction. However, the required band of control of low NO_x applications may be limited in both the fuel rich and fuel lean directions. Also, traditional cross limited systems do not communicate excessive excursions in the measured air / fuel ratio to the burner management system to initiate a master fuel trip

Due to these limitations, one recommended practice for metering control applications is to monitor the instantaneous air / fuel ratio in the digital controller. The measured fuel flow signal is divided by the measured air flow signal. During commissioning, upper and lower limit points, as a function of firing rate demand, are established that correspond to the system's band of control. At any firing rate, if the measured air / fuel ratio reaches either the high or the low limit point, the boiler demand signal is held at the value where excursion began as the fuel and air flow controllers work to return the system to a normal firing ratio. Once the air / fuel ratio returns to within its acceptable range, the hold is released, and the controls again track the boiler load signal.

Additionally, as a function of firing rate demand, there are also high high and low low trips beyond the above-mentioned limit points. If the air / fuel ratio reaches either the high high or the low low trip, the control system sends a signal to Burner Management System to perform a Master Fuel Trip. This system is designed to initiate a master fuel trip in anticipation of, yet prior to, unsafe operating conditions. Other logic schemes within the metering combustion control logic are also available to achieve similar advanced cross-limiting results. Advanced cross limits as described above will also serve as an additional protection against transmitter failure.

When oxygen trim is used with metering combustion controls, a correction based on the measured flue gas oxygen level is usually applied to the air flow measurement. The air flow measurement, which is the process variable to the air flow controller, is conditioned in relation to the measured flue gas oxygen reading. If measured oxygen is higher than set point, the oxygen trim control block will apply a multiplier to the air flow signal that is greater than 1. The higher air flow reading will help drive the air flow controller to reduce the air flow to the burner. The converse is true when the measured flue gas oxygen is lower than set point. Other mechanisms for oxygen trim also may be employed that provide similar results. The oxygen trim set point should be a function of boiler firing rate fuel flow rate or air flow rate.

It is important to note that the significant lag time that is inherent with oxygen analyzers preclude the oxygen trim loop from being relied upon for any primary air flow control function. A common error is for plants to rely too heavily upon the oxygen trim loop to respond to oxygen requirements for a variable fuel chemistry. For applications where significant variations in the fuel chemistry is expected, the control system must incorporate specific features, other than oxygen trim, to accommodate the variations in the heat content in the fuel.

- FGR Control with Metering Applications

Even in metering controls applications, it is typical for the FGR to be controlled in parallel to the fuel flow. When this is the chosen method of FGR control, the guidelines described above for parallel positioning applications should be followed.

A wide variety of other FGR flow control methods are also common and acceptable for use on metered combustion control applications.

2.2 Application Guidelines for Selecting an Appropriate Combustion Control Scheme

Selecting the proper combustion controls scheme is the first step towards a successful boiler combustion control system. The combustion controls should accommodate the operational requirements of the facility while not over-complicating the system.

As boiler performance requirements are increased to higher efficiency and smaller size, and boiler emission limits become more restrictive, it is increasingly important that the burner supplier be consulted for the combustion controls scheme and the performance specifications for the control system. To this end, it is recommended that the performance capabilities of the combustion controls for Low NO_x applications with the most restrictive emission requirements be specified by the burner vendor.

The following is a list of some typical combustion variables that can be subject to deviations from set point:

1. Fuel Supply Pressure:

Fuel supply pressure deviations from the “as tuned” value will affect the downstream pressure drop, and thus fuel flow, per standard volume. Consistent and repeatable fuel supply pressure is critically important for liquid as well as gaseous fuels.

2. Fuel Supply Temperature:

Fuel temperature changes affect density, and therefore flow through downstream elements, especially the burner. This is most important for gaseous fuels, however, liquid fuels, especially residual fuel oils may require viscosity control to maintain a repeatable flow versus pressure drop curve and to maintain proper atomization.

3. Fuel Composition:

Positioning controls require consistent fuel properties, including fuel chemistry, heat of combustion, and specific gravity, as differences in these properties can adversely impact air fuel ratios.

4. Combustion Air Temperature and Humidity:
Air temperature swings impact the density of air, and thus affects the volume of oxygen delivered by the combustion air fan. Indoor boiler applications are less susceptible to problems arising from temperature swings. Similarly, humidity in the air displaces oxygen and reduces the volume of oxygen delivered to the burner.
5. Atmospheric Pressure at the Fan Inlet:
Changes in the atmospheric barometric pressure can have an impact on the air delivered by the combustion air fan. Of more concern is an indoor installation where the boiler room is not adequately ventilated. Without sufficient fresh air admission to the boiler room, the combustion air fan will not be able to consistently deliver the appropriate volume of combustion air to the burners.
6. FGR Temperature:
Controls may be required to limit FGR flow until the boiler is at normal operating temperature.
7. FGR Pressure:
FGR pressure variations can be significant when multiple boilers feed a common stack. Applications with multiple boilers on a common stack usually require draft controls.
8. Draft at Boiler Outlet:
Applications with non-repeatable furnace draft may require some form of draft control. Most commonly, draft controls are used to maintain a slightly negative pressure in the furnace of balanced draft boilers. Additionally, the draft control can be used to manage draft variations caused by multiple boilers on a common stack. Draft control may also be required for installations with a high stack and high draft conditions at light off, or if severe wind conditions at the stack exit could lead to draft excursions that exceed the allowable band of control.

Also, the furnace draft can be affected by fouling of the flue gas passages. Although this is usually a concern for solid fuel fired boilers, some boilers fired with residual fuel oils can also experience significant increase in furnace back-pressure, and therefore reduced combustion air flow, as a result of fouling of the flue gas passages. Routine soot blowing or other cleaning procedures can minimize this potential problem.

The accuracy of positioning and metering control applications can also be compromised by mechanical hysteresis. To minimize the effects of hysteresis, care must be given to properly size the actuators, power units and other final control elements. All mechanical linkages must be sufficiently rigid, and drive bearings as well as fuel control valve plugs and seats should be periodically inspected and maintained.

Metering Control:

The fully metered, cross-limited combustion control application is preferred. With the cost of control equipment continuously decreasing, most combustion control systems are of the Metering Type. When properly applied, tuned, and maintained, it has the capability of providing a precise level of control over a dynamic and variable operating range. Boilers firing multiple simultaneous fuels at variable ratios require metered controls. Also, metered controls are typically used for applications with significantly variable supply side conditions. Metering systems require additional maintenance and more extensive operator training than parallel positioning combustion control systems.

The boiler owner is ultimately responsible for the safe, reliable and long term operation of his or her boiler. There are five primary factors that the owner, or his/her representative, must control for a successful boiler combustion control application. These factors are:

- Proper selection and engineering of the control scheme.
- Proper selection of the controller hardware, final control elements, and field measuring devices.
- Proper commissioning.
- Proper operation (including operator training and staffing).
- Proper maintenance.

This guideline will briefly address each of these issues, focusing on the control of the three primary controlled variables (fuel, combustion air, and recirculated flue gas) that are required to modulate in common multiple-burner boiler applications. Other metered fluids such as atomizing steam (or air) and secondary or tertiary simultaneous fuels are also briefly covered. Experience has shown that energy, efficiency, and safety go hand in hand. Focused attention to these issues will help most boiler rooms reliably supply steam or hot water to the plant's processes.