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Using control systems to enhance boiler efficiency

MARC R. NIEPOW, PE, MANAGER, CONTROLS AND SYSTEMS, CLEAVER-BROOKS, MILWAUKEE, WI

The optimal boiler generates steam or hot water safely, reliably, and efficiently. Selecting a control system for that boiler depends on a number of factors, among them capacity, operating pressure, temperature, boiler type, application, regulatory requirements, and economics.

Various control schemes are available, from the very basic to the highly sophisticated. These systems encompass a number of operating areas, including flame safeguards, combustion controls, steam/waterside controls, and boiler sequencing.

Flame safeguards

The flame safeguard is the heart of the boiler control system. It monitors the presence of flame, fuel and air interlocks, water level, and operating pressure or temperature. And it controls the purge, lightoff, and shutdown sequences of the boiler/burner.

Before a forced-draft type power burner can light off, the boiler first must be purged to ensure no combustibles are present. Either four or eight volume changes are required, depending on the type of boiler and approval requirements, before light-off can occur.

Purging a hot boiler with ambient air results in unwanted heat loss. Flame safeguards that have a means for selecting the actual purge time let purge requirements for a specific boiler/burner be customized, thereby minimizing purge losses. The setting of the high-fire switch (the device that proves the combustion air damper is in the purge position) is critical. Some flame safeguards even delay starting the forced draft fan until this switch activates, maximizing savings.

Processes that need a continuous supply of steam may require special controls to ensure the steam supply is uninterrupted. A dual or redundant flame safeguard system uses two flame detectors and lets the burner continue firing (while sounding an alarm) should one fail. Some burner control systems permit fuels to be changed *on the fly* without shutdown.

Control systems help ensure that the plant boiler generates steam or hot water safely, reliably, and efficientiy.

Key concepts

Choosing a boiler control system depends on a variety of factors, including the capacity, operating pressure or temperature, application, and type.

Control systems embrace four operating areas: flame safeguards, combustion controls, steam/waterside controls, and boiler sequencing.

The application should always be carefully evaluated before any controls are specified, and the boiler or burner manufacturer's recommendations should always be followed.

Combustion controls

Types of combustion controls vary with the size and sophistication of the boiler involved. Simple boilers are on/off fired, cycling on and off on demand. They have one fixed firing rate and a flame that may be ignited either by a standing pilot, direct spark ignition, or spark-ignited pilot.

The next level of sophistication offers a power burner with high/low firing capabilities. These burners have two distinct firing rates and can fire alternately between them to maintain the load. Below the minimum firing rate, the burner cycles on and off.

Full modulation burners incorporate modulating dampers and control valves. These burners are designed to modulate their firing rates to match the load. The most common version of this type of system is called *single-point positioning*. Here, the air damper and fuel control valves are mechanically linked together and controlled by a single actuator. A basic modulating control system would use a proportional-type control to maintain the temperature or pressure close to the setpoint. A more advanced system would use a digital PID controller to maintain the setpoint more precisely.

Parallel positioning systems have separate actuators to drive the air and fuel. They are generally selected when logistics or torque requirements make a single actuator impractical or when oxygen compensation is used. Full metering/cross limiting systems take this type of design a step further, actually measuring air and fuel flows in an effort to meter and control the fuel/air ratio more precisely.

Oxygen trim is used to maintain the optimum fuel/air ratio under varying operating conditions (ambient temperature, barometric pressure, fuel composition, etc.). It can be applied to single point, parallel, or metering type systems. Some oxygen trim systems also monitor flue gas temperature and/or carbon monoxide to provide even closer control of boiler efficiency. The effect of ambient conditions on excess air levels is shown in the table, "Effects of air properties."

In some cases — namely, when stack conditions may vary, when boilers share a common stack, or when the burners are sensitive to stack draft conditions — some burners may require modulating draft controls. These controls monitor the furnace or flue gas outlet pressure (draft) and modulate an outlet damper to keep this pressure constant. With this arrangement, the burner is able to maintain a consistent fuel/air ratio, *and* retain residual heat by closing the damper during on/off cycles.

Steam/waterside controls

As combustion-side controls affect the combustion efficiency of the burner, waterside controls optimize overall boiler performance in terms of response, steam quality, and efficiency.

On a steam boiler, the major waterside control variable is water level. Maintaining the proper water level contributes to consistent steam quality, safe operation, and ability to respond to rapid load swings. The simplest level control consists of a float or probe-operated switch that either turns the feed pump on and off or opens and closes a solenoid valve to feed water into the boiler.

At the next level of control is the motorized valve that either opens, closes, or modulates to maintain the proper water level. A more sophisticated system, known as a single-element feedwater control, uses a water level transmitter, a PID process controller, and a modulating valve to control the water level more precisely. Water level alone determines how far the feedwater valve should open.

Boilers that experience dramatic load swings may be subject to a condition called *shrink and swell* (see "Feedwater control systems" and accompanying illustrations). When a load increases suddenly, the water level rises temporarily, causing the feedwater valve to start closing when it should be opening. A two-element feedwater control system counteracts this phenomenon by

Defining some common terms

Burner turndown ratio - The ratio of a burner's maximum to minimum firing rate.

Deadband - The difference between the on and off points of an operating pressure or temperature control switch.

Feed-forward control - A device that uses a control method that anticipates changes in load requirements before they affect the controlled variable.

Fuel/air ratio - The ratio of fuel to air in a burner, which affects the combustion process.

PID (proportional/integral/derivative) control - A type of control based on an algorithm that permits precise maintenance of the setpoint.

Power burner - A burner that uses a blower or forced-draft fan to supply combustion air.

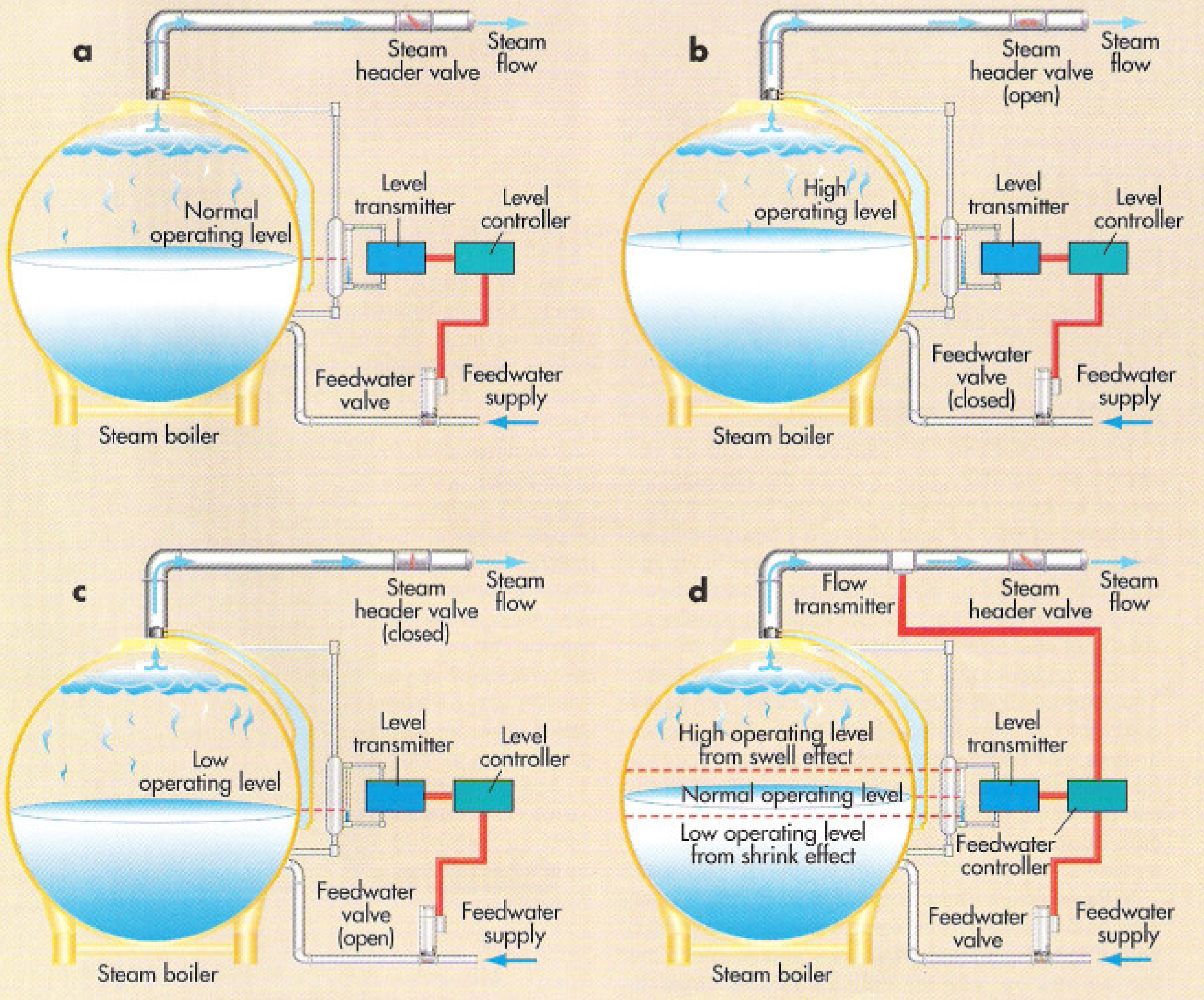
PRV (pressure reducing valve) - A regulator or valve used to reduce high-pressure steam to supply a low-pressure heating load.

Feedwater control systems

Among the more sophisticated waterside controls are single and two-element feedwater control systems. When the load is relatively steady, a single-element feedwater control system can be applied (***a***). In this configuration, the level controller maintains the water level by opening the feedwater valve as the level drops and closing the feedwater valve as the level rises. However, boilers subject to significant load swings may experience *shrink and swell*, which can confuse a single-element system.

When the load increases suddenly, pressure in the boiler drops, causing the burner firing rate to increase and the water level to temporarily rise (***b***, *swell* effect). This temporary increase in water level prompts the level controller to close the feedwater valve, rather than opening it, to satisfy the demand. When the load decreases suddenly, the pressure in the boiler increases, causing the burner firing rate to decrease and the water level to drop (***c***, *shrink* effect). This decrease in the water level prompts the level controller to open the feedwater valve rather than closing it. The lower temperature of the feedwater then can cause the water level to drop farther.

In the two-element configuration (***d***), a flow transmitter measures steam flow output from the boiler and sends the signal to the feedwater controller. The signal is internally added to the normal level control output to the feedwater valve, compensating for the *shrink and swell* effects.



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measuring the actual steam flow output and using this measurement as a feed-forward signal to control the feedwater valve. Three-element feedwater systems take this design a step farther by measuring feedwater flow as well and effectively closing the loop on feedwater control.

Steam boilers typically are designed to provide steam at a specific pressure based on the requirements of the load. Sometimes that pressure is required only during normal business hours. After hours and/or on weekends, a much lower pressure and reduced capacity heating load are required. Under these conditions, a night/weekend setback may be used to reduce radiant and pressure reducing valve losses when high-pressure steam is not required.

This modification can be made as simply as using a time clock to switch pressure controls or by using a sophisticated building automation system to operate the boiler remotely. Hot-water boilers also benefit from temperature setback, although care must be taken not to shock the boiler when it is returned to the daytime operating setpoint.

Outdoor reset offers another way to enhance boiler performance. Here, water temperature is varied on the basis of the outdoor temperature. The colder the outdoor temperature is, the hotter the water temperature. However, operating at too high or low a temperature can cause condensation, thermal shock, or other damage. Outdoor reset is easily accomplished using a local controller or a building automation system.

Effects of air properties

For a burner originally adjusted to 15% excess air, changes in combustion air temperature and barometric pressure produce the following changes in excess air.

Air temperature, F	Barometric pressure, in.	Resulting excess air, %*
40	29	25.5
60	29	20.2
80	*29*	*15.0***
100	29	9.6
120	29	1.1
80	27	7.0
80	28	11.0
80	*29*	*15.0***
80	30	19.0
40	31	34.5
60	30	25.0
80	*29*	*15.0***
100	28	5.0
120	27	-5.5

* Expressed as a percent of the stoichiometric air required.
** Original set-up condition.

Boiler sequencing

Purge losses can be reduced by lowering the amount of on/off cycling done by the burner. This action is achieved by increasing the burner's turndown ratio (ratio of maximum to minimum firing rate), allowing it to remain online at lower loads and not cycle. Spreading out the deadband on the operating control (pressure or temperature) to an acceptable limit also achieves this end.

Boilers experience losses during their off-cycles. The induced draft caused by a hot stack can cause cool air to be drawn through the boiler. The result is heat loss. Flame safeguard/damper motors that incorporate separate closed and light-off positions can minimize this loss. A boiler outlet damper that closes during the boiler off-cycle also reduces standby losses.

When multiple boilers are used to supply a common load or header, their operation can be optimized with a lead-lag system. This equipment sequences the boilers on and off and modulates them in response to the load. Lead-lag systems that provide series (or lead-lag) modulation are best suited for steady, heating-type loads. Parallel or unison modulation systems provide better response to load swings. Some lead-lag systems even have a feature that rotates the operation of the boilers to equalize the use of each unit.

A variety of control systems are available to optimize boiler operation today. The advent of microprocessor technology has brought enhanced levels of performance, functionality, safety, and operator interface as well as an array of choices and decisions when it comes to specifying boiler controls. However, there is no substitute for a properly designed control system selected to meet safety, reliability, and efficiency requirements after a careful evaluation of the application. For that reason, following the boiler or burner manufacturer's recommendations is always best.

— Edited by Jeanine Katzel, Senior Editor, 847-390-2701 j.katzel@cahners.com

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