Understanding Fuel Savings In the Boiler Room

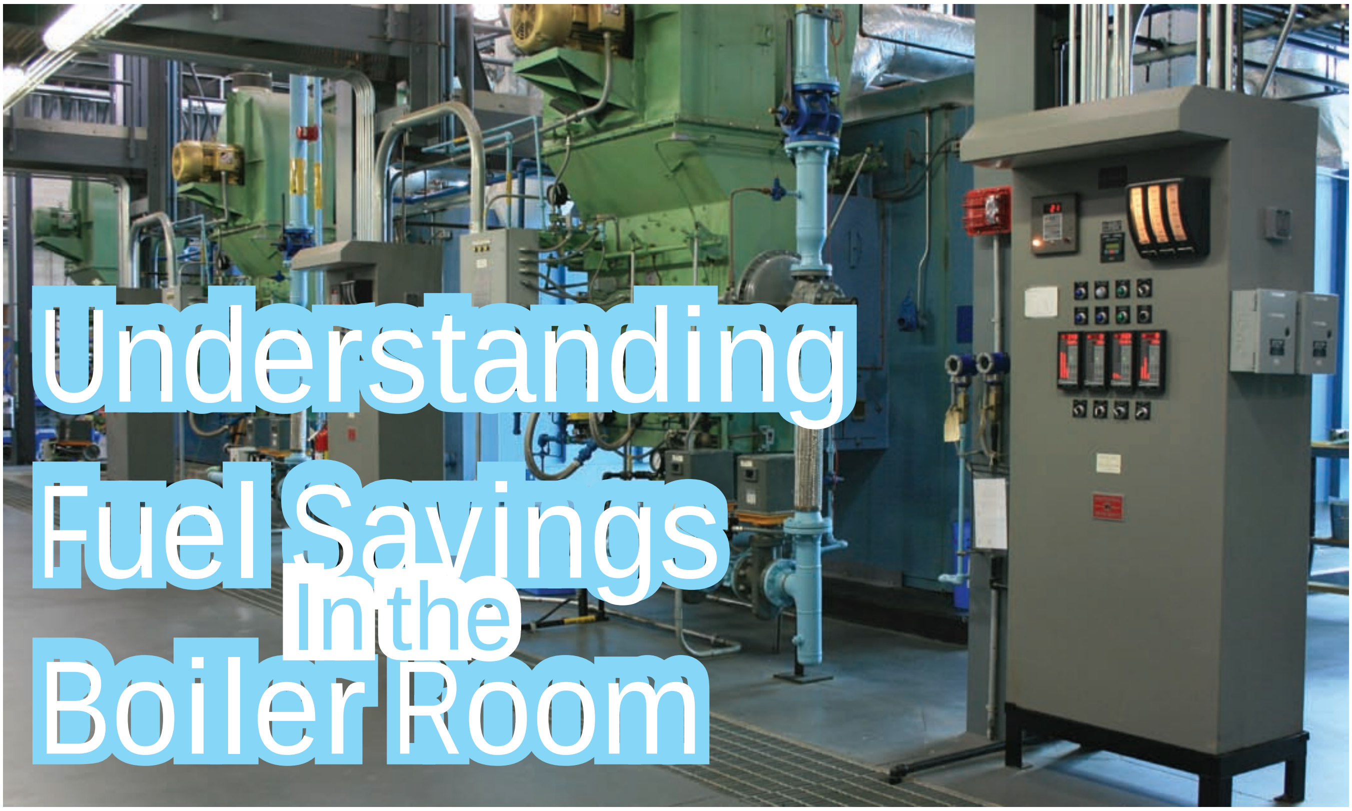

Photo 1: A boiler room at Southern Connecticut State University. The control cabinets feature multiple loop controllers, vertical draft indicator, and a tank gage and leak detection system.

By David Eoff

The crude oil peak price of $147 per barrel in July 2008 demonstrated that fuel oil prices going forward will be volatile and subject to extreme price spikes. Boiler owners and plant engineers need to understand boiler efficiency and what can be done to save fuel in the typical boiler room.

Table 1 illustrates the amount of fuel a typical small boiler consumes, compared with the capital cost of the boiler, burner, and controls.

The data in *Table 1* are based on natural gas at $10 per MMBtu and heating oil at $3.63 per gallon ($0.97 per L). It becomes apparent that when operated at a 25% capacity factor, a boiler will consume at least twice its capital cost in fuel every year. An oil-fired boiler will consume at least four times its cost in fuel every year. Because of their relatively low capital cost and high impact on boiler efficiency, burner and combustion control retrofits offer boiler owners the quickest paybacks based on energy savings.

Understanding Boiler Heat Losses

To better understand the effect of burner and controls performance on efficiency, we need to have an understanding of boiler heat losses. Using typical packaged boiler operating data, boiler efficiency calculated according to the American Society of Mechanical Engineers (ASME) PTC 4.1, *Power Test Codes for Steam Generating Units*, yields typical boiler losses *(Table 2)*.

ASME PTC 4.1 includes instructions for calculating boiler efficiency by the direct method comparing steam output versus heat input. It also calculates boiler efficiency by the indirect (by losses) method where individual boiler losses are calculated and totaled. The "by losses" method requires only stack temperature and oxygen content and can easily be calculated with a portable combustion analyzer or built into the combustion controls. ANSI Standard Z21.13 outlines efficiency calculations for hot water boilers. The loss mechanisms are similar. *Table 3* details the equations used to calculate three of the largest boiler losses to illustrate how these losses can be affected by boiler/burner performance.

The three equations in *Table 3* for different boiler losses have several elements in common, suggesting a common strategy for reducing boiler losses, including:

- Reducing stack temperature;
- Minimizing excess air levels;
- Raising boiler feedwater temperature; and
- Raising combustion air temperature to the burner.

About the Author

David Eoff is national sales manager at Preferred Utilities, Danbury, Conn.

Boiler Size/Type	Annual Fuel Cost at 25% Capacity Factor		Equipment Capital Cost		
	Gas	Oil	Boiler Cost	Burner Cost	Controls Cost
300 hp Firetube	$325,000	$775,000	$110,000	$15,000	$3,000–10,000
600 hp Firetube	$650,000	$1.55 million	$155,000	$35,000	$5,000–15,000
40,000 lb/h Watertube	$1.3 million	$3.1 million	$550,000	$70,000	$7,000–50,000

Table 1: Boiler fuel costs vs. equipment costs.

Reducing stack temperature and raising feedwater temperature are done at the boiler level by specifying a high-efficiency boiler with an economizer. If a steam boiler does not have an economizer, it can be retrofitted in the field. According to Kenneth McKelvy of Babcock and Wilcox, the rule of thumb is every 40°F (22°C)decrease in stack temperature equates to a 1% increase in boiler efficiency. A typical economizer can increase boiler efficiency by 4% to 6%.

Using an air heater to raise the combustion air temperature is commonplace with utility boilers but is almost never done with packaged boilers. The necessary ductwork is expensive and can affect the low-NO_x performance of the burner. Adding air preheaters to packaged boilers is usually considered to be impractical. However, a little-used “trick of the trade” called an air stack can increase boiler efficiency. An air stack is simply ductwork run from the combustion air inlet to the top of the boiler room, where the air may be as much as 20°F (11°C) warmer. This inexpensive, purely mechanical boiler modification will increase boiler efficiency in enclosed boiler rooms.

Boiler Loss	Explanation	Typical Loss as Percentage of Boiler Heat Input
Dry Gas Loss	Energy Required to Heat Combustion Air From Ambient to Stack Temperature	8%–12%
Hydrogen Loss	Energy Required to Heat Water Formed From Combustion of Fuel From Ambient to Stack Temperature	4%–7%
Radiation Loss	Heat Lost to Boiler Surroundings	0.25%–2%
Unburned Carbon	Energy in Unburned Fuel or Carbon Monoxide That Exits The Stack	0%–0.5%
Moisture in Air	Energy Required to Heat Water in the Combustion Air From Ambient To Stack Temperature	0.1%–0.4%

Table 2: Typical boiler losses.

Dry Gas Loss = $C_{P(Air)} \times (T_S - T_A) * (1 + \text{Excess Air\%}) \times M_{\text{Theoretical Air}}$

Hydrogen Loss = $C_{P(H_2O)} \times (\text{Enthalpy of Steam at 1 psi and } T_{Stack} - \text{Enthalpy of Water at } T_{Ambient})/100$

Moisture in Air = $C_{P(H_2O)} \times H_2O \text{ in Air} \times (T_{Stack} - T_{Ambient})$

Radiation Loss = Value determined from table maintained by the American Boiler Manufacturers Association

Table 3: Boiler loss nomenclature.

Low Excess Air Burners Save Fuel

One of the most cost-effective fuel-saving strategies for a packaged boiler is specifying/retrofitting to a low excess air burner. The typical standard burner offered by the boiler manufacturer has a guarantee of 15% to 20% excess air operation *at high fire only*. (5% excess air is approximately 1% stack oxygen.) Because ambient air is 79% inert (nitrogen, argon, and water vapor), it’s important to minimize the amount of fuel wasted heating mostly inert air. A high-performance burner will deliver 12.5% to 15% excess air performance *from midfire to high fire*. This lower excess air performance over a much larger boiler load will deliver significant fuel savings because less fuel will be wasted heating mostly inert combustion air.

Many burners are not tuned in the field to meet published excess air guarantees, and many boiler owners do not hold the manufacturers responsible for achieving these guarantees—especially with low-NO_x burners. When aggressive emission guarantees are made for NO_x or carbon monoxide, excess air and burner turndown guarantees are sometimes sacrificed. Boiler owners often cannot operate a boiler if the emissions are out of compliance. However, the only penalty for operating a boiler with higher than guaranteed excess air, or lower than guaranteed turndown, is additional fuel consumption. Although fuel consumption is an important consideration, it is less urgent than the threat of government regulators shutting down a boiler because of an air permit violation.

Real-World Boiler Operation

Even for burners that are operating within their guaranteed emissions, the technician doing the boiler tuneup should maintain an “excess air cushion” to accommodate higher ambient temperatures, variations in fuel pressure, and other unexpected changes that affect burner stoichiometry. To reduce the amount of “excess air cushion,” the new burner should be equipped with a combustion control system that can compensate for changes in ambient conditions (*Figure 1*).

It is important to understand that boiler manufacturer ef-

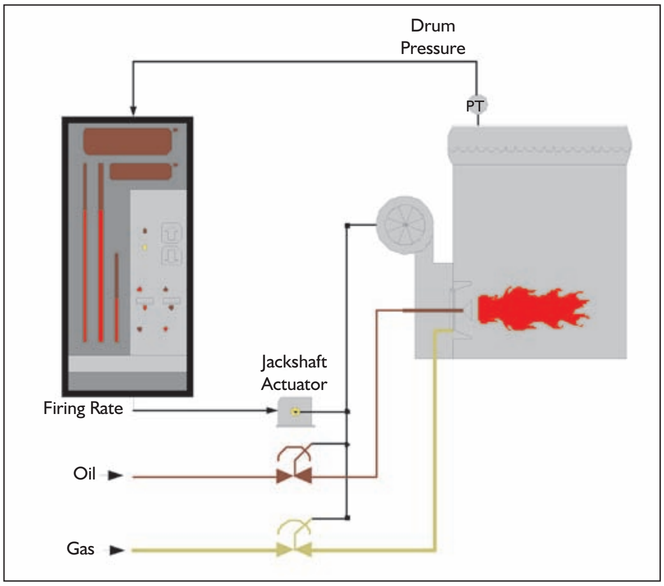

***Figure 1:** Single point positioning (jackshaft) combustion control system fuel and air control devices are mechanically linked. Adjustable fuel valves or linkage assemblies allow fuel flow and airflow to be characterized at all firing rates.*

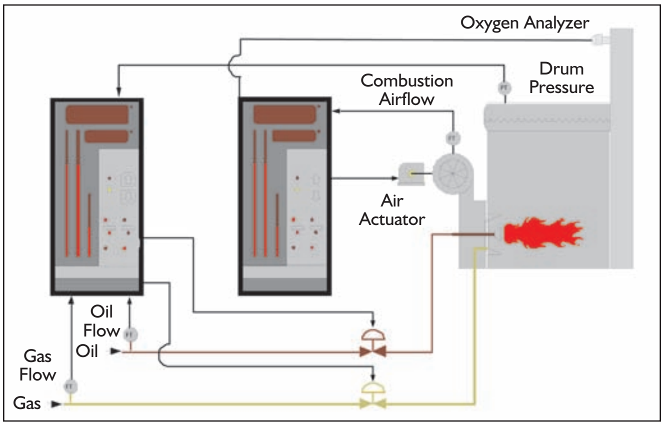

***Figure 2:** Fully metered combustion control flow transmitters are used to monitor fuel and air flow. The controllers modulate fuel control valves and air dampers(s) to maintain the correct fuel-air ratios despite changing conditions.*

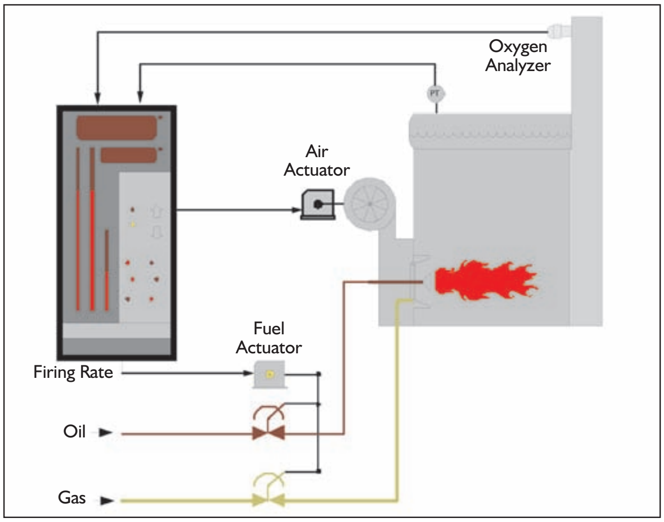

***Figure 3:** Parallel positioning with oxygen trim fuel and air are electronically characterized in the controller. Air is biased to maintain stack oxygen on the setpoint curve established during burner commissioning.*

ficiency guarantees, ASME PTC 4.1 efficiency calculations, and the discussion above assume:

- The boiler is fired by hand;
- Firing rate is fixed at 100% and run to steady state; and
- No changes in ambient conditions occur.

Few boilers operate under these conditions in the field. The objective of good burner combustion controls is to operate the burner in real-life conditions as close to these optimum conditions as possible—despite changing boiler loads, varying ambient temperatures, and other environmental factors.

Fully metered combustion control systems monitor fuel and air flow and will adjust fuel valves and air dampers to keep burner flow rates constant despite changing conditions. Oxygen trim can be added to these systems to help ensure that the stack oxygen setpoint established during burner commissioning is maintained over time. In the past, fully metered combustion control systems were limited to large watertube boilers because of their high capital cost. Newer combustion control systems offer fully metered combustion control with oxygen compensation available off the shelf at substantially lower prices (*Figure 2*).

Parallel-positioning combustion control systems offer oxygen trim without the expense of fuel and air meters. These systems safely compensate for changing ambient conditions and will maintain peak low excess air operation over time. They are extremely economical and now are often applied to boilers as small as 150 hp (1470 kW) (*Figure 3*).

Advertisement formerly in this space.

Burner Turndown Affects Efficiency

Burner turndown is important for fuel savings—especially during low-load conditions. The typical burner is designed for 6:1 turndown firing natural gas and 4:1 turndown firing oil (6:1 turndown means high-fire fuel flow is six times low-fire fuel flow). In practice, many burners operate at 3:1 turndown—meaning they light off at 33% of high-fire heat input. If 33% firing rate produces more steam (or hot water) than the plant load, the burner eventually shuts down on high steam pressure or high water temperature, and all the losses associated with post purge, standby and purge are incurred again. Frequent boiler cycling also introduces thermal shock to the boiler tubes and refractory to shorten boiler life.

Because boilers tend to be oversized (typically 5% for every engineer who touches the design), it is common for boilers to cycle on and off during low-load conditions. Each time a boiler cycles off, it drafts cold combustion air during the post purge and standby periods. When the boiler is cycled on again, it must go through a purge period when more cold air is cycled through the boiler to purge the furnace of possible combustibles prior to ignition. All the heat lost to this cold air has to be recouped by the burner when it lights off again. It is not uncommon to see small boilers cycle up to 10 times per hour during low-load periods.

A high-performance burner will operate safely at 10:1 turndown on gas and 8:1 turndown on oil. A turndown ratio of 10:1 means low-fire heat input is just 10% of high-fire heat input. A high-turndown burner is much more likely to stay on during low-load conditions and not incur all the cycling losses of a typical burner.

To determine boiler turndown, put the boiler in manual firing rate, lock it at high fire, and clock the fuel meter. Repeat the procedure with the burner at low fire. Divide the high-fire fuel flow by the low-fire fuel flow. If the burner doesn't have a dedicated gas or oil meter, Bernoulli's equation provides a way to approximate burner turndown when firing gas. Simply measure the gas manifold pressure (downstream of the gas flow control valve) at high fire, divide by the gas manifold pressure at low fire, and calculate the square root. The number that is left is the burner turndown.

Multiple Boiler Plants

Finally, multiple-boiler plants can save additional fuel by installing a modern lead/lag controller. A typical system monitors one header pressure or temperature transmitter, operates the optimal number of boilers to meet the current plant load, and fires the boilers at their most efficient firing rates to minimize fuel consumption.

When fuel prices were relatively inexpensive, it was common to have one boiler running in automatic and a second boiler running at low fire in case the first boiler tripped offline. A modern lead/lag controller will keep the lag boiler off, cycle it on occasionally to keep it hot, and only bring it online if the lead boiler trips offline or is not capable of handling the current plant load. Because steam and noncondensing hot water boilers are more efficient at high fire, a lead/lag controller will fire fewer boilers at the highest firing rate possible for highest efficiency. Condensing boilers are more efficient at low fire, so this strategy is reversed for condensing boilers.

With the high fuel prices in the U.S., high-performance burners and controls are inexpensive compared with the price of fuel wasted by the typical boiler. Boiler owners who previously installed high-performance burners and combustion controls now can reap the benefits.

Because of fuel price volatility, the old adage should apply: "Hope for the best, but plan for the worst."

Bibliography

Dukelow, S.G. 1991. *The Control of Boilers,* pp. 74–85. Research Triangle Park: Instrument Society of America.

Stultz, S.C. and J.B. Kitto. 1992. *Steam. Its Generation and Use*, 40th Edition, pp. 9–22 to 9–27. Lynchburg, Va.: The Babcock & Wilcox Company.

White, F.M. 1986. *Fluid Mechanics, 2nd edition* p. 169. N.Y.: McGraw-Hill Higher Education. ◆