Energy Tips – Steam

Steam Tip Sheet #4 • January 2006

Industrial Technologies Program

Suggested Actions

Boilers often operate at excess air levels higher than the optimum. Periodically monitor flue gas composition and tune your boilers to maintain excess air at optimum levels.

Resources

U.S. Department of Energy—DOE's software, the *Steam System Assessment Tool* and *Steam System Scoping Tool,* can help you evaluate and identify steam system improvements. In addition, refer to *Improving Steam System Performance: A Sourcebook for Industry* for more information on steam system efficiency opportunities.

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Improve Your Boiler's Combustion Efficiency

Combustion Efficiency

Operating your boiler with an optimum amount of excess air will minimize heat loss up the stack and improve combustion efficiency. Combustion efficiency is a measure of how effectively the heat content of a fuel is transferred into usable heat. The stack temperature and flue gas oxygen (or carbon dioxide) concentrations are primary indicators of combustion efficiency.

Given complete mixing, a precise or stoichiometric amount of air is required to completely react with a given quantity of fuel. In practice, combustion conditions are never ideal, and additional or "excess" air must be supplied to completely burn the fuel.

The correct amount of excess air is determined from analyzing flue gas oxygen or carbon dioxide concentrations. Inadequate excess air results in unburned combustibles (fuel, soot, smoke, and carbon monoxide) while too much results in heat lost due to the increased flue gas flow—thus lowering the overall boiler fuel-to-steam efficiency. The table relates stack readings to boiler performance.

Combustion Efficiency for Natural Gas

Excess, %		Combustion Efficiency				
		Flue Gas Temperature Minus Combustion Air Temperature, °F				
Air	Oxygen	**200**	**300**	**400**	**500**	**600**
9.5	2.0	85.4	83.1	80.8	78.4	76.0
15.0	3.0	85.2	82.8	80.4	77.9	75.4
28.1	5.0	84.7	82.1	79.5	76.7	74.0
44.9	7.0	84.1	81.2	78.2	75/2	72.1
81.6	10.0	82.8	79.3	75.6	71.9	68.2

Assumes complete combustion with no water vapor in the combustion air.

On well-designed natural gas-fired systems, an excess air level of 10% is attainable. An often-stated rule of thumb is that boiler efficiency can be increased by 1% for each 15% reduction in excess air or 40°F reduction in stack gas temperature.

Example

A boiler operates for 8,000 hours per year and consumes 500,000 million Btu (MMBtu) of natural gas while producing 45,000 lb/hour of 150-psig steam. Stack gas measurements indicate an excess air level of 44.9% with a flue gas minus combustion air temperature of 400°F. From the table, the boiler combustion efficiency is 78.2% (E_1). Tuning the boiler reduces the excess air to 9.5% with a flue gas minus combustion air temperature of 300°F. The boiler combustion efficiency increases to 83.1% (E_2). Assuming a fuel cost of $8.00/MMBtu, the annual savings are:

Annual Savings = Fuel Consumption x (1–E_1/E_2) x Fuel Cost
= 29,482 MMBtu/yr x $8.00/MMBtu
= $235,856

Flue Gas Analyzers

The percentage of oxygen in the flue gas can be measured by inexpensive gas-absorbing test kits. More expensive (ranging in cost from $500 to $1,000) hand-held, computer-based analyzers display percent oxygen, stack gas temperature, and boiler efficiency. They are a recommended investment for any boiler system with annual fuel costs exceeding $50,000.

Oxygen Trim Systems

When fuel composition is highly variable (such as refinery gas, hog fuel, or multi-fuel boilers), or where steam flows are highly variable, an online oxygen analyzer should be considered. The oxygen "trim" system provides feedback to the burner controls to automatically minimize excess combustion air and optimize the air-to-fuel ratio.

Adapted from an Energy TIPS fact sheet that was originally published by the Industrial Energy Extension Service of Georgia Tech.

BestPractices is part of the Industrial Technologies Program Industries of the Future strategy, which helps the country's most energy-intensive industries improve their competitiveness. BestPractices brings together emerging technologies and best energy-management practices to help companies begin improving energy efficiency, environmental performance, and productivity right now.

BestPractices emphasizes plant systems, where significant efficiency improvements and savings can be achieved. Industry gains easy access to near-term and long-term solutions for improving the performance of motor, steam, compressed air, and process heating systems. In addition, the Industrial Assessment Centers provide comprehensive industrial energy evaluations to small- and medium-size manufacturers.

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A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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Energy Tips – Steam

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Industrial Technologies Program

Minimize Boiler Short Cycling Losses

Boiler "short cycling" occurs when an oversized boiler quickly satisfies process or space heating demands, and then shuts down until heat is again required. Process heating demands can change over time. Boilers may have been oversized for additions or expansions that never occurred. Installing energy conservation or heat recovery measures may also reduce the heat demand. As a result, a facility may have multiple boilers, each rated at several times the maximum expected load.

Boilers used for space heating loads are often oversized, with their capacity chosen to meet total building heat losses plus heating of ventilation and infiltration air under extreme or design-basis temperature conditions. No credit is taken for thermal contributions from lights, equipment, or people. Excess capacity is also added to bring a facility to required settings quickly after a night setback.

Cycling Losses

A boiler cycle consists of a firing interval, a post-purge, an idle period, a pre-purge, and a return to firing. Boiler efficiency is the useful heat provided by the boiler divided by the energy input (useful heat plus losses) over the cycle duration. This efficiency decreases when short cycling occurs or when multiple boilers are operated at low firing rates.

This decrease in efficiency occurs, in part, because fixed losses are magnified under lightly loaded conditions. For example, if the radiation loss from the boiler enclosure is 1% of the total heat input at full-load, at half-load the losses increase to 2%, while at one-quarter load the loss is 4%. In addition to radiation losses, pre- and post-purge losses occur. In the pre-purge, the fan operates to force air through the boiler to flush out any combustible gas mixture that may have accumulated. The post-purge performs a similar function. During purging, heat is removed from the boiler as the purged air is heated.

Example

A 1,500 horsepower (hp) (1 hp = 33,475 Btu/hr) boiler with a cycle efficiency of 72.7% (E_1) is replaced with a 600 hp boiler with a cycle efficiency of 78.8% (E_2). Calculate the annual cost savings.

Fractional Fuel Savings = $(1 - E_1/E_2)$
= (1 – 72.7/78.8) x 100
= **7.7%**

If the original boiler used 200,000 MMBtu of fuel annually, the savings from switching to the smaller boiler (given a fuel cost of $8.00/MMBtu) are:

Annual Savings = 200,000 MMBtu x 0.077 x $8.00/MMBtu
= $123,200

Suggested Actions

- Determine the efficiency and operating cost of each of your boilers and adopt a control strategy for maximizing overall efficiency of multiple boiler operations. (See page 2.)
- Avoid short cycling by purchasing a burner with a high turndown ratio, or by adding a small boiler to your boilerhouse to provide better flexibility and high efficiency at all loads. Refer to Steam Tip Sheet #24, *Upgrade Boilers with Energy-Efficient Burners.* (See also page 2: Boiler Downsizing.)

Resources

U.S. Department of Energy—DOE's software, the *Steam System Assessment Tool* and *Steam System Scoping Tool,* can help you evaluate and identify steam system improvements. In addition, refer to *Improving Steam System Performance: A Sourcebook for Industry* for more information on steam system efficiency opportunities.

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Multiple Boiler Operations

The most efficient boilers should be brought on-line as loads increase, with less-efficient units taken off-line first as loads drop. Subject to emissions, operations, or firing rate limits, shift loads from a boiler where steam production is expensive to one where it is less expensive.

Use automatic controllers that determine the incremental costs (change in steam cost/change in load) for each boiler in the facility, and then shift loads accordingly. This maximizes efficiency and reduces energy costs. If possible, schedule loads to help optimize boiler system performance. Powerhouses containing multiple boilers that are simultaneously operated at low-fire conditions offer energy-saving opportunities for using proper boiler allocation strategies.

Boiler Downsizing

Fuel savings can be achieved by adding a smaller boiler sized to meet average loads at your facility, or by re-engineering the power plant to consist of multiple small boilers. Multiple small boilers offer reliability and flexibility to operators to follow load swings without over-firing and short cycling. Facilities with large seasonal variations in steam use operate small boilers when demand drops rather than operating their large boilers year-round.

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Energy Tips – Steam

Upgrade Boilers with Energy-Efficient Burners

Background

The purpose of the burner is to mix molecules of fuel with molecules of air. A boiler will run only as well as the burner performs. A poorly designed boiler with an efficient burner may perform better than a well-designed boiler with a poor burner. Burners are designed to maximize combustion efficiency while minimizing the release of emissions.

A power burner mechanically mixes fuel and combustion air and injects the mixture into the combustion chamber. All power burners essentially provide complete combustion while maintaining flame stabilization over a range of firing rates. Different burners, however, require different amounts of excess air and have different turndown ratios. The turndown ratio is the maximum inlet fuel or firing rate divided by the minimum firing rate.

An efficient natural gas burner requires only 2% to 3% excess oxygen, or 10% to 15% excess air in the flue gas, to burn fuel without forming excessive carbon monoxide. Most gas burners exhibit turndown ratios of 10:1 or 12:1 with little or no loss in combustion efficiency. Some burners offer turndowns of 20:1 on oil and up to 35:1 on gas. A higher turndown ratio reduces burner starts, provides better load control, saves wear-and-tear on the burner, reduces refractory wear, reduces purge-air requirements, and provides fuel savings.

Efficient Burner Technologies

An efficient burner provides the proper air-to-fuel mixture throughout the full range of firing rates, without constant adjustment. Many burners with complex linkage designs do not hold their air-to-fuel settings over time. Often, they are adjusted to provide high levels of excess air to compensate for inconsistencies in the burner performance.

An alternative to complex linkage designs, modern burners are increasingly using servomotors with parallel positioning to independently control the quantities of fuel and air delivered to the burner head. Controls without linkage allow for easy tune-ups and minor adjustments, while eliminating hysteresis, or lack of retraceability, and provide accurate point-to-point control. These controls provide consistent performance and repeatability as the burner adjusts to different firing rates.

Alternatives to electronic controls are burners with a single drive or jackshaft. Avoid purchasing standard burners that make use of linkages to provide single-point or proportional control. Linkage joints wear and rod-set screws can loosen, allowing slippage, the provision of suboptimal air-to-fuel ratios, and efficiency declines.

Applications

Consider purchasing a new energy-efficient burner if your existing burner is cycling on and off rapidly. Rotary-cup oil burners that have been converted to use natural gas are often inefficient. Determining the potential energy saved by replacing your

Suggested Actions

- Perform burner maintenance and tune your boiler.
- Conduct combustion-efficiency tests at full- and part-load conditions.
- If excess oxygen exceeds 3%, or combustion efficiency values are low, consider modernizing the fuel/air control system to include solid-state sensors and controls without linkage. Also consider installing improved process controls, an oxygen trim system, or a new energy-efficient burner.
- A new energy-efficient burner should also be considered if repair costs become excessive, reliability becomes an issue, energy savings are guaranteed, and/or utility energy conservation rebates are available.
- Install a smaller burner on a boiler that is oversized relative to its steam load.

Resources

U.S. Department of Energy—DOE's software, the *Steam System Assessment Tool* and *Steam System Scoping Tool,* can help you evaluate and identify steam system improvements. In addition, refer to *Improving Steam System Performance: A Sourcebook for Industry* for more information on steam system efficiency opportunities.

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existing burner with an energy-efficient burner requires several steps. First, complete recommended burner-maintenance requirements and tune your boiler. Conduct combustion efficiency tests at full- and part-load firing rates. Then, compare the measured efficiency values with the performance of the new burner. Most manufacturers will provide guaranteed excess levels of oxygen, carbon monoxide, and nitrous oxide.

Example

Even a small improvement in burner efficiency can provide significant savings. Consider a 50,000 pound-per-hour process boiler with a combustion efficiency of 79% (E_1). The boiler annually consumes 500,000 million Btu (MMBtu) of natural gas. At a price of $8.00/MMBtu, the annual fuel cost is $4 million. What are the savings from an energy efficient burner that improves combustion efficiency by 1%, 2%, or 3%?

Cost Savings = Fuel Consumption x Fuel Price x (1 - E_1/E_2)

Energy Savings Due to Installation of an Energy-Efficient Burner

Burner Combustion Efficiency Improvement, %	Annual Energy Savings, MMBtu/yr	Annual Dollar Savings, $
1	6,250	50,000
2	12,345	98,760
3	18,290	146,320

If the installed cost is $75,000 for a new burner that provides an efficiency improvement of 2%, the simple payback on investment is:

Simple Payback = $75,000 / $98,760/year = 0.76 year

Maintenance Requirements

Conduct burner maintenance at regular intervals. Wear on the firing head, diffuser, or igniter can result in air leakage or failure of the boiler to start. One burner distributor recommends maintenance four times per year, with the change of seasons. A change in weather results in a change in combustion.

Fan Selection

Fan selection is also important. Backward-curved fans provide more reliable air control than forward-curved fans. Radial-damper designs tend to provide more repeatable air control at lower firing rates than blade-type damper assemblies.

Steam Tip Information is adapted from material supplied by PBBS Equipment Corp. and Blesi-Evans Company and reviewed by the DOE BestPractices Steam Technical Subcommittee. For additional information, refer to Steam Tip Sheet #4, Improve Your Boiler's Combustion Efficiency, *available online at www.eere.energy.gov/industry/bestpractices .*

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