

ENERGY EFFICIENCY AND RENEWABLE ENERGY



Improve Your Boiler's Combustion Efficiency

Combustion Efficiency

Operating a boiler with an optimum amount of excess air minimizes heat loss up the stack and improves combustion efficiency. Combustion efficiency is a measure of how effectively the heat content of a fuel is converted into usable heat. The stack temperature and the flue gas oxygen (or carbon dioxide) concentrations are the 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 burn the fuel completely.

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

Suggested Actions

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

Consider on-line monitoring of the flue gas oxygen level to identify energy loss trends quickly. This gives you early warning of control system failures and lets you base your decisions on data.

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-quoted rule of thumb is that boiler efficiency can be increased by 1% for each 15% reduction in excess air or each 40°F reduction in stack gas temperature.

Example

A boiler operates for 8,000 hours per year and annually consumes 500,000 million Btu (MMBtu) of natural gas while producing 45,000 lb/hr of steam at 150 psig. 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% (E1). Tuning the boiler reduces excess air to 9.5% with a flue gas minus combustion air temperature of 300°F, and the combustion efficiency rises to 83.1% (E2). Assuming a fuel cost of \$8.00/MMBtu, the annual savings are:

$$\begin{aligned}
 \text{Annual Savings} &= \text{Fuel Consumption} \times (1 - E1/E2) \times \text{Fuel Cost} \\
 &= 29,482 \text{ MMBtu/yr} \times \$8.00/\text{MMBtu} \\
 &= \$235,856
 \end{aligned}$$

Flue Gas Analyzers

The percentage of oxygen in the flue gas can be measured with inexpensive gas-absorbing test kits. More expensive hand-held, computer-based analyzers, ranging in cost from \$500 to \$1,000, 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 (for example, refinery gas, wood waste fuel or multi-fuel boilers), or where steam flows are highly variable, an on-line 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.

For more information on monitoring, you can download case studies on the following submetering applications from the AMO publication library:

- **Solutia:** Using Submetering to Drive Energy Project Approvals Through Data
- **Nissan North America:** How Submetering Changed the Way a Plant Does Business

You can also refer to the following guidebook on the Federal Energy Management Program (FEMP) website: www.femp.energy.gov

- **Metering Best Practices:** A Guide to Achieving Utility Resource Efficiency, Release 2.0

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

Resources

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

Visit the Advanced Manufacturing Office website at manufacturing.energy.gov to access these and many other industrial efficiency resources and training information.