Steam System Energy Efficiency Opportunities and Waste Heat Recovery

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Power Lunch Overview

• Rule of thumb or “rules of dumb”
• Benchmarking
• Boiler plant energy efficient improvement possibilities
• Moving to waste heat recovery and increased operational efficiency
• Distribution side of the steam system
• Steam end uses and possible improvements
“Rules of Dumb” & General Assumptions

- Cost Natural Gas $1.00/therm or $10.00/Lbs of steam (assumed 1,000 Btu/ Lbs\textsubscript{steam})
- Steam pressure used for examples 100 psig
- Condensate return temperature 150\textdegree F and feedwater 50\textdegree F
- Standard combustion O\textsubscript{2} 6%, High Efficiency Combustion O\textsubscript{2} 3%
Benchmarking your steam cost per 1,000 Lbs.

To determine your steam cost per 1,000 Lbs. you will want to know all of your fuel delivery and supply costs, and your system efficiency. Ideally a steam flow meter on the steam system supply header would provide you with steam production.
Calculate Steam Cost

We calculate steam cost per 1,000 Lbs. as follows:

- Steam cost = ($1.00/therm_{NG}/100,000 \text{ Btu}) \times 1,000 \text{ Lbs}_{\text{steam}} \times 1,000 \text{ Btu/Lbs}_{\text{steam}} / \text{system at efficiency of 85\%} = $11.76/1,000 \text{ Lbs}_{\text{steam}}

- The system efficiency should include all the known losses of the system from combustion losses, condensate, blowdown, deaerator, distribution, steam pressure drops, values etc.
Steam Boilers
Steam Boiler Efficiency Improvements

- Consider Steam Pressure
- Mode of Operating (cycling, turndown ratio, level loading)
- Parallel Positioning with O$_2$ trim
- Exhaust Gas Analyzing Control
- Automatic Blowdown Control
Steam Pressure

Excess steam pressure not only effects the boiler and its efficiency but it also affects the distribution side and traps.

On the boiler side reducing steam pressure in a hospital system can reduce annual therms usage by about 5% with a pressure drop for 65 psig down to 15 psig.
Mode of Operating Boilers

• There are several ways to operate steam boiler systems
  • Boiler operators of larger steam systems like to have two boilers online and contributing to the load in some way
  • Increases reliability and helps the equipment last longer. It also can be less efficient than operating a single boiler at a higher rate
  • The are many factors that can effect this including burner turndown ratio, combustion controls, and cycling
  • If boilers are having significant cycling the size of the boiler should be looked at in detail
Parallel Positioning with $O_2$ trim

- Boilers with a single shaft to control the fuel and air simultaneously can benefit from independent control. To further advance the boiler’s combustion efficiency, controls can be added to independently control the fuel and air to minimize the excess air through the boiler by monitoring the $O_2$ in the exhaust stream.

- Systems without Parallel Positioning and $O_2$ trim operate down to 6% $O_2$.

- Highly efficient burner controls can control $O_2$ down to 3%. This can reduce the excess air from 44.2% down to 14%. This can result in annual fuel savings of 2%-3% for the boiler system.
Automatic Blowdown Systems

• Blowdown is the release of heated water to help improve the water quality.

• This heated water is typically dumped down the drain on smaller to medium sized systems. Adding a control can help eliminate these variables.
Steam Distribution Systems
Steam Distribution Systems Improvements

- Steam Trap Maintenance
- Water Chemistry
- Condensate Return
- Pipe Insulation
- Valve and PRV insulation
Steam Trap Maintenance

• Steam Trap Maintenance in the single biggest area for energy improvement opportunity that we see year in and out

• Typical failure rates can range from 3%-5% per year for systems that have a maintenance program

• Failure rates for systems without a maintenance plan and annual survey can be as high as 30%
Steam Trap Maintenance

The typical savings for repaired traps range depending on the steam pressure.

• For low pressure systems (15 psig) you can assume 100-250 therms saved per repaired trap

• For higher pressure systems (100 psig) the range can be from 400 therms up to as high as 800 therms per year saved from a repaired trap

• The size, steam demand and location of the trap can all impact the likelihood and frequency for failure and the savings potential as well
Water Chemistry

• Keeping up with water chemistry can be particularly important on larger systems with older distribution and high return rates of condensate.

• The better the water chemistry the lower the likelihood for distribution system and boiler system degradation over time.

• If proper chemistry is not maintained the presence of higher concentrations of dissolved solids can affect the heat transfer of the system. Additionally, system components including traps can be negatively affected.
Condensate Return

Improving the amount of condensate returned to the boiler and also trying to maintain the highest return water temperature can have significant energy impacts on steam systems.
Pipe Insulation

• The first inch of insulation is the most effective.

• We use a free software tool to determine the energy savings from increasing the thickness and effectiveness of steam pipe insulation. The tool can be found at: https://insulationinstitute.org/tools-resources/free-3e-plus/

• For example a 2 inch diameter steam line 200 ft long with no insulation, rejects over 8,400 therms a year, while with 3 inches of insulation the losses are reduced to 519 therms a year.
Waste Heat Recovery in Steam Systems
Waste Heat Recovery in Steam Systems

• Blowdown Heat Recovery

• Stack Economizer

*Special Note: These two resources should be evaluated to determine if one or both options can be fully utilized.
Blowdown Heat Recovery

• Let’s assume a fairly high total blowdown rate of 6% is taking place (top and bottom). The total waste heat recovery is about 2,800 therms/year.

• Assumptions – 280 hours/year of blowdown, 100 psig steam pressure.
Stack Economizer

• With many stack systems having between 350-400°F exhaust gas temperatures and a high load factor on the boilers there is the potential to capture and reuse some of that heat.

• For example a 700 HP_{boiler} (25 MMBtuh) system has the ability to recover over 50,000 therms per year.
Ameren Illinois Energy Efficiency Incentives

Process Steam & Steam Trap Incentives

• Cash incentives are available for a variety of process steam projects, including:
  • Steam trap surveys
  • Steam trap repair or replacement

Custom Incentives

• Gas Incentives increased through December 31, 2017

• Incentives for Custom Gas Projects $1.25/annual therm saved

• Preapproval is required for all Custom Projects
Ameren Illinois Energy Efficiency Incentives

Example of Custom incentives ($1.25/therm thru Dec 31, 2017)

• Stack Economizer and Condensing Economizer
• Boiler Burner
• Pipe Insulation
• $O_2$ trim
• Process Boiler Controls
• Blowdown Heat Recovery
• Condensate Return
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Install an Automatic Blowdown-Control System

Background
To reduce the levels of suspended and total dissolved solids in a boiler, water is periodically discharged or blown down. High dissolved solids concentrations can lead to foaming and carryover of boiler water into the steam. This could lead to water hammer, which may damage piping, steam traps, or process equipment. Surface blowdown removes dissolved solids that accumulate near the boiler liquid surface and is often a continuous process.

Suspended and dissolved solids can also form sludge. Sludge must be removed because it reduces the heat-transfer capabilities of the boiler, resulting in poor fuel-to-steam efficiency and possible pressure vessel damage. Sludge is removed by mud or bottom blowdown.

During the surface blowdown process, a controlled amount of boiler water containing high dissolved solids concentrations is discharged into the sewer. In addition to wasting water and chemicals, the blowdown process wastes heat energy, because the blowdown liquid is at the same temperature as the steam produced—approximately 366°F for 150-pounds-per-square-inch-gauge (psig) saturated steam—and blowdown heat recovery systems, if available, are not 100% efficient. (Waste heat may be recovered through the use of a blowdown heat exchanger or a flash tank in conjunction with a heat recovery system. For more information, see Steam Tip Sheet #10, Recover Heat from Boiler Blowdown.)

Advantages of Automatic Control Systems
With manual control of surface blowdown, there is no way to determine the concentration of dissolved solids in the boiler water, nor the optimal blowdown rate. Operators do not know when to blow down the boiler, or for how long. Likewise, using a fixed rate of blowdown does not take into account changes in makeup and feedwater conditions, or variations in steam demand or condensate return.

An automatic blowdown-control system optimizes surface-blowdown rates by regulating the volume of water discharged from the boiler in relation to the concentration of dissolved solids present. Automatic surface-blowdown control systems maintain water chemistry within acceptable limits, while minimizing blowdown and reducing energy losses. Cost savings come from the significant reduction in the consumption, disposal, treatment, and heating of water.
How it Works
With an automatic blowdown-control system, high- or low-pressure probes are used to measure conductivity. The conductivity probes provide feedback to a blowdown controller that compares the measured conductivity with a set-point value, and then transmits an output signal that drives a modulating blowdown release valve.

Conductivity is a measure of the electrical current carried by positive and negative ions when a voltage is applied across electrodes in a water sample. Conductivity increases when the dissolved ion concentrations increase.

The measured current is directly proportional to the specific conductivity of the fluid. Total dissolved solids, silica, chloride concentrations, and/or alkalinity contribute to conductivity measurements. These chemical species are reliable indicators of salts and other contaminants in the boiler water.

Applications
Boilers without a blowdown heat-recovery system and with high blowdown rates offer the greatest energy-savings potential. The optimum blowdown rate is determined by a number of factors, including boiler type, operating pressure, water treatment, and makeup-water quality. Savings also depend upon the quantity of condensate returned to the boiler. With a low percentage of condensate return, more makeup water is required and additional blowdown must occur. Boiler blowdown rates often range from 1% to 8% of the feedwater flow rate, but they can be as high as 20% to maintain silica and alkalinity limits when the makeup water has a high solids content.

Price and Performance Example
For a 100,000 pound-per-hour (lb/hr) steam boiler, decreasing the required blowdown rate from 8% to 6% of the feedwater flow rate will reduce makeup water requirements by approximately 2,300 lb/hr. (See Steam Tip Sheet #9, Minimize Boiler Blowdown.) Annual energy, water, and chemicals savings due to blowdown rate reductions for a sample system are summarized in the table below. In many cases, these savings can provide a 1- to 3-year simple payback on the investment in an automatic blowdown-control system.

<table>
<thead>
<tr>
<th>Blowdown Reduction, lb/hr</th>
<th>Annual Savings, $</th>
<th>Fuel</th>
<th>Water and Chemicals</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td></td>
<td>27,200</td>
<td>4,200</td>
<td>31,400</td>
</tr>
<tr>
<td>2,000</td>
<td></td>
<td>54,400</td>
<td>8,400</td>
<td>62,800</td>
</tr>
<tr>
<td>4,000</td>
<td></td>
<td>108,800</td>
<td>16,800</td>
<td>125,600</td>
</tr>
</tbody>
</table>

Note: Based on continuous operation of a 150-psig, natural gas-fired steam boiler with fuel valued at $8.00 per million Btu ($8.00/MMBtu), a makeup water temperature of 60°F, and a boiler efficiency of 80%. Water, sewage, and chemical treatment costs are estimated at $0.004 per gallon.
Purchasing and installing an automatic blowdown-control system can cost from $2,500 to $6,000. The complete system consists of a low- or high-pressure conductivity probe, temperature compensation and signal conditioning equipment, and a blowdown-modulating valve. Some systems are designed to monitor both feedwater and blowdown conductivity from multiple boilers. A continuous conductivity recording capability might also be desired. The total cost of the automatic blowdown system is dependent upon the system operating pressure and the design and performance options specified.

**Recommended Practices**

The American Society of Mechanical Engineers (ASME) has developed a consensus on operating practices for boiler blowdown. Sections VI and VII of the ASME Boiler and Pressure Vessel Code describe recommended practices. The ASME Boiler and Pressure Vessel Code can be ordered through the ASME website at [www.asme.org](http://www.asme.org).

**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.

Visit the Advanced Manufacturing Office website at [manufacturing.energy.gov](http://manufacturing.energy.gov) to access these and many other industrial efficiency resources and information on training.
Benchmark the Fuel Cost of Steam Generation

Benchmarking the fuel cost of steam generation, in dollars per 1,000 pounds ($/1,000 lb) of steam, is an effective way to assess the efficiency of your steam system. This cost is dependent upon fuel type, unit fuel cost, boiler efficiency, feedwater temperature, and steam pressure. This calculation provides a good first approximation for the cost of generating steam and serves as a tracking device to allow for boiler performance monitoring. Table 1 shows the heat input required to produce 1 lb of saturated steam at different operating pressures and varying feedwater temperatures. Table 2 lists the typical energy content and boiler combustion efficiency for several common fuels.

Table 1. Energy Required to Produce One Pound of Saturated Steam, Btu*

<table>
<thead>
<tr>
<th>Operating Pressure, psig</th>
<th>Feedwater Temperature, °F</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td></td>
<td>1,178</td>
<td>1,128</td>
<td>1,078</td>
<td>1,028</td>
<td>977</td>
</tr>
<tr>
<td>450</td>
<td></td>
<td>1,187</td>
<td>1,137</td>
<td>1,087</td>
<td>1,037</td>
<td>986</td>
</tr>
<tr>
<td>600</td>
<td></td>
<td>1,184</td>
<td>1,134</td>
<td>1,084</td>
<td>1,034</td>
<td>984</td>
</tr>
</tbody>
</table>

* Calculated from steam tables based on the difference between the enthalpies of saturated steam and feedwater.

Table 2. Energy Content and Combustion Efficiency of Fuels

<table>
<thead>
<tr>
<th>Fuel Type, sales unit</th>
<th>Energy Content, Btu/sales unit</th>
<th>Combustion Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas, MMBtu</td>
<td>1,000,000</td>
<td>85.7</td>
</tr>
<tr>
<td>Natural Gas, thousand cubic feet</td>
<td>1,030,000</td>
<td>85.7</td>
</tr>
<tr>
<td>Distillate/No. 2 Oil, gallon</td>
<td>138,700</td>
<td>88.7</td>
</tr>
<tr>
<td>Residual/No. 6 Oil, gallon</td>
<td>149,700</td>
<td>89.6</td>
</tr>
<tr>
<td>Coal, ton</td>
<td>27,000,000</td>
<td>90.3</td>
</tr>
</tbody>
</table>

Note: Combustion efficiency is based on boilers equipped with feedwater economizers or air preheaters and 3% oxygen in flue gas.

Data from the tables above can be used to determine the cost of usable heat from a boiler or other combustion unit. The calculations can also include the operating costs of accessories such as feedwater pumps, fans, fuel heaters, steam for fuel atomizers and soot blowing, treatment chemicals, and environmental and maintenance costs.
Example

A boiler fired with natural gas costing $8.00/MBtu produces 450-pounds-per-square-inch-gauge (psig) saturated steam and is supplied with 230°F feedwater. Using values from the tables, calculate the fuel cost of producing steam.

\[
\text{Steam Cost} = \frac{8.00}{10^6 \text{ Btu/MBtu}} \times 1,000 \text{ lb} \times 1.006 \text{ (Btu/lb)} / 0.857
\]

\[
= $9.39/1,000 \text{ lb}
\]

Effective Cost of Steam

The effective cost of steam depends on the path it follows from the boiler to the point of use. Take a systems approach and consider the entire boiler island, including effect of blowdown, parasitic steam consumption, and deaeration. Further complications arise because of the effects of process steam loads at different pressures, multiple boilers, and waste heat recovery systems. To determine the effective cost of steam, use a combined heat and power simulation model that includes all the significant effects.

Multi-Fuel Capability

For multi-fuel capability boilers, take advantage of the volatility in fuel prices by periodically analyzing the steam generation cost, and use the fuel that provides the lowest steam generation cost.

Higher Versus Lower Heating Values

Fuel is sold based on its gross or higher heating value (HHV). If, at the end of the combustion process, water remains in the form of vapor, the HHV must be reduced by the latent heat of vaporization of water. This reduced value is known as the lower heating value (LHV).
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.

### 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.

Consider online monitoring of flue gas oxygen level to quickly identify energy loss trends that can provide early warning of control failures and allow data to drive your decision making.

### Combustion Efficiency for Natural Gas

<table>
<thead>
<tr>
<th>Excess, %</th>
<th>Flue Gas Temperature Minus Combustion Air Temperature, °F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200</td>
</tr>
<tr>
<td>Air</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
</tr>
<tr>
<td>9.5</td>
<td>85.4</td>
</tr>
<tr>
<td>15.0</td>
<td>85.2</td>
</tr>
<tr>
<td>28.1</td>
<td>84.7</td>
</tr>
<tr>
<td>44.9</td>
<td>84.1</td>
</tr>
<tr>
<td>81.6</td>
<td>82.8</td>
</tr>
</tbody>
</table>

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 annually 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% (E1). 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% (E2). Assuming a fuel cost of $8.00/MMBtu, the annual savings are:

\[
\text{Annual Savings} = \text{Fuel Consumption} \times (1-E1/E2) \times \text{Fuel Cost}
\]
\[
= 29,482 \text{ MMBtu/yr} \times 8.00/\text{MMBtu}
\]
\[
= 235,856
\]

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.

For additional information on monitoring, download the following sub-metering case studies from the AMO publication library:

- Solutia: Utilizing Sub-Metering to Drive Energy Project Approvals Through Data
- Nissan North America: How Sub-Metering Changed the Way a Plant Does Business

Also refer to the following guidebook on the EERE Federal Energy Management website at www.femp.energy.gov:


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

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.

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

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.
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% (E1). 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 - E1/E2)

<table>
<thead>
<tr>
<th>Burner Combustion Efficiency Improvement, %</th>
<th>Annual Energy Savings, MMBtu/yr</th>
<th>Annual Dollar Savings, $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6,250</td>
<td>50,000</td>
</tr>
<tr>
<td>2</td>
<td>12,345</td>
<td>98,760</td>
</tr>
<tr>
<td>3</td>
<td>18,290</td>
<td>146,320</td>
</tr>
</tbody>
</table>

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 AMO Steam Technical Subcommittee. For additional information, refer to Steam Tip Sheet #4, Improve Your Boiler’s Combustion Efficiency.

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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U.S. DEPARTMENT OF ENERGY

Energy Efficiency & Renewable Energy

The Advanced Manufacturing Office (AMO) works with diverse partners to develop and deploy technologies and best practices that will help U.S. manufacturers continually improve their energy performance and succeed in global markets. AMO’s Better Plants program works with U.S. corporations through a CEO-endorsed pledge to improve energy efficiency. AMO’s tools, training, resources, and recognition programs can help build energy management capacity within the industrial sector and supply chains. Use these resources to comply with requirements of the ISO 50001 standard and the Superior Energy Performance program.

With our partners, AMO leverages additional federal, state, utility, and local resources to help manufacturers save energy, reduce climate and environmental impacts, enhance workforce development, and improve national energy security and competitiveness throughout the supply chain.

Advanced Manufacturing Office
Energy Efficiency and Renewable Energy
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manufacturing.energy.gov
Use Feedwater Economizers for Waste Heat Recovery

A feedwater economizer reduces steam boiler fuel requirements by transferring heat from the flue gas to incoming feedwater. Boiler flue gases are often rejected to the stack at temperatures more than 100°F to 150°F higher than the temperature of the generated steam. Generally, boiler efficiency can be increased by 1% for every 40°F reduction in flue gas temperature. By recovering waste heat, an economizer can often reduce fuel requirements by 5% to 10% and pay for itself in less than 2 years. The table provides examples of the potential for heat recovery.

Recoverable Heat from Boiler Flue Gases

<table>
<thead>
<tr>
<th>Initial Stack Gas Temperature, °F</th>
<th>Recoverable Heat, MMBtu/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boiler Thermal Output, MMBtu/hr</td>
</tr>
<tr>
<td></td>
<td>25</td>
</tr>
<tr>
<td>400</td>
<td>1.3</td>
</tr>
<tr>
<td>500</td>
<td>2.3</td>
</tr>
<tr>
<td>600</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Based on natural gas fuel, 15% excess air, and a final stack temperature of 250°F.

Example

An 80% efficient boiler generates 45,000 pounds per hour (lb/hr) of 150-pounds-per-square-inch-gauge (psig) steam by burning natural gas. Condensate is returned to the boiler and mixed with makeup water to yield 117°F feedwater. The stack temperature is measured at 500°F. Determine the annual energy savings that will be achieved by installing an economizer given 8,400 hours per year (hr/yr) of boiler operation at a fuel cost of $8.00 per million Btu ($8.00/MMBtu).

From the steam tables, the following enthalpy values are available:

- For 150-psig saturated steam: 1,195.5 Btu/lb
- For 117 °F feedwater: 84.97 Btu/lb

Boiler heat output = 45,000 lb/hr x (1,195.5 – 84.97) Btu/lb
= 50 million Btu/hr

The recoverable heat corresponding to a stack temperature of 500°F and a natural gas-fired boiler load of 50 MMBtu/hr is read from the table (above) as 4.6 MMBtu/hr.

Annual Savings = (4.6 MMBtu/hr x $8.00/MMBtu x 8,400 hr/yr)/0.80
= $386,400
Exhaust Gas Temperature Limits
The lowest temperature to which flue gases can be cooled depends on the type of fuel used: 250°F for natural gas, 300°F for coal and low sulphur content fuel oils, and 350°F for high sulphur fuel oils. These limits are set to prevent condensation and possible corrosion of the stack.

Potential Economizer Applications
A feedwater economizer is appropriate when insufficient heat transfer surface exists within the boiler to remove combustion heat. Boilers that exceed 100 boiler horsepower, operating at pressures exceeding 75 psig or above, and that are significantly loaded all year long are excellent candidates for an economizer retrofit.

For additional information on heat recovery, refer to the factsheet titled Unlock Energy Savings with Waste Heat Recovery in the publication library on the AMO website.

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

When steam transfers its heat in a manufacturing process, heat exchanger, or heating coil, it reverts to a liquid phase called condensate. An attractive method of improving your power plant’s energy efficiency is to increase the condensate return to the boiler.

Returning hot condensate to the boiler makes sense for several reasons. As more condensate is returned, less make-up water is required, saving fuel, makeup water, and chemicals and treatment costs. Less condensate discharged into a sewer system reduces disposal costs. Return of high purity condensate also reduces energy losses due to boiler blowdown. Significant fuel savings occur as most returned condensate is relatively hot (130°F to 225°F), reducing the amount of cold makeup water (50°F to 60°F) that must be heated.

A simple calculation indicates that energy in the condensate can be more than 10% of the total steam energy content of a typical system. The graph shows the heat remaining in the condensate at various condensate temperatures, for a steam system operating at 100 pounds per-square-inch-gauge (psig), with makeup water at 55°F.

Let:
\[ h_c = \text{enthalpy of condensate at } 180^\circ \text{F} = 148 \text{ Btu/lb} \]
\[ h_m = \text{enthalpy of makeup water at } 55^\circ \text{F} = 23 \text{ Btu/lb} \]
\[ h_s = \text{enthalpy of steam at } 100 \text{ psig} = 1,189 \text{ Btu/lb} \]

Heat remaining in condensate (%):
\[ = \frac{(h_c - h_m)}{(h_s - h_m)} \times 100 \]
\[ = \frac{(148 - 23)}{(1,189 - 23)} \times 100 = 11.0\% \]

Example
Consider a steam system that returns an additional 10,000 pounds per hour (lb/hr) of condensate at 180°F after distribution modifications. Assume this system operates 8,000 hours annually with an average boiler efficiency of 80%, and makeup water temperature of 55°F. The water and sewage costs for the plant are
$0.002 per gallon ($/gal), and the water treatment cost is $0.002/gal. The fuel cost is $8.00 per million Btu ($8.00/MMBtu). Assuming a 12% flash steam loss,* calculate overall savings.

**Annual Water, Sewage, & Chemicals Savings**

\[
\text{Annual Water, Sewage, & Chemicals Savings} = (1 - \text{Flash Steam Fraction}) \times (\text{Condensate Load, lb/hr}) \times \text{Annual Operating Hours} \times \left( \frac{\text{Total Water Costs, $/gal}}{\text{Water Density, lb/gal}} \right)
\]

\[
= (1 - 0.12) \times 10,000 \times 8,000 \times \frac{0.004}{8.34}
\]

\[
= \$33,760
\]

**Annual Fuel Savings**

\[
\text{Annual Fuel Savings} = (1 - \text{Flash Steam Fraction}) \times (\text{Condensate Load, lb/hr}) \times \text{Annual Operating Hours} \times (\text{Makeup Water Temperature Rise, °F}) \times (\text{Fuel Cost, $/MMBtu}) \times (\text{Heat Capacity of Makeup Water, Btu/lb-°F}) / (\text{Boiler Efficiency} \times 10^6 \text{Btu/MMBtu})
\]

\[
= (1 - 0.12) \times 10,000 \times 8,000 \times (180 - 55) \times 8.00 \times 1 \times (0.80 \times 10^6)
\]

\[
= \$88,000
\]

**Total Annual Savings Due to Return of an Additional 10,000 lb/hr of Condensate**

\[
= \$33,760 + \$88,000
\]

\[
= \$121,760
\]

**Condensate Recovery Produces Savings**

A large specialty paper plant reduced its boiler makeup water rate from about 35% of steam production to between 14% and 20% by returning additional condensate. Annual savings added up to more than $300,000.

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

*When saturated condensate is reduced to some lower pressure, some condensate flashes off to steam again. This amount is the flash steam loss.
Insulate Steam Distribution and Condensate Return Lines

Uninsulated steam distribution and condensate return lines are a constant source of wasted energy. The table shows typical heat loss from uninsulated steam distribution lines. Insulation can typically reduce energy losses by 90% and help ensure proper steam pressure at plant equipment. Any surface over 120°F should be insulated, including boiler surfaces, steam and condensate return piping, and fittings.

Insulation frequently becomes damaged or is removed and never replaced during steam system repair. Damaged or wet insulation should be repaired or immediately replaced to avoid compromising the insulating value. Eliminate sources of moisture prior to insulation replacement. Causes of wet insulation include leaking valves, external pipe leaks, tube leaks, or leaks from adjacent equipment. After steam lines are insulated, changes in heat flows can influence other parts of the steam system.

Example

In a plant where the fuel cost is $8.00 per million Btu ($8.00/MMBtu), a survey of the steam system identified 1,120 feet (ft) of bare 1-inch-diameter steam line, and 175 feet of bare 2-inch line, both operating at 150 pounds per square inch gauge (psig). An additional 250 ft of bare 4-inch-diameter line operating at 15 psig was found. From the table, the quantity of heat lost per year is:

- 1-inch line: $1,120 \times 285 \text{ MMBtu/yr per 100 ft} = 3192 \text{ MMBtu/yr}$
- 2-inch line: $175 \times 480 \text{ MMBtu/yr per 100 ft} = 840 \text{ MMBtu/yr}$
- 4-inch line: $250 \times 415 \text{ MMBtu/yr per 100 ft} = 1037 \text{ MMBtu/yr}$

Total Heat Loss = 5,069 MMBtu/yr

Given a boiler efficiency of 80%, the annual cost savings from installing 90% efficient insulation is:

\[
(0.90 \times 8.00/\text{MMBtu} \times 5,069 \text{ MMBtu/yr}) / 0.80 = 45,620
\]
Insulation Optimization Software Available
The North American Insulation Manufacturers Association has developed a software package (3E Plus) that determines the optimum thickness for a wide variety of insulating materials. Outputs include the simple payback period, surface heat loss, and surface temperature for each specified insulation thickness. 3E Plus is available at no cost on AMO’s website at [manufacturing.energy.gov](http://manufacturing.energy.gov).

Use Insulating Jackets
Removable insulating jackets are available for valves, flanges, steam traps, and other fittings. Remember that a 6-inch gate valve may have more than 6 square feet of surface area from which to radiate heat.

Install insulating jackets on steam traps according to steam trap manufacturer’s directions to maintain proper trap operation.

For additional information on removable insulation, refer to the related steam tip sheet #17 Install Removable Insulation on Valves and Fittings in the publication library on the AMO website.

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

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.

Visit the Advanced Manufacturing Office website at [manufacturing.energy.gov](http://manufacturing.energy.gov) to access these and many other industrial efficiency resources and information on training.
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.

\[
\text{Fractional Fuel Savings} = (1 - \frac{E_1}{E_2}) = (1 - \frac{72.7}{78.8}) \times 100 = 7.7\%
\]

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:

\[
\text{Annual Savings} = 200,000 \text{ MMBtu} \times 0.077 \times 8.00/\text{MMBtu} = 123,200
\]
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.

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.

Visit the Advanced Manufacturing Office website at manufacturing.energy.gov to access these and many other industrial efficiency resources and information on training.
Recover Heat from Boiler Blowdown

Heat can be recovered from boiler blowdown by using a heat exchanger to preheat boiler makeup water. Any boiler with continuous blowdown exceeding 5% of the steam rate is a good candidate for the introduction of blowdown waste heat recovery. Larger energy savings occur with high-pressure boilers. The following table shows the potential for heat recovery from boiler blowdown.

Recoverable Heat from Boiler Blowdown

<table>
<thead>
<tr>
<th>Blowdown Rate, % Boiler Feedwater</th>
<th>Heat Recovered, Million Btu per hour (MMBtu/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steam Pressure, psig</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>0.45</td>
</tr>
<tr>
<td>4</td>
<td>0.9</td>
</tr>
<tr>
<td>6</td>
<td>1.3</td>
</tr>
<tr>
<td>8</td>
<td>1.7</td>
</tr>
<tr>
<td>10</td>
<td>2.2</td>
</tr>
<tr>
<td>20</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Based on a steam production rate of 100,000 pounds per hour, 60°F makeup water, and 90% heat recovery.

Example

In a plant where the fuel cost is $8.00 per million Btu ($8.00/MMBtu), a continuous blowdown rate of 3,200 pounds per hour (lb/hr) is maintained to avoid the buildup of high concentrations of dissolved solids. What are the annual savings if a makeup water heat exchanger is installed that recovers 90% of the blowdown energy losses? The 80% efficient boiler produces 50,000 pounds per hour (lb/hr) of 150-pounds-per-square-inch-gauge (psig) steam. It operates for 8,000 hours per year. The blowdown ratio is:

\[
\text{Blowdown Ratio} = \frac{3,200}{3,200 + 50,000} = 6.0\%
\]

From the table, the heat recoverable corresponding to a 6% blowdown ratio with a 150-psig boiler operating pressure is 1.7 MMBtu/hr. Since the table is based on a steam production rate of 100,000 lb/hr, the annual savings for this plant are:

\[
\text{Annual Energy Savings} = \left[1.7 \text{ MMBtu/hr} \times \frac{(50,000 \text{ lb/hr/100,000 lb/hr})}{8,000 \text{ hr/yr}}/0.80\right] \\
= 8,500 \text{ MMBtu}
\]

\[
\text{Annual Cost Savings} = \left[8,500 \text{ MMBtu/yr} \times $8.00/\text{MMBtu}\right] \\
= $68,000
\]

Suggested Actions

If there is a continuous blowdown system in place, consider installing a heat recovery system. If there is a noncontinuous blowdown system, then consider the option of converting it to a continuous blowdown system coupled with heat recovery.
Blowdown Energy Recovery

Blowdown waste heat can be recovered with a heat exchanger, a flash tank, or flash tank in combination with a heat exchanger. Lowering the pressure in a flash tank allows a portion of the blowdown to be converted into low-pressure steam. This low-pressure steam is most typically used in deaerators. Drain water from the flash tank is then routed through a heat exchanger. Cooling the blowdown has the additional advantage of helping to comply with local codes limiting the discharge of high-temperature liquids into the sewer system.

For additional information on heat recovery, refer to the factsheet Unlock Energy Savings with Waste Heat Recovery in the publication library on the AMO website.

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

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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The Advanced Manufacturing Office (AMO) works with diverse partners to develop and deploy technologies and best practices that will help U.S. manufacturers continually improve their energy performance and succeed in global markets. AMO’s Better Plants program works with U.S. corporations through a CEO-endorsed pledge to improve energy efficiency. AMO’s tools, training, resources, and recognition programs can help build energy management capacity within the industrial sector and supply chains. Use these resources to comply with requirements of the ISO 50001 standard and the Superior Energy Performance program.

With our partners, AMO leverages additional federal, state, utility, and local resources to help manufacturers save energy, reduce climate and environmental impacts, enhance workforce development, and improve national energy security and competitiveness throughout the supply chain.
Inspect and Repair Steam Traps

In steam systems that have not been maintained for 3 to 5 years, between 15% to 30% of the installed steam traps may have failed—thus allowing live steam to escape into the condensate return system. In systems with a regularly scheduled maintenance program, leaking traps should account for less than 5% of the trap population. If your steam distribution system includes more than 500 traps, a steam trap survey will probably reveal significant steam losses.

Example

In a plant where the value of steam is $10.00 per thousand pounds ($10.00/1,000 lb), an inspection program indicates that a trap on a 150-pound-per-square-inch-gauge (psig) steam line is stuck open. The trap orifice is 1/8th inch in diameter. The table shows the estimated steam loss as 75.8 pounds per hour (lb/hr). After the failed trap is repaired, annual savings are:

\[
\text{Annual Savings} = 75.8 \text{ lb/hr} \times 8,760 \text{ hr/yr} \times \$10.00/1,000 \text{ lb} \\
= \$6,640
\]

Leaking Steam Trap Discharge Rate*

<table>
<thead>
<tr>
<th>Trap Orifice Diameter, inches</th>
<th>Steam Pressure, psig</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
</tr>
<tr>
<td>1/32</td>
<td>0.85</td>
</tr>
<tr>
<td>1/16</td>
<td>3.4</td>
</tr>
<tr>
<td>1/8</td>
<td>13.7</td>
</tr>
<tr>
<td>3/16</td>
<td>30.7</td>
</tr>
<tr>
<td>1/4</td>
<td>54.7</td>
</tr>
<tr>
<td>3/8</td>
<td>123</td>
</tr>
</tbody>
</table>

*From the Boiler Efficiency Institute. Steam is discharging to atmospheric pressure through a re-entrant orifice with a coefficient of discharge equal to 0.72.
Steam Trap Testing Facts
Steam traps are tested to determine if they are functioning properly and not cold plugging or failing in an open position and allowing live steam to escape into the condensate return system. There are four basic ways to test steam traps: temperature, sound, visual, and electronic.

Recommended Steam Trap Testing Intervals
• High-Pressure (150 psig and above): Weekly to Monthly
• Medium-Pressure (30 to 150 psig): Monthly to Quarterly
• Low-Pressure (below 30 psig): Annually

For additional information on monitoring, download the following sub-metering case studies from the AMO publication library:
• Solutia: Utilizing Sub-Metering to Drive Energy Project Approvals Through Data
• Nissan North America: How Sub-Metering Changed the Way a Plant Does Business

Also refer to the following guidebook on the EERE Federal Energy Management website at www.femp.energy.gov:

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

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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Consider Installing Turbulators on Two- and Three-Pass Firetube Boilers

Firetube Boilers

The packaged firetube boiler is the most common boiler design used to provide heating or process steam in industrial and heavy commercial applications. The American Boiler Manufacturers Association (ABMA) surveyed sales of high-pressure [15- to 350-pounds-per-square-inch-gauge (psig)] firetube and small watertube boilers between 1978 and 1994. ABMA found that firetube boilers comprised more than 85% of the sales of these boilers to industry.

Although firetube boilers are available in ratings up to 85,000 pounds of steam per hour (lb/hr), they are generally specified when the required steam pressure is under 150 psig and the boiler capacity is less than 25,000 lb/hr. Watertube boilers are designed for larger, high-pressure, and superheated steam applications.

In a firetube boiler, hot combustion gases pass through long, small-diameter tubes, where heat is transferred to water through the tube walls. Firetube boilers are categorized by their number of “passes,” or the number of times that the hot combustion gases travel across the boiler heat-exchange surfaces. For example, a two-pass boiler provides two opportunities for hot gases to transfer heat to the boiler water. Hot combustion gases enter the tubes in a turbulent flow regime, but within a few feet, laminar flow begins and a boundary layer of cooler gas forms along the tube walls. This layer serves as a barrier, retarding heat transfer.

Turbulators, which consist of small baffles, angular metal strips, spiral blades, or coiled wire, are inserted into the boiler tubes to break up the laminar boundary layer. This increases the turbulence of the hot combustion gases and the convective heat transfer to the tube surface. The result is improved boiler efficiency. Turbulators are usually installed on the last boiler pass.

Turbulator installers can also balance gas flow through the tubes by placing longer turbulators in the uppermost tubes. This practice increases the effectiveness of the available heat-transfer surface by eliminating thermal stratification and balancing the gas flow through the firetubes.

Applications

Turbulators can be a cost-effective way to reduce the stack temperature and increase the fuel-to-steam efficiency of single-pass horizontal return tubular (HRT) brick-set boilers and older two- and three-pass oil- and natural-gas-fueled firetube boilers. Turbulators are not recommended for four-pass boilers or coal-fired units. A four-pass unit provides four opportunities for heat transfer. It has more heat exchange surface area, a lower stack temperature, higher fuel-to-steam efficiency, and lower annual fuel costs than a two- or three-pass boiler operating under identical conditions. New firetube boilers perform better than older two- and three-pass designs.

Turbulators can also be installed to compensate for efficiency losses when a four-pass boiler is being converted to a two-pass boiler because of door warpage and loose and leaking tubes.

Turbulators are substitutes for more costly economizers or air-preheaters. They are simple, easy to install, and low cost. Their installed cost is about $10 to $15 per boiler tube. Current turbulator designs do not cause a significant increase in pressure drop or

Suggested Actions

Consider installing turbulators in natural gas or oil-fired boilers with two- or three-pass firetube boiler tubes if your stack gas temperature is 100°F or more above your steam or hot water temperature.
contribute to soot formation in natural-gas-fired boilers. Turbulators are held in place with a spring lock and are easily removed to allow for tube brushing.

Turbulators come in various lengths and widths and should be installed by a qualified installer. To avoid combustion problems, the boiler burner should be retuned after the turbulators have been installed. The installer must also verify that the stack temperature does not fall below the flue gas dew point.

**Price and Performance Example**

A manufacturing facility installed 150 turbulators into its firetube boiler. Tests conducted both before and after turbulator installation indicated a reduction in the stack gas temperature of 130°F. More combustion heat was being transferred into the boiler water. Because each 40°F reduction in the boiler flue gas temperature results in a 1% boiler-efficiency improvement, overall boiler efficiency has improved by about 3.25%. Fuel costs have decreased by approximately 4%.

**Example**

Consider a two-pass firetube boiler that consumes 60,000 million Btu (MMBtu) of natural gas annually while producing 15,000 lb/hr of 100-psig saturated steam. What are the annual energy and cost savings, given that the installation of turbulators improves the boiler efficiency from 79% (E₁) to 82% (E₂)? Natural gas is priced at $8.00/MMBtu.

Annual Energy Savings = \( \text{Annual Fuel Consumption (MMBtu) x } (1 – \frac{E_1}{E_2}) \)

or \( \frac{60,000 \text{ MMBtu} x (1 – 79/82)}{2,195 \text{ MMBtu}} \)

Annual Cost Savings = \( \text{$8.00/MMBtu x 2,195 MMBtu/yr} \)

= $17,560

If the boiler has 250 tubes and the installed cost for the turbulator is $15 per tube, the simple payback on the investment in the energy efficiency measure is:

Simple Payback = \( \frac{(250 \text{ tubes x $15/tube})/\text{$17,560/year}}{0.21 \text{ year}} \)

Steam Tip Sheet information is adapted from material provided by Brock Turbulators and Fuel Efficiency, LLC, and reviewed by the AMO Steam Technical Subcommittee.

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**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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With our partners, AMO leverages additional federal, state, utility, and local resources to help manufacturers save energy, reduce climate and environmental impacts, enhance workforce development, and improve national energy security and competitiveness throughout the supply chain.
Install Removable Insulation on Valves and Fittings

During maintenance, the insulation that covers pipes, valves, and fittings is often damaged or removed and not replaced. Pipes, valves, and fittings that are not insulated can be safety hazards and sources of heat loss. Removable and reusable insulating pads are available to cover almost any surface. The pads are made of a noncombustible inside cover, insulation material, and a noncombustible outside cover that resists tears and abrasion. Material used in the pads resists oil and water and has been designed for temperatures up to 1,600°F. Wire laced through grommets or straps with buckles hold the pads in place.

Applications

Reusable insulating pads are commonly used in industrial facilities for insulating flanges, valves, expansion joints, heat exchangers, pumps, turbines, tanks, and other irregular surfaces. The pads are flexible and vibration-resistant and can be used with equipment that is horizontally or vertically mounted or that is difficult to access. Any high-temperature piping or equipment should be insulated to reduce heat loss, reduce emissions, and improve safety. As a general rule, any surface that reaches temperatures greater than 120°F should be insulated to protect personnel. Insulating pads can be easily removed for periodic inspection or maintenance, and replaced as needed. Insulating pads can also contain built-in acoustical barriers to help control noise.

Energy Savings

The table below summarizes energy savings due to the use of insulating valve covers for a range of valve sizes and operating temperatures. These values were calculated using a computer program that meets the requirements of ASTM C 680—Heat Loss and Surface Temperature Calculations. Energy savings is defined as the difference in heat loss between the uninsulated valve and the insulated valve operating at the same temperature.

<table>
<thead>
<tr>
<th>Operating Temperature, °F</th>
<th>Valve Size, inches</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>800</td>
<td>1,090</td>
<td>1,560</td>
<td>2,200</td>
<td>2,900</td>
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<td>25,200</td>
<td>29,300</td>
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</table>

*Based on installation of a 1-inch thick insulating pad on an ANSI 150-pound-class flanged valve with an ambient temperature of 65°F and zero wind speed.

Example

Interpolating from the table above, calculate the annual fuel and dollar savings from installing a 1-inch thick insulating pad on an uninsulated 6-inch gate valve in
a 250-pound-per-square-inch-gauge (psig) saturated steam line (406°F). Assume continuous operation with natural gas at a boiler efficiency of 80% and a fuel price of $8.00 per million Btu ($8.00/MMBtu).

**Results:**

\[
\text{Annual Fuel Savings} = 5,992 \text{ Btu/hr} \times 8,760 \text{ hr/yr} / (0.80 \times 10^6 \text{ Btu/MMBtu}) = 65.6 \text{ MMBtu}
\]

\[
\text{Annual Dollar Savings} = 65.6 \text{ MMBtu/yr} \times 8.00 / \text{MMBtu} = 525 \text{ per 6-inch gate valve}
\]

**Availability**

Insulation supply companies are located regionally; this expedites delivery and helps meet site-specific job requirements. Most supply companies can take measurements on-site to ensure the best fit on irregular surfaces. For customized applications, manufacturers can provide instructions regarding the installation and removal of insulating pads.

**Noise Control Benefits**

Specify insulating pads that contain built-in barriers for noise control.

**Insulation for Steam Traps**

Effectively insulate inverted bucket traps with removable and reusable snap-on insulation. Thermostatic traps and disk traps should be insulated according to manufacturers’ specifications to ensure proper operation.

Before removal of all or any existing insulation material, check for asbestos in accordance with Occupational Safety and Health Administration (OSHA) regulations.

Steam Tip Sheet information adapted from information provided by the Industrial Energy Extension Service of Georgia Tech and reviewed by the AMO Steam Technical Subcommittee.