Energy Tips – Steam

Steam Tip Sheet #22 • January 2006

Industrial Technologies Program

Suggested Actions

Consider installing a high-pressure boiler with a back-pressure turbine-generator whenever undertaking a boiler upgrade. When evaluating this opportunity, you should:

- Determine how much steam enthalpy, pressure and temperature are required at the header downstream from your boiler.
- Calculate the incremental fuel cost between a low-pressure boiler and a high-pressure boiler.
- Develop steam flow/duration curves for your boiler. (Remember that electrical generation will follow your steam load or process heating requirements).
- Obtain plant electricity and fuel cost information.
- Use the tools provided in this fact sheet to estimate your electricity generation potential and to determine savings from purchas-ing and installing a high-pressure boiler plus a backpressure turbine-generator

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 BestPractices Web site at www.eere.energy.gov/industry/bestpractices to access these and many other industrial efficiency resources and information on training.

Consider Installing High-Pressure Boilers with Backpressure Turbine-Generators

When specifying a new boiler, consider a high-pressure boiler with a backpressure steam turbine-generator placed between the boiler and the steam distribution network. A turbine-generator can often produce enough electricity to justify the capital cost of purchasing the higher-pressure boiler and the turbine-generator.

Since boiler fuel usage per unit of steam production increases with boiler pressure, facilities often install boilers that produce steam at the lowest pressure consistent with end use and distribution requirements.

In the backpressure turbine configuration, the turbine does not consume steam. Instead, it simply reduces the pressure and energy content of steam that is subsequently exhausted into the process header. In essence, the turbogenerator serves the same steam function as a pressure-reducing valve (PRV)—it reduces steam pressure—but uses the pressure drop to produce highly valued electricity in addition to the low-pressure steam. Shaft power is produced when a nozzle directs jets of high-pressure steam against the blades of the turbine's rotor. The rotor is attached to a shaft that is coupled to an electrical generator.

Background

The capital cost of a back-pressure turbogenerator complete with electrical switchgear varies from about $900 per kilowatt (kW) for a small system (150 kW) to less than $200/kW for a larger system (>2,000 kW). Installation costs vary, depending upon piping and wiring runs, but they typically average 75% of equipment costs.

Packaged or "off-the-shelf" backpressure turbogenerators are now available in ratings as low as 50 kW. Backpressure turbogenerators should be considered when a boiler has steam flows of at least 3,000 pounds per hour (lb/hr), and when the steam pressure drop between the boiler and the distribution network is at least 100 pounds per square inch gauge (psig). The backpressure turbine is generally installed in parallel with a PRV, to ensure that periodic turbine-generator maintenance does not interfere with plant thermal deliveries.

Cost-Effective Power Generation

In a backpressure steam turbine, energy from high-pressure inlet steam is efficiently converted into electricity, and low-pressure exhaust steam is provided to a plant process. The turbine exhaust steam has a lower temperature than the superheated steam created when pressure is reduced through a PRV. In order to make up for this heat or enthalpy loss and meet process energy requirements, steam plants with backpressure turbine installations must increase their boiler steam throughput (typically by 5% to 7%). Every Btu that is recovered as high-value electricity is replaced with an equivalent Btu of heat for downstream processes.

Thermodynamically, steam turbines achieve an isentropic efficiency of 20% to 70%. Economically, however, the turbine generates power at the efficiency of the steam boiler. The resulting power generation efficiency (modern steam boilers operate at approximately 80% efficiency) is well in excess of the efficiency for state-of-the-art single- or combined-cycle gas turbines. High efficiency means low electricity generating costs. Backpressure turbines can produce electrical energy at costs that are often less than $0.04/kWh. The electricity savings alone—not to mention ancillary benefits from enhanced on-site electricity reliability and reduced emissions of carbon dioxide and criteria pollutants—are often sufficient to completely recover the cost of the initial capital outlay.

Estimating Your Savings

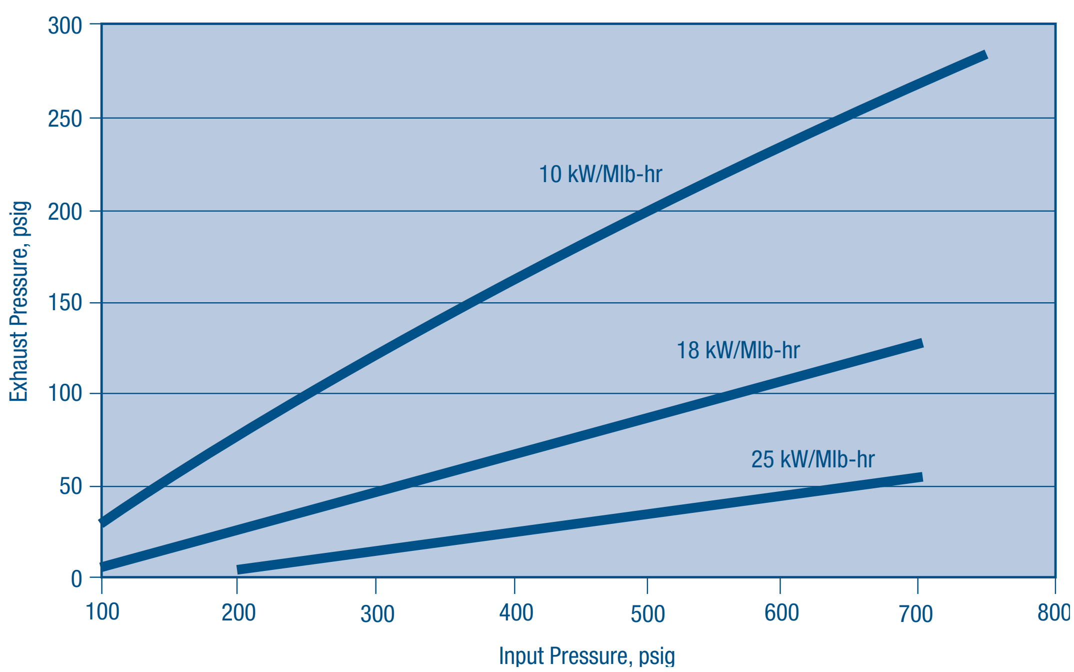
Since you have already determined that you need a boiler to satisfy your process thermal loads, the marginal cost of power produced from the backpressure turbine-generator is:

> Cost of Power Production = (Annual Boiler Fuel Cost after Pressure Increase – Annual Boiler Fuel Cost before Pressure Increase) / Annual kWh Produced by Turbine-Generator

The cost of boiler fuel before and after a proposed pressure increase can be calculated directly from the boiler fuel cost, boiler efficiency, and inlet and outlet steam conditions. The annual kWh produced by the turbine generator can be calculated from the inlet and exhaust pressures at the turbine, along with the steam flow rate through the turbine, in thousand pounds per hour (Mlb-hr).

To estimate the potential power output of your system, refer to the figure below, which shows lines of constant power output, expressed in kW of electricity output per Mlb-hr of steam throughput as a function of the inlet and exhaust pressure through the turbine. Look up your input and output pressure on the axes shown, and then use the lines provided to estimate the power output, per Mlb/hr of steam flow rate for a backpressure turbogenerator. You can then estimate the turbine power output by multiplying this number by your known steam flow rate.

Estimating Power Output Using Steam Inlet and Exhaust Pressures



Example

A chemical company currently uses a 100-psig boiler with 78% boiler efficiency (E_1) to produce 50,000 lb/hr of saturated steam for process loads. The boiler operates at rated capacity for 6,000 hours per year (hr/yr). The boiler has reached the end of its service life, and the company is considering replacing the boiler with a new 100-psig boiler or with a high-pressure 600-psig boiler and a backpressure steam turbine-generator. Both new boiler alternatives have rated efficiencies (E_2) of 80%. The company currently pays $0.06/kWh for electricity, and purchases boiler fuel for $8.00 per million Btu (MMBtu). Condensate return mixed with makeup water has an enthalpy of 150 Btu/lb. What are the relative financial merits of the two systems?

Step 1: Calculate the current annual boiler fuel cost: $3,200,000 per year

Current Boiler Fuel Cost = Fuel Price x Steam Rate x Annual Operation x Steam Enthalpy Gain / E_1
= $8.00/MMBtu x 50,000 lb/hr x 6,000 hr/yr x (1,190 Btu/lb – 150 Btu/lb) / (0.78 x 10^6 Btu/MMBtu)
= $3,200,000 per year

Step 2: Calculate the boiler fuel cost of a new 100-psig, low-pressure (LP) boiler: $3,120,000 per year
Resulting reductions in fuel costs are due solely to the higher efficiency of the new boiler.

New LP Boiler Fuel Cost = Fuel Price x Steam Rate x Annual Operation x Steam Enthalpy Gain / E_2
= $8.00/MMBtu x 50,000 lb/hr x 6,000 hr/yr x (1,190 Btu/lb – 150 Btu/lb) / (0.80 x 10^6 Btu/MMBtu)
= $3,120,000 per year

Step 3: Calculate the boiler fuel cost of a new high-pressure (HP) boiler capable of producing 600 psig, 750ºF superheated steam: $3,318,300 per year
We must now take into account the additional enthalpy necessary to raise the pressure of the boiler steam to 600 psig. With a 50% isentropic turbine efficiency, the exhaust steam from the backpressure turbine is at 100 psig and 527ºF and must be desuperheated by adding 5,000 lb/hr of water. In order to provide an equivalent amount of thermal energy to the process loads, the boiler steam output is reduced to 45,000 lb/hr.

New HP Boiler Fuel Cost = Fuel Price x Steam Rate x Annual Operation x Steam Enthalpy Gain / E_2
= $8.00/MMBtu x 45,000 lb/hr x 6,000 hr/yr x (1,379 Btu/lb – 150 Btu/lb) / (0.80 x 10^6 Btu/MMBtu)
= $3,318,300 per year

Step 4: Estimate the electricity output of the steam turbine-generator: 6,750,000 kWh per year
At 600-psig inlet pressure with 750ºF superheated steam and 100-psig exhaust pressure, the system will satisfy existing steam loads but will also produce approximately 25 kW of electric power per Mlb-hr of steam production (you can use the figure on page 2 to estimate your power output for steam at saturated conditions). Thus,

Turbine-Generator Power Output = 45 Mlb-hr x 25 kW/Mlb-hr
= 1,125 kW

Assuming a 6,000-hr operating year, the electricity output of this turbine will be:

Turbine-Generator Electricity Output = 1,125 kW x 6,000 hr/yr
= 6,750,000 kWh/yr

Step 5: Determine the cost of electricity produced by the turbine: $0.029/kWh
The value is derived from the difference in fuel costs between the two boiler alternatives, divided by the power produced by the turbine:

Fuel Cost of Produced Electricity = ($3,318,300/yr – $3,120,000/yr) / 6,750,000 kWh/yr
= $0.029/kWh

Step 6: Calculate energy savings benefits: $209,250 per year

Cost Savings = 6,750,000 kWh x ($0.06/kWh – $0.029/kWh) = **$209,250/yr**

This level of savings is often more than adequate to justify the capital and maintenance expenditures for the backpressure turbine-generator set and the incremental cost of purchasing and installing the higher-pressure boiler.

Steam Tip Sheet information is adapted from material provided by TurboSteam Corporation. For additional information on steam system efficiency measures, refer to Steam Tip Sheet No. 20, Replace Pressure-Reducing Valves with Backpressure Turbogenerators*, and the 'Steam System Basics: End Use' section of* Improving Steam System Performance—A Sourcebook for Industry*, available online at www.eere.energy.gov/industry/bestpractices.*

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.

FOR ADDITIONAL INFORMATION, PLEASE CONTACT:

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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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