Energy Tips – Steam

Steam Tip Sheet #22 • September 2004

Industrial Technologies Program

Background

The capital cost of a back-pressure turbogenerator complete with electrical switchgear varies from about $700/kW for a small system (50 kW) to less than $200/kW for a larger system (>2,000 kW). Installation costs vary depending upon piping and wiring runs, but 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 lbs/hr, and when the steam pressure drop between the boiler and the distribution network is at least 100 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.

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. These materials are available from the EERE Information Center at 1-877-337-3463.*

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 turbo-generator 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.

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%-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%-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 3 cents/kWh. The electricity savings alone—not to mention ancillary benefits from enhanced on-site electricity reliability and reduced emissions of CO_2 and criteria pollutants—are often sufficient to completely recover the cost of the initial capital outlay in less than 2 years.

Estimating Your Savings

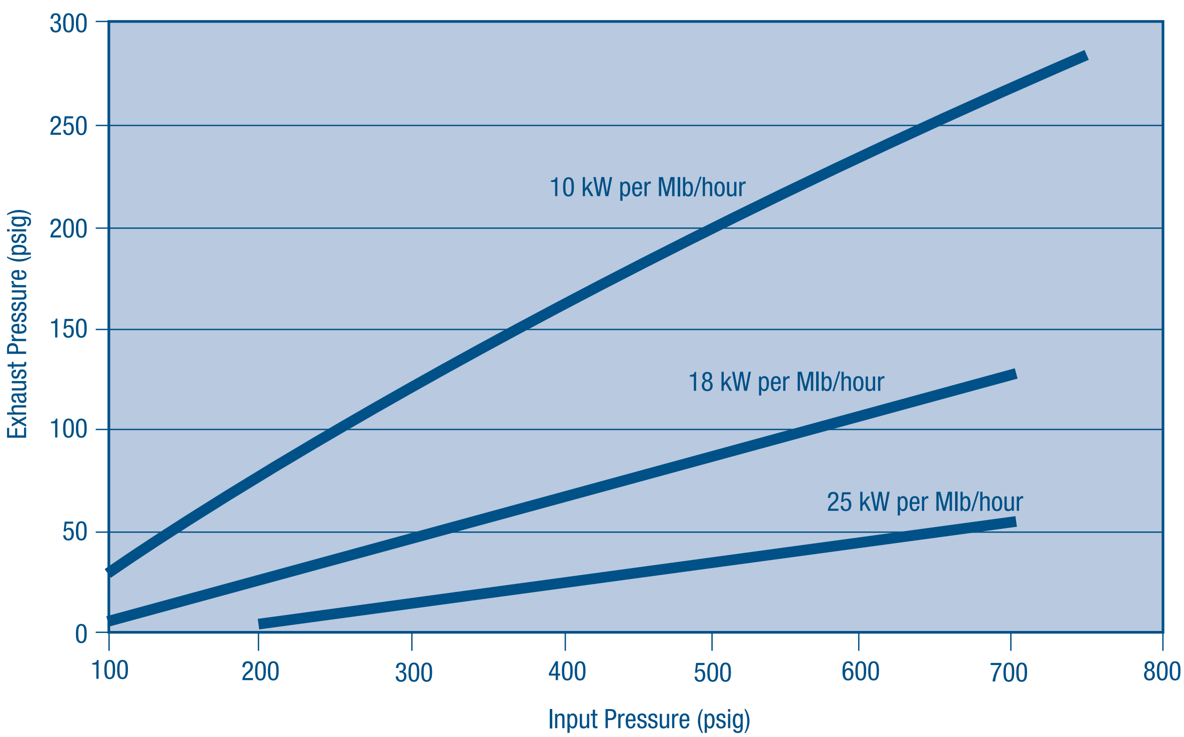
Since you have already determined that you need a boiler to satisfy your process thermal loads, the marginal cost of power produced from the backpressure turbine-generator is:

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/hour).

To estimate the potential power output of your system, refer to Figure 1, which shows lines of constant power output, expressed in kW of electricity output per Mlb/hour 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/hour 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.

Figure 1. Estimating Power Output Using Steam Inlet & Exhaust Pressures



Note: Assumes 50% isentropic turbine efficiency, a 96% efficient generator, and dry unsaturated inlet steam.

Example

A chemical company currently uses a 100-psig boiler with 78% boiler efficiency (ηboiler) to produce 50,000 pounds per hour (lb/hr) of saturated steam for process loads. The plant operates two shifts per day, with the boiler operating at rated capacity for 6,000 hours/year. 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 of 80%. The company currently pays 6 cents/kWh for electricity, and purchases boiler fuel for $5.00/MMBtu. Condensate return to the boiler 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 = $2,000,000 per year

Current boiler fuel cost
= [fuel price] x [steam rate] x [annual operation] x [steam enthalpy gain] / [ηboiler]
= $5.00/MMBtu x 50,000 lb/hr x 6,000 hrs/yr x (1,190 Btu/lb – 150 Btu/lb) /0.78
= $2,000,000 per year

Step 2: Calculate the boiler fuel cost of a new 100-psig low-pressure (LP) boiler = $1,950,000 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] / [ηboiler]
= $5.00/MMBtu x 50,000 lb/hr x 6,000 hrs/yr x (1,190 Btu/lb – 150 Btu/lb) /0.80
= $1,950,000 per year

Step 3: Calculate the boiler fuel cost of a new high-pressure (HP) boiler capable of producing 600-psig, 750ºF superheated steam = $2,073,940 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. In order to provide an equivalent amount of thermal energy to the process loads, the boiler steam output is reduced to 45,000 lbs/hour.

New HP boiler fuel cost
= [fuel price] x [steam rate] x [annual operation] x [steam enthalpy gain] / [ηboiler]
= $5.00/MMBtu x 45,000 lb/hr x 6,000 hrs/yr x (1,379 Btu/lb – 150 Btu/lb) / 0.80
= $2,073,940 per year

Step 4: Estimate the electricity output of the steam turbine-generator = 6,750,000 kWh/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/hour of steam production (Refer to Figure 1 to estimate your power output for steam at saturated conditions). Thus,

Turbine-generator power output = 45 Mlb/hour x 25 kW/Mlb/hour = 1,125 kW

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

Turbine-generator electricity output = 1,125 kW x 6,000 hours/year = 6,750,000 kWh/year

Step 5: Determine the cost of electricity produced by the turbine = $0.018/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
= [$2,073,940/year - $1,950,000/year] / 6,750,000 kWh/year
= $0.018/kWh

Step 6: Calculate energy savings benefits = $283,500 per year

Cost savings
= 1,125 kW x ($0.06/kWh – $0.018/kWh) x 6,000 hours per year
= $283,500 per year

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.

Suggested Actions

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

- Determine how much steam enthalpy, pressure and temperature is 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 purchasing and installing a high-pressure boiler plus a backpressure turbine-generator set.

About DOE's Industrial Technologies Program

The Industrial Technologies Program, through partnerships with industry, government, and non-governmental organizations, develops and delivers advanced energy efficiency, renewable energy, and pollution prevention technologies for industrial applications. The Industrial Technologies Program is part of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

The Industrial Technologies Program encourages industry-wide efforts to boost resource productivity through a strategy called Industries of the Future (IOF). IOF focuses on the following eight energy and resource intensive industries:

- Aluminum
- Forest Products
- Metal Casting
- Petroleum
- Chemicals
- Glass
- Mining
- Steel

The Industrial Technologies Program and its BestPractices activities offer a wide variety of resources to industrial partners that cover motor, steam, compressed air, and process heating systems. For example, BestPractices software can help you decide whether to replace or rewind motors (MotorMaster+), assess the efficiency of pumping systems (PSAT), compressed air systems (AirMaster+), steam systems (Steam Scoping Tool), or determine optimal insulation thickness for pipes and pressure vessels (3E Plus). Training is available to help you or your staff learn how to use these software programs and learn more about industrial systems. Workshops are held around the country on topics such as "Capturing the Value of Steam Efficiency," "Fundamentals and Advanced Management of Compressed Air Systems," and "Motor System Management." Available technical publications range from case studies and tip sheets to sourcebooks and market assessments. The Energy Matters newsletter, for example, provides timely articles and information on comprehensive energy systems for industry. You can access these resources and more by visiting the BestPractices Web site at **www.eere.energy.gov/ industry/bestpractices** or by contacting the EERE Information Center at **877-337-3463** or via email at **www.eere.energy.gov/informationcenter/.**

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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