Replace Pressure-Reducing Valves with Backpressure Turbogenerators

Many industrial facilities produce steam at a pressure higher than that demanded by process requirements. Steam passes through pressure-reducing valves (PRVs, also known as *letdown valves*) at various locations in the steam distribution system to let down or reduce its pressure. A non-condensing or backpressure steam turbine can perform the same pressure-reducing function as a PRV while converting steam energy into electrical energy.

In a backpressure steam turbogenerator, 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. The steam turbine does not consume steam. It simply reduces the pressure of the steam that is subsequently exhausted into the process header.

Cost-Effective Power Generation

In a conventional, power-only steam turbine installation, designers increase efficiency by maximizing the pressure drop across the turbine. Modern Rankine-cycle power plants with 1,800-pounds-per-square-inch-gauge (psig) superheated steam boilers and condensing turbines exhausting at near-vacuum pressures can generate electricity with efficiencies of approximately 40%.

Most steam users do not have the benefit of ultra-high-pressure boilers and cannot achieve such high levels of generation efficiency. However, by replacing a PRV with a backpressure steam turbine, where the exhaust steam is provided to a plant process, energy in the inlet steam can be effectively removed and converted into electricity. This means the exhaust steam has a lower temperature than it would have had if its pressure had been reduced through a PRV. In order to make up for this heat loss, steam plants with backpressure turbine installations increase their boiler steam throughput.

Thermodynamically, the steam turbine still behaves the same way that it would in a conventional Rankine-cycle power plant, achieving isentropic efficiencies of 20% to 70%. Economically, however, the turbine generates power at the efficiency of your particular steam boiler (modern steam boilers operate at approximately 80% efficiency), which then must be replaced with equivalent kilowatt-hours (kWh) of heat for downstream purposes. The resulting power generation efficiencies are well in excess of the average U.S. electricity grid generating efficiency of 33%. Greater efficiency means less fuel consumption; backpressure turbines can produce power at costs that are often less than $0.04/kWh.

Applicability

Packaged or "off-the-shelf" backpressure turbogenerators are now available in ratings as low as 50 kW. Backpressure turbogenerators should be considered when a PRV has constant steam flows of at least 3,000 pounds per hour (lb/hr), and when the steam pressure drop is at least 100 psi. The backpressure turbine is generally installed in parallel with the PRV.

Estimating Your Savings

To make a preliminary estimate of the cost of producing electrical energy from a backpressure steam turbine, divide your boiler fuel cost in dollars per million British Thermal Unit (Btu) ($8.00/MMBtu) by the product of your boiler efficiency (E_b, 80%) and electrical generator efficiency (E_g, 95%). Then convert the resulting number into cost per kWh, as shown in the sample calculation below:

Electricity Cost = Fuel Cost ($/MMBtu) x 0.003412 MMBtu/kWh / (E_b x E_g)

Example: ($8.00/MMBtu x 0.003412 MMBtu/kWh) / (0.80 x 0.95) = **$0.036/kWh**

To estimate the potential power output at a PRV, refer to the figure on page 2, which shows lines of constant power output, expressed in kW of electrical output per 1,000 pounds per hour (Mlb-hr) of steam throughput, as a function of turbine inlet and exhaust pressures. Look up your input and output pressure on the horizontal and vertical axes, and then use the reference lines to estimate the backpressure turbogenerator power output per Mlb-hr of steam flow. Then estimate the total installed generating capacity (kW) by multiplying this number by your known steam flow rate. The annual cost savings from the backpressure turbine can then be estimated as:

Power Output (kW) x Steam Duty (hr/yr) x (Cost of Grid Power – Cost of Generated Power, $/kWh)

Life and Cost of Backpressure Turbogenerators

Turbogenerators with electrical switchgear cost about $900/kW for a 150 kW system to less than $200/kW for a 2,000 kW system. Installation costs vary, but typically average 75% of equipment costs.

Backpressure steam turbines are designed for a 20-year minimum service life and are known for having low maintenance requirements.

Suggested Actions

Consider installing backpressure turbogenerators in parallel with PRVs when purchasing new boilers or if your boiler operates at a pressure of 150 psig or greater.

- Develop a current steam balance and actual process pressure requirements for your plant.
- Develop steam flow/duration curves for each PRV station.
- Determine plant electricity, fuel cost, and operating voltage.
- Consider either one centralized turbogenerator or multiple turbogenerators at PRV stations.

Resources

The U.S. Department of Energy'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 Industrial Technologies Program Web site at *www.industry.energy.gov* to access these and many other industrial efficiency resources and information on training.

节能措施——蒸汽系统

蒸汽系统内情报告20

用背压汽轮发电机替代减压阀

许多工业设施由于工艺的需要，产生出的蒸汽气压高于实际所需要的蒸汽气压。通过位于蒸汽分配系统中的减压阀（PRV），蒸汽气压得到降低。一个非冷凝或背压蒸汽涡轮机不仅可以像减压阀那样降低蒸汽的气压，还可以将蒸汽能源转换为电能。

在背压汽轮发电机中，当对涡轮的转轮直接喷射高压蒸汽时，会产生轴功率。该转轮与传动轴相连，而传动轴又与发电机相连。蒸汽涡轮机并不消耗蒸汽，它只是降低蒸汽压力，然后该蒸汽在工艺进程中得到利用。

符合成本效益的发电

在传统蒸汽涡轮机的设计中，工程师通过最大限度地降低蒸汽压力来提高能效。现代的朗肯循环发电厂——具有12,400千帕（即1800磅/平方英寸）的过热蒸汽锅炉和排出气压接近真空气压的冷凝涡轮机，它的发电效率可以达到约40%。

大多数的蒸汽系统都没有安装超高压锅炉，因此难以达到如此高的发电能效。但是，用背压蒸汽涡轮机替代减压阀，排出的蒸汽可以在工艺进程中得到利用，输入蒸汽中的能源可以有效地转换为电能。这意味着输出蒸汽的温度要比利用减压阀得到的温度还要低，因此背压汽轮发电机提高了蒸汽锅炉的生产能力。

从热力学的角度上看，蒸汽涡轮机的运行与传统朗肯循环发电机一样，实现20%到70%的等熵效率。但是，从经济的角度看，涡轮发电机根据工厂典型蒸汽锅炉（现代蒸汽锅炉的效率大约在80%左右）的效率发电，然后由于下游生产的需要，必须转换为等量的热力。最后得到的发电效率远高于美国电网平均的发电效率（即33%），而较高的发电效率就意味着较少的燃料消耗。背压汽轮发电机的发电成本通常低于0.27元/千瓦时（0.04美元/千瓦时）。

适用范围

成套的背压汽轮发电机最低的功率额定值为50千瓦。当减压阀的蒸汽气流稳定在至少每小时1.36吨（即每小时3000磅），蒸汽气压下降至少689千帕（即100psi）时，可以考虑背压汽轮发电机。通常来说，背压汽轮发电机与减压阀同时安装。

节省量估算

为了初步估算背压汽轮发电机的发电效率，可以用锅炉燃料成本（8美元/百万英制热量单位）除以锅炉效率（Eb, 80%）和发电机效率（Eg, 95%）的乘积，然后将结果转化为每千瓦时的成本消耗，如以下公式所示:

电力成本= 燃料成本（$美元/百万英制热量单位）× 0.003412百万英制热量单位/千瓦时 /（Eb x Eg）

示例:

（$8.00/百万英制热量单位 × 0.003412 百万英制热量单位/千瓦时）/（0.80 × 0.95）= $0.036/千瓦时

可以通过上表来估算减压阀的潜在输出功率。该表显示的是输出功率，单位为千瓦/每1000磅蒸汽-每小时，输出功率根据涡轮输入和排出气压而变化。根据工厂蒸汽系统的输入和输出压力，在横纵坐标上找到符合工厂情况的横线，从而来估算背压汽轮发电机的输出功率。然后将得出的输出功率和已知的蒸汽流量相乘，得到总安装发电容量（千瓦）。因此，背压汽轮发电机的年均成本节省量可以从以下的公式中得出:

输出功率（千瓦）× 蒸汽流量（每小时/每年）×（购电成本 – 发电成本，$美元/千瓦时）

背压汽轮发电机的使用寿命和成本

带有电气开关设备的背压汽轮发电机的成本大约是: $900美元/千瓦（对于150千瓦的系统）和$200美元/千瓦（对于2000千瓦的系统）。安装成本根据情况而定，但典型价格为设备成本的75%。 背压汽轮发电机的设计使用寿命至少为20年，对维护的要求也很低。

建议采取的行动

在购买新的锅炉时，或者工厂锅炉运行压力大于等于1033千帕（即150 磅/平方英寸）时，同时考虑安装背压汽轮发电机和减压阀。

- 建立有关目前现状的蒸汽平衡表，以及明确工厂实际蒸汽压力的要求。
- 对每个减压站建立蒸汽流量/历时曲线。
- 确定工厂电力、燃料消耗和工作电压。
- 考虑安装一个中央汽轮发电机，或考虑在减压站安装多个汽轮发电机。

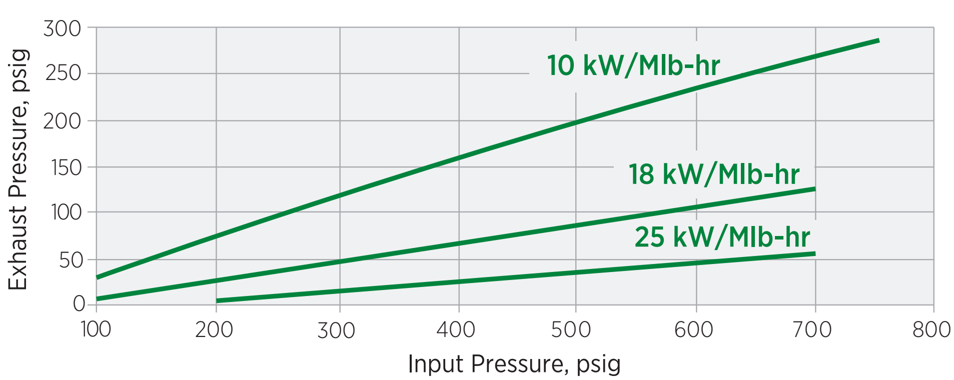
参考资料

美国能源部——美国能源部的“蒸汽系统评估工具和蒸汽系统调查工具”可以对蒸汽系统的评估和改进提供帮助。此外，如果想了解更多有关蒸汽系统节能机会的信息，请查询《提高蒸汽系统能效：工业资料读物》。

请访问美国能源部工业技术项目的网站*www.industry.energy.gov* 查询上述这些资料以及更多有关工业能效的资料，以及有关培训的信息。

Backpressure Turbogenerator Generating Potential, kW/Mlb-hr

背压汽轮发电机的发电潜力



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

注：纵坐标为排出气压(psig)，横坐标为输入压力(psig)。假定涡轮等熵效率为50%，发电机效率为96%和使用娜干饱和蒸汽。

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