

HOW TO MINIMIZE MAJOR AND MINOR LOSSES PIPE INSTALLATIONS SUPPORTING FOR FLUID WITH IMPROVE TRAP SYSTEM TO ACHIEVE INCREASING EFFICIENCY OF OUTPUT STEAM GENERATION

By :
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ABSTRACT

Steam system generation was very complexity, more than thousand installation and control one of the system was steam trap system, trap system installed in the trap discharge piping, visual inspection is the most positive method of testing Thermostatic Traps, and Traps modulate in operation. The discharge should be steady. Bucket Traps and Disc Traps cycle and the discharge should be intermittent. The trap is often discharging condensate above 212°F. When this high temperature condensate discharges to atmosphere flash steam may be present. Flash steam is normal and is not an indication of trap failure. Flash steam is a low velocity white colored discharge with a large stream of condensate. If the trap is blowing live steam it will be at high velocity—a clear area will be present ahead of where the steam begins to condense. Also steam trap must be applied and should meet the requirements of the highly competitive combined cycle (CC) power plant, steam turbines (STs)

FUNDAMENTALS OF STEAM POWER

Steam is a principle energy source for chemical industrial processes. It provides energy for process heating, pressure control, mechanical drives, and component separation, and is also a source of water for many industrial operations and chemical reactions. The popularity of steam as an energy source stems from its many advantages, which include low toxicity, transportability, high efficiency, high heat capacity, and low production costs relative to other energy transport mediums. [Steam Source Document DOE/A 1997 study by the Gas Research Institute indicates that throughout industry steam production has been the second-most energy-intensive of all process applications in manufacturing operations. According to Figure 1, steam production and steam process uses are responsible for the consumption of over 5 quadrillion Btus (quads) of energy within the manufacturing industry. Of this amount, the chemical industry consumes about 1.54 quads, or nearly 30% of the steam energy used by the industry.

The ability of steam to retain a significant amount of energy on a unit mass basis (between 1,000 and 1,250 Btu/lb) makes it ideal for use as an energy transport medium. Energy can be extracted from the steam in the form of mechanical work through a turbine or as heat for process heating. Since most of the heat contained in steam is in the form of latent heat, large quantities of energy can be transferred efficiently at a constant temperature, which is a useful attribute in many process-heating applications. Steam is also used in contact applications such as the reforming of natural gas for nitrogen fertilizer production

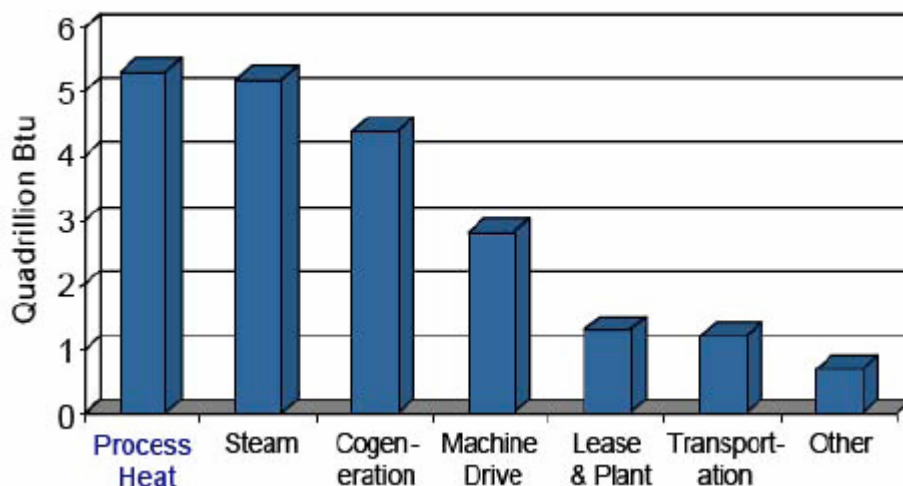


Figure 1 Industrial Energy Use by Process Application [GRI, 1997]

Natural gas is the dominant fuel source of process steam systems (Figure.2). Due to the increased volatility of the fossil fuel market, energy efficiency measures must be taken to ensure steam remains an economically favorable energy source in the future.

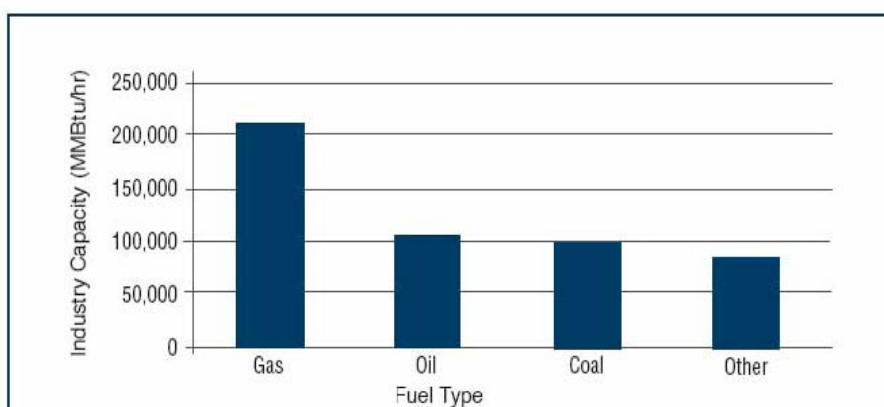


Figure2 Chemical Industry Boiler Capacity by Fuel Type [Steam Asses DOE]

Many manufacturing facilities have older, inefficient equipment. For them, applying energy efficiency measures known as best practices is the easiest way to realize energy savings. With the concurrent use of advanced technologies, new operating practices, and implementation of best practices, reductions of 20 to 30% in energy costs are possible [Steam Overview DOE].

1.2 Explanation of Use

In addition, process steam systems are used to control the pressures and temperatures of many chemical processes, and in applications such as stripping of contaminants, facilitating fractionation of hydrocarbons, and in certain drying operations. [Steam Source Document DOE] The configuration and operation of process steam systems used by chemical manufacturers are widely ranging. Many facilities do not disclose details of their systems, making it difficult to assess information and pass specific opportunities for savings on to others. This document will discuss four categories of process steam systems and then list best practices based that may be applied to nearly any process steam

system. Figure .3 represents a typical process steam operation used by a chemical manufacturer.

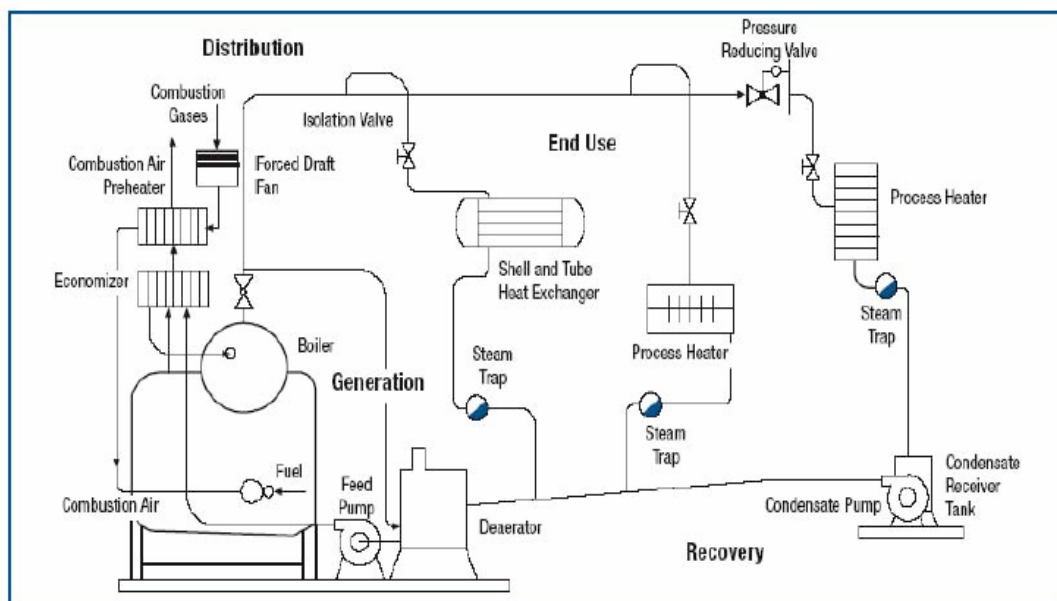


Figure 3 A Typical Process Steam System Schematic

A process steam system consists of the four categories listed below:

□ generation □ distribution □ end use □ recovery

1.3 Generation

Steam is normally generated in a boiler or waste heat recovery device by transferring heat from, hot combustion gases or other hot process streams to water. The water absorbs the heat, facilitating the phase change necessary to produce steam. The steam is then transferred under pressure from the boiler to the distribution system. In general, two types of boilers are used to generate steam.

□ **Firetube boilers**—Combustion gases pass through tubes, transferring heat to boiler water flowing over the tubes on the shell side. Benefits of this type of boiler include low initial costs as well as efficiency and durability. The boilers are limited, however, to lower pressure steam production temperatures, generally not exceeding 300 psig, due to the steam being contained in the shell.

□ **Watertube boilers**—Boiler water passes through tubes while hot gases contained on the shell side circulate over the outside of the tubes, transferring heat. The fact that the steam is contained in the tubes and not the shell allows for much higher pressure steam production, on the order of up to 3000 psig is practical. For this reason, and due to their high efficiency, watertube boilers are ideal for applications that require saturated or superheated steam, especially those applications insisting on dry, high pressure, high heat energy steam. About 60% of the steam produced in the chemical industry lies in the range of 300 to 1000 psig. [Steam Assess DOE]

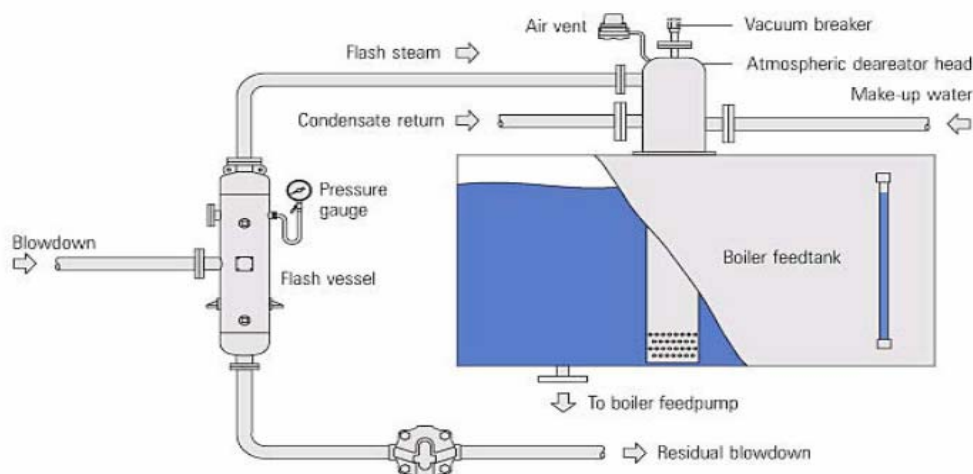


Figure 4. The two boiler types listed are both fuel-fired boilers; in addition, heat recovery waste heat recovery boilers (WHRB), heat recovery steam generators (HRSG), superheaters, and economizers are used in industry to generate steam.

1.4 Distribution

The distribution system is critical because it carries the pressurized steam produced in the boilers to the end-use operations. Systems often have numerous take-off lines that operate at different steam pressures, which are achieved by using isolation valves, pressure regulating valves, and, in some cases, back pressure turbines to separate take-off lines from the original headers. The goal of any distribution system is to deliver to the end-user sufficient quantities of steam at a specified temperature and pressure. An efficient system requires proper pressure balance and regulation, good condensate drainage, and proper insulation. [Steam Source DOE] Typical steam distribution system components include:

- piping
- proper insulation
- valves or turbines
- steam separators, accumulators, and traps

1.5 End Use

Steam end-use equipment transfers steam energy into other useful forms of energy that can then be used further in process applications. This document separates process steam end use operations into two categories: steam heat transfer and operational end uses. Steam heat transfer is explained that Specific Heat Transfer Operationse on operational end uses that perform applications based on the concept of heat transfer to receive a desired outcome. Table 5.1 lists some of the equipment that is used for process steam operational end uses.

PROCESS STEAM SYSTEMS

The chemical manufacturing industry depends heavily on steam for process applications. Given its prominence, it's discussed here in greater detail than other process heating operations. This chapter will focus on best practices in process heat systems; many of these practices yield highenergy savings for minimum initial capital investment.

Steam is a principle energy source for chemical industrial processes. It provides energy for process heating, pressure control, mechanical drives, and component separation, and is also a source of water for many industrial operations and chemical reactions. The popularity of steam as an energy source stems from its many advantages, which include low toxicity, transportability, high efficiency, high heat capacity, and low production costs relative to other energy transport mediums. [Steam Source Document DOE 1997 study by the Gas Research Institute indicates that throughout industry steam production has been the second-most energy-intensive of all process applications in manufacturing operations. The chemical manufacturing industry depends heavily on steam for process applications. Given its prominence, it's discussed here in greater detail than other process heating operations. This chapter will focus on best practices in process heat systems; many of these practices yield high energy savings for minimum initial capital investment.

MODERN STEAM ENGINE APPLICATIONS

Dispatched Operation

Most small scale power systems are envisioned as operating in a base loaded mode – running 24/7 and permanently removing the load from the grid. Where possible economically, this is a good application and serves to reduce the required capacity of the grid theoretically reducing the number of large power plants needed to support a power pool. It is increasingly obvious, however, that base loaded power plants lose money much of the time. Many power plants operate in a profitable mode only a few days a month³. This may be necessary for large fossil plants, but small scale operators facing daunting IRRs on their power projects need to consider operating in a dispatched mode – namely making power when it is economically smart to do so, and buying power when it is not. Without directly acknowledging it, the power pool is already accepting dispatched power from renewables – wind and solar are dispatched by “God.” There is no reason why clean or efficient power could not be handled in the same way. It is necessary to consider two broad types of dispatching. The first would be daily economic dispatching where a system might run only a few hours a day when “real time pricing” of electricity makes the spark spread favorable. In <1 MW situations, steam engines have many advantages. Design considerations in this case revolve around startup times and offload operations. Steam turbines have low torque at startup and are designed for full load operation. Steam engines have full torque at almost zero RPM making them ideal for systems with simple startup logic. Using new designs including steam buffers, the startup times and response to load changes can be as fast as a diesel engine. The second would be seasonal dispatching, where either the industrial operation is seasonal in nature (agribusiness being the best example), or with combined cycle operations where steam power is used when space heating is not needed. This is where the opening comment about sugar factories is connected to other applications. The seasonal nature of those production facilities combined with the use of waste or opportunities fuels (bagasse) leads to common use of steam engines. While anecdotal, there are observations that “a reciprocating steam engine is more commonly used in Indian sugar industry than a steam turbine or diesel generating set.”⁴ Indeed, while the low capital cost of steam engine power is a critical design consideration, long out-of-service times and the ability to start up easily after a long layoff make the decision obvious.

COMBINED CYCLE APPLICATIONS

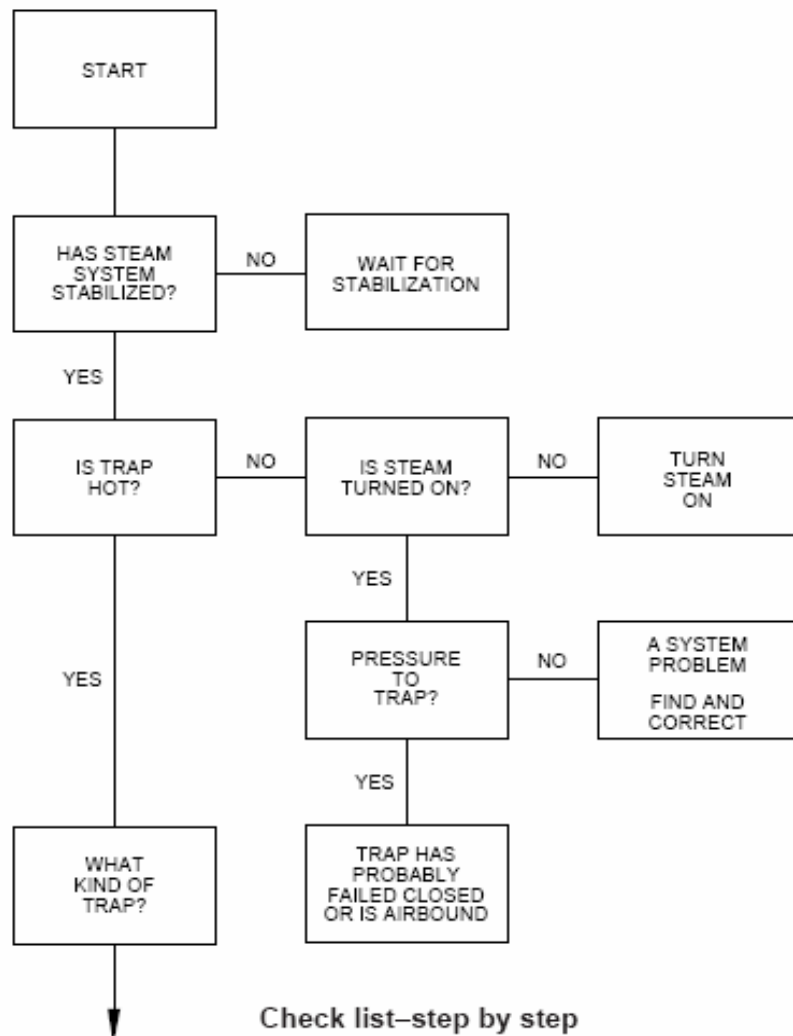
This application perhaps has the largest potential of those discussed in this paper.

Because of economies of scale, small gas turbine or IC engine cogen systems often do not use steam as a bottoming cycle during those times when waste heat cannot be used. In many cases waste heat is used for space heating in the winter only, leaving many months of the year when the system is operating only as a power source. This reduces the overall benefit of the CHP system. While it would be best to take power systems offline, such dispatching is often not economically viable. Hence systems operate while losing money and emitting more emissions than more efficient scenarios. Consider a common, well designed, CHP application such as a industrial campus. Waste heat may be used in the winter for space heating, in the summer in support of absorption refrigeration systems, but over the shoulder months, there is little to no waste heat needs. If the prime mover is 30% efficient and waste heat normally captures half of the waste heat, a typical CHP efficiency is calculated at 65%. But in reality, this is the maximum efficiency and for a significant fraction of the year the system only capitalizes on 30% of the energy consumed. While it is true that ideal applications have constant heat needs, allowing baseline operation and high efficiencies, the truth is that much of that potential has already been tapped. Continued market penetration of CHP requires novel system designs in applications with seasonal or periodic heating loads. In these cases, either nothing is installed, a system is put in place and operated only when profitable, or the system operates in base load mode losing money a significant amount of the time. A fourth possible outcome is to have a secondary use of the waste heat, in this case in a power cycle, as long as whatever the new prime mover is discharges heat at a lower temperature. The best candidate for this is a steam cycle which uses the wasteheat from the “topping” cycle to make steam, uses a turbine or an engine to get power from that energy, and then discharges the remaining heat at a temperature usually somewhere slightly above ambient. The thermodynamics that supports this model is very well established and is the basis for most combined cycle power plants. It is, however, rare to see such a combined cycle in CHP systems. The reasons for this have to do with both scale and economics – the steam turbines normally used in powerplants do not scale down in size for small power systems, and the costs usually do not make economic sense. This is especially true, because the bottoming cycle is only needed when waste heat cannot be otherwise utilized. A simple case was studied using a power cycle modeling software (Gatecycle) with a small gas turbine (Solar Saturn 20) with and without a steam bottoming cycle.

INCREASING EFFICIENCY OF STEAM TRAP

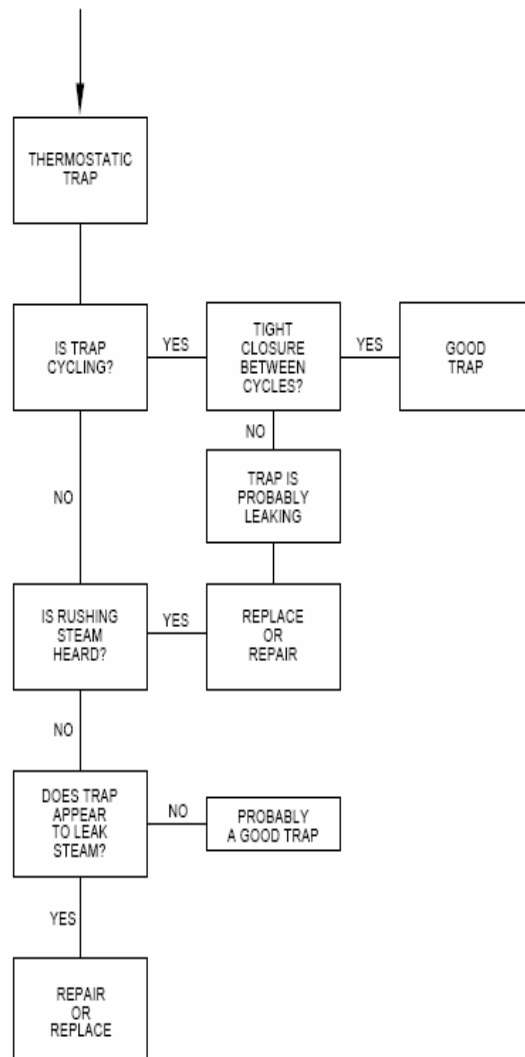
Where a test valve is installed in the trap discharge piping, visual inspection is the most positive method of testing Thermostatic Traps, and F & T Traps modulate in operation. The discharge should be steady. Bucket Traps and Disc Traps cycle and the discharge should be intermittent. The trap is often discharging condensate above 212°F. When this high temperature condensate discharges to atmosphere flash steam may be present. Flash steam is normal and is not an indication of trap failure. Flash steam is a low velocity white colored discharge with a large stream of condensate. If the trap is blowing live steam it will be at high velocity—a clear area will be present ahead of where the steam begins to condense. Then, a bluish steam will begin and there will be less condensate along with the steam. When no test valve is installed other methods may be used. When the piping ahead of the steam trap is cold, this is an indication that the trap has failed in a closed position. Temperature measuring devices may be used ball should seat.

If the trap is blowing live steam the ball will move inside the housing. Many independent trap survey companies will do field testing of traps. Due to the high cost of waste energy from defective steam traps, a trap survey normally has a good payback.



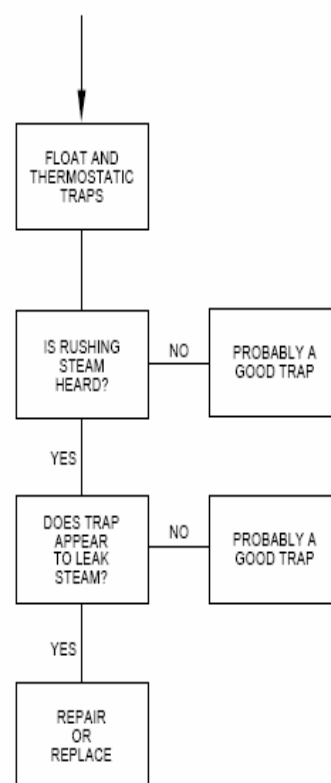
Thermostatic

- Modulates
- Discharges continuously.
- Sound test—rush of condensate, hiss of live steam.
- Visual—must distinguish between flash & live steam.



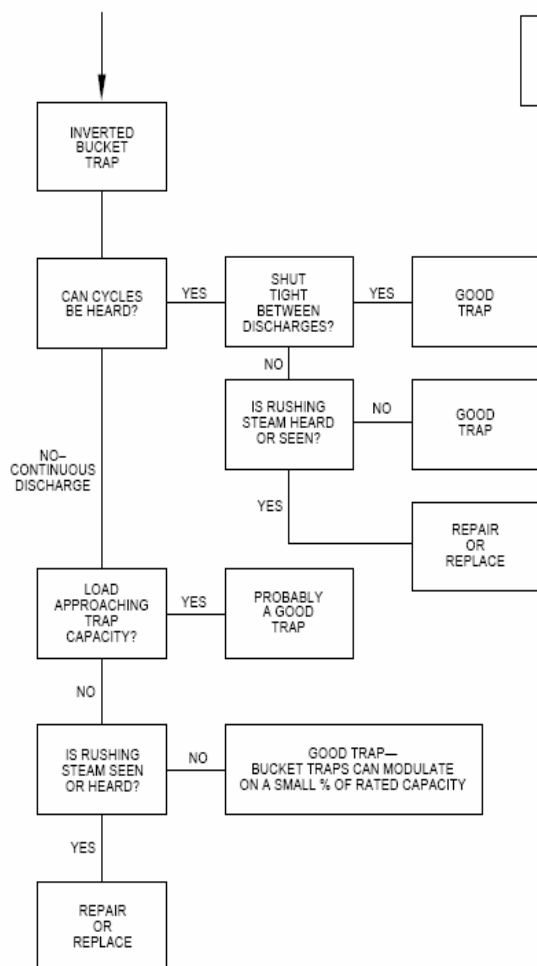
Float & Thermostatic

- Modulating device.
- Element passes air.
- More intense—for failed element passing steam.
- Orifice failure—erosion.
- Must distinguish between live steam & flash steam.
- Crushed ball—failure mode is closed.



Bucket Trap

- Discharges full capacity then shuts off.
- Muffled rattle of bucket on outer chamber.
- Violent bucket rattle & sound of rushing steam—lost prime.
- Clogged air vent—fails closed.
- Discharge under loads
 - Modulates under light load
 - Continuous discharge at full capacity.



Disc

- Best test is sound.
- Trap cycling is audible.
- Disc slams against seat.
- Leaking seat—would be heard.
- Rapid cycle—excessive wear.
- Machine gunning—live steam.

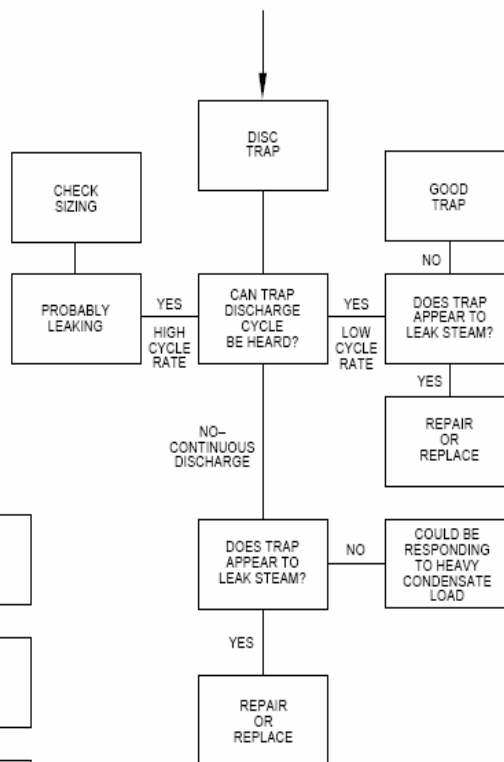


Figure 5 flowchart trap inspections

Condensate that collects ahead of a steam trap is approximately at saturation temperature and corresponds to the operating pressure. As the condensate (normally above 212°F.) drains into the return line, it must flash to reach saturation temperature at atmospheric pressure. The excess Btu's are released in the form of flash steam in the return

lines. The return lines must be sized to handle the volume of steam and condensate at reasonable velocities to minimize any backpressure. The volume of steam is normally several times the volume of condensate and is generally maintained at less than 7,000 feet per minute. The following tables are for horizontal return lines draining to a return system. Return lines should pitch 1 1/2 in. per 10 ft. of horizontal run. Select the return line size based on the steam operating pressure and the allowable p/L, psi/100 ft. Selections for 100 and 150 psig steam for either a vented return system or a 15 psig pressurized return system such as a flash tank, deaerator or closed return system.

Example: A condensate return system has a steam supply at 100 psig and the return line is at 0 psig and not vented. The return line is horizontal and must have a capacity of 2500 lbs./hr. What size pipe is required? **Solution:** Since the system will be throttling non-subcooled condensate from 100 psig to 0 psig there will be flash steam and the system will be a dry-closed return with horizontal pipe. Select a pressure drop of 1/4 psi/100 ft. and use a 2 1/2 in. pipe for this system.

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 \$4.50 per thousand pounds (\$/1,000 lbs), an inspection program indicates that a trap on a 150 psig steam line is stuck open. The trap orifice is 1/8 inch in diameter. The table shows the estimated steam loss as 75.8 lbs/hr. By repairing the failed trap, annual savings are:

Savings = 75.8 lbs/hr x 8,760 hrs/yr x \$4.50/1,000 lbs = \$2,988/yr

Leaking Steam Trap Discharge Rate				
Trap Orifice Diameter (inches)	Steam Loss (lbs/hr)			
	Steam Pressure (psig)			
	15	100	150	300
1/32	0.85	3.3	4.8	-
1/16	3.4	13.2	18.9	36.2
1/8	13.7	52.8	75.8	145
3/16	30.7	119	170	326
1/4	54.7	211	303	579
3/8	123	475	682	1,303

From the Boiler Efficiency Institute. Steam is discharging to atmospheric pressure.

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.

Clean Boiler Waterside Heat Transfer Surfaces

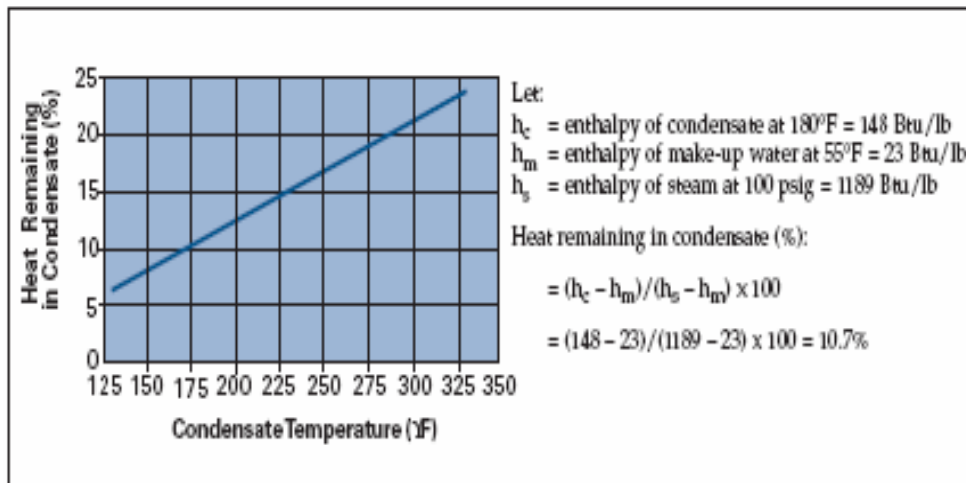
Even on small boilers, the prevention of scale formation can produce substantial energy savings. Scale deposits occur when calcium, magnesium, and silica, commonly found in most water supplies, react to form a continuous layer of material on the waterside of the boiler heat exchange tubes. Scale creates a problem because it typically possesses a

thermal conductivity an order of magnitude less than the corresponding value for bare steel. Even thin layers of scale serve as an effective insulator and retard heat transfer. The result is overheating of boiler tube metal, tube failures, and loss of energy efficiency. Fuel waste due to boiler scale may be 2% for water-tube boilers and up to 5% in fire-tube boilers. Energy losses as a function of scale thickness and composition are given in the table below.

A boiler annually uses 450,000 million Btu (MMBtu) of fuel while operating for 8,000 hours at its rated capacity of 45,000 pounds-per-hour (lbs/hr) of 150-psig steam. If scale 1/32nd of an inch thick is allowed to form on the boiler tubes, and the scale is of “normal” composition, the table indicates a fuel loss of 2%. The increase in operating costs, assuming energy is priced at \$3.00/MMBtu, is: **Annual Operating Cost Increase** = 450,000 MMBtu/year x \$3.00/MMBtu x 0.02 = **\$27,000**

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, make-up 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 make-up 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 psig, with make-up water at 55°F.



Consider a steam system that returns an additional 10,000 lbs/hr of condensate at 180°F due to distribution modifications. Assume this system operates 8,000 hours annually with an average boiler efficiency of 82%, and make-up water temperature of 55°F. The water and sewage costs for the plant are \$0.002/gal, and the water treatment cost is \$0.002/gal. The fuel cost is \$3.00 per Million Btu (MMBtu). Assuming a 12% flash steam loss*, calculate the overall annual savings.

Annual Water, Sewage, and Chemicals Savings = (1 – Flash Steam Fraction) x
 (Condensate Load in lbs/hr) x Annual Operating Hours x (Total Water Costs in \$/gal) ÷
 (Water Density in lbs/gal), (1 - 0.12) x 10,000 x 8,000 x \$0.004
 = = \$33,760

Annual Fuel Savings = (1 – Flash Steam Fraction) x (Condensate Load in lbs/hr) x
 Annual Operating Hours x (Makeup Water Temperature rise in °F) x (Fuel Cost in \$/Btu))
 ÷ Boiler Efficiency
 (1 - 0.12) x 10,000 x 8,000 x (180 – 55) x \$3.00
 = = \$32,1950.82 x 106

Total Annual Savings Due to Return of an Additional 10,000 lbs/hr of Condensate
 = \$33,760 + \$32,195 = **\$65,955**

FLASH HIGH-PRESSURE CONDENSATE TO REGENERATE LOW-PRESSURE STEAM

Low-pressure process steam requirements are usually met by throttling high-pressure steam, but a portion of the process requirements can be achieved at low cost by flashing high-pressure condensate. Flashing is particularly attractive when it is not economically feasible to return the high-pressure condensate to the boiler. In the table below, the quantity of steam obtained per pound of condensate flashed is given as a function of both condensate and steam pressures.

High-Pressure Condensate Flashing				
High-Pressure Condensate (psig)	Percent of Condensate Flashing, lb steam/lb condensate			
	Low-Pressure Steam (psig)			
	50	30	15	5
200	10.4	12.8	15.2	17.3
150	7.8	10.3	12.7	14.9
100	4.6	7.1	9.6	11.8
75	2.5	5.1	7.6	9.9

In a plant where the cost of steam is \$4.50 per million Btu (MMBtu), saturated steam at 150 pounds per square inch gauge (psig) is generated, and a portion of it throttled to supply 30-psig steam. Assuming continuous operation, determine the annual energy savings of producing low-pressure steam by flashing 5,000 pounds per hour of 150-psig condensate. The average temperature of the boiler make-up water is 70°F. From the table above, when 150-psig condensate is flashed at 30 psig, 10.3 percent of the condensate vaporizes.

Low-Pressure Steam Produced = 5,000 lbs/hr x 0.103 = **515 lbs/hr**

From the ASME Steam Tables, the enthalpy values are:

For 30-psig saturated steam = 1171.9 Btu/lb

For 70°F makeup water = 38.0 Btu/lb

Annual savings are obtained as follows:

Annual = 515 lb/hr x (1171.9–38.0) Btu/lb x 8,760 hours/year x \$4.50/MMBtu

Savings = \$23,019

Use Low-Grade Waste Steam to Power Absorption Chillers

Absorption chillers use heat, instead of mechanical energy, to provide cooling. The mechanical vapor compressor is replaced by a thermal compressor (see figure) that consists of an absorber, a generator, a pump, and a throttling device. The refrigerant vapor from the evaporator is absorbed by a solution mixture in the absorber. This solution is then pumped

to the generator where the refrigerant is revaporized using a waste steam heat source. The refrigerant-depleted solution is then returned to the absorber via a throttling device. The two most common refrigerant/absorbent mixtures used in absorption chillers are water/lithium bromide and ammonia/water.

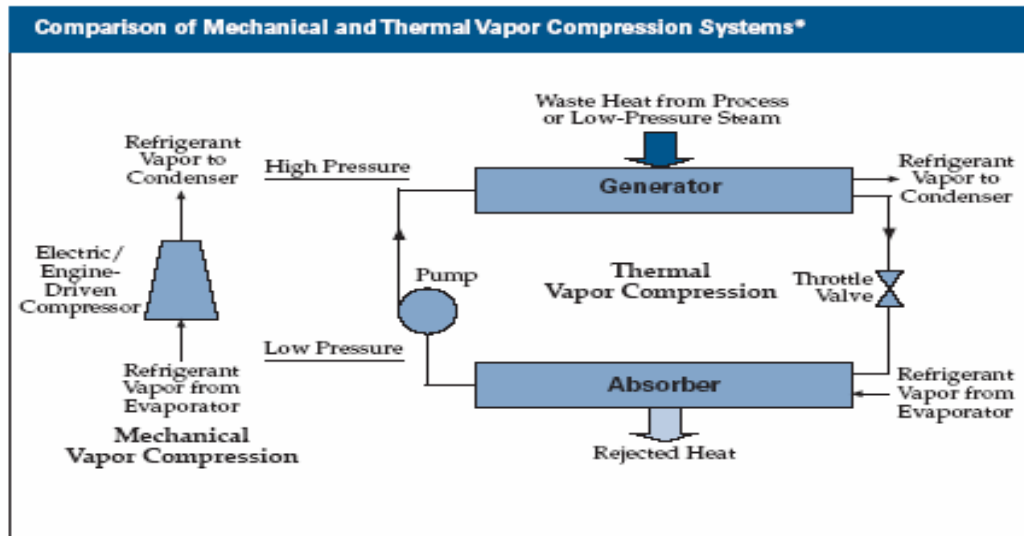


Figure 7. Power Absorption Chillers

Compared to mechanical chillers, absorption chillers have a low coefficient of performance ($COP = \text{chiller load/heat input}$). Nonetheless, they can substantially reduce operating costs because they are energized by low-grade waste heat, while vapor compression chillers must be motor- or engine-driven. Low-pressure, steam-driven absorption chillers are available in capacities ranging from 100 to 1,500 tons. Absorption chillers come in two commercially available designs: single-effect and double-effect. Single-effect machines provide a thermal COP of 0.7 and require about 18 pounds of 15-psig steam per ton-hour of cooling. Double-effect machines are about 40 percent more efficient, but require a higher grade of thermal input, using about 10 pounds of 100- to 150-psig steam per ton-hour. In a plant where low-pressure steam is currently being exhausted to the atmosphere, a mechanical chiller with a COP of 4.0 is used 4,000 hours per year to produce an average of 300 tons of refrigeration. The cost of electricity at the plant is \$0.05 per kilowatt-hour. An absorption unit requiring 5,400 lbs/hr of 15-psig steam could replace the mechanical chiller, providing annual electrical cost savings of:

Annual = 300 tons x (12,000 Btu/ton / 4.0) x 4,000 hrs/year x \$0.05/kWh x kWh/3,413 Btu
Savings = \$52,740

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 hp (1 hp = 33,475 Btu/hr) boiler with a cycle efficiency of 72.7% (E1) is replaced with a 600 hp boiler with a cycle efficiency of 78.8% (E2). Calculate the annual cost savings. Fractional Fuel Savings = $(1 - E1/E2)$
 $= (1 - 72.7/78.8) \times 100 = 7.7\%$

If the original boiler used 200,000 MMBtu of fuel annually, the savings from switching to the smaller boiler (given a fuel cost of \$3.00/MMBtu) are:

Annual Savings = 200,000 MMBtu $\times$ 0.077 $\times$ \$3.00/MMBtu = **\$46,200**

Install Removable Insulation on Uninsulated Valves and Fittings

During maintenance, insulation over pipes, valves, and fittings is often damaged or removed and not replaced. Uninsulated pipes, valves, and fittings 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 non-combustible inside cover, insulation material, and a non-combustible outside cover that is tear- and abrasion-resistant. Materials used in the pads are oil- and water-resistant and can be designed for temperatures up to 1600°F. The pads are held in place by wire laced through grommets or by using straps and buckles.

Applications

Reusable insulating pads are commonly used in industrial facilities for 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 difficult to access. Any high-temperature piping or equipment should be insulated to reduce heat loss, reduce emissions, and improve safety. As a rule of thumb, any surface over 120°F should be insulated for protection of 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 for noise control.

Example

Using the table above, calculate the annual fuel and dollar savings from a 2-inch thick insulating pad installed on an uninsulated 6-inch gate valve in a 250 psig saturated steam line (406°F). Assume continuous operation with natural gas at a boiler efficiency of 80% and a fuel price of \$3.00 per million Btu.

Annual Fuel Savings = 11,210 Btu/hr $\times$ 8760 hours $\times$ 1/0.80 = 122.75 MMBtu

Annual Dollar Savings = 122.75 MMBtu $\times$ \$3.00/MMBtu = **\$368**

per 6-inch gate valve

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.

Energy Savings (Btu/hr) from Using Removable Insulated Valve Covers ^{a,b}						
Operating Temperature, °F	Valve Size, inches					
	3	4	6	8	10	12
200	1,690	2,020	3,020	4,030	4,790	6,050
300	3,630	4,340	6,500	8,670	10,300	13,010
400	6,260	7,470	11,210	14,940	17,750	22,420
500	9,700	11,680	17,375	23,170	27,510	34,750
600	14,150	16,900	25,340	33,790	40,130	50,690

^a Based on 2-inches of insulation on 150 pound class flanged valves with an ambient temperature of 65°F.

^b From a personal communication and with permission from E.J. Bartells Co.

Using the table above, calculate the annual fuel and dollar savings from a 2-inch thick insulating pad installed on an uninsulated 6-inch gate valve in a 250 psig saturated steam line (406°F). Assume continuous operation with natural gas at a boiler efficiency of 80% and a fuel price of \$3.00 per million Btu.

Annual Fuel Savings = 11,210 Btu/hr x 8760 hours x 1/0.80 = 122.75 MMBtu

Annual Dollar Savings = 122.75 MMBtu x \$3.00/MMBtu = \$368 per 6-inch gate valve

Where a test valve is installed in the trap discharge piping, visual inspection is the most positive method of testing. Thermostatic Traps, and F & T Traps modulate in operation. The discharge should be steady. Bucket Traps and Disc Traps cycle and the discharge should be intermittent. The trap is often discharging condensate above 212°F. When this high temperature condensate discharges to atmosphere flash steam may be present. Flash steam is normal and is not an indication of trap failure. Flash steam is a low velocity white colored discharge with a large stream of condensate. If the trap is blowing live steam it will be at high velocity—a clear area will be present ahead of where the steam begins to condense. Then, a bluish steam will begin and there will be less condensate along with the steam. When no test valve is installed other methods may be used. When the piping ahead of the steam trap is cold, this is an indication that the trap has failed in a closed position. Temperature measuring devices may be used to test thermostatic traps. The temperature immediately ahead of the trap should be lower than the steam coil, radiator, etc. Listening devices may be used to test traps that cycle, these include Bucket Traps and Disc Traps. As the linkage or disc opens, a low pitch sound occurs as condensate discharges. The linkage or disc closing can then be heard. No other sound should follow. A trap blowing live steam will have a higher pitch whistle as steam blows across the orifice. F & T Traps modulate and discharge at saturation temperature. A fast response temperature scanner may be used to test operation. You will be looking for two-phase flow in the discharge line. Two-phase flow has steam in the discharge line and will be over 212° F. along the piping. Flash steam normally condenses in a short length of piping and will drop in temperature along the pipe.

Live steam carried through the pipe will maintain a near constant temperature. Where several traps are used in similar applications make a comparison between different trap discharge temperatures. You will soon be able to pick out a defective trap. Both a listening device and a temperature scanner should be available to spot trap problems. Sight checkers provide a positive way to check steam traps. A sight checker would be installed in the outlet piping from the trap. When the trap opens the ball check lifts off the seat. It can be seen moving inside the glass enclosure. When the trap closes the ball should seat. If the trap is blowing live steam the ball will move inside the housing. Many independent trap survey companies will do field testing of traps. Due to the high cost of waste energy from defective steam traps, a trap survey normally has a good payback.

Bucket Trap

- Discharges full capacity then shuts off.
- Muffled rattle of bucket on outer chamber.
- Violent bucket rattle & sound of rushing steam—lost prime.
- Clogged air vent—fails closed.
- Discharge under loads
 - Modulates under light load
 - Continuous discharge at full capacity.

Disc

- Best test is sound.
- Trap cycling is audible.
- Disc slams against seat.
- Leaking seat—would be heard.
- Rapid cycle—excessive wear.
- Machine gunning—live steam.

Air Valve: See Vent Valve.

Atmospheric Pressure: The weight of a column of air, one square inch in cross section and extending from the earth to the upper level of the blanket of air surrounding the earth. This air exerts a pressure of 14.7 pounds per square inch at sea level, where water will boil at 212°F. High altitudes have lower atmospheric pressure

with correspondingly lower boiling point temperatures. **Boiler:** A closed vessel in which steam is generated or in which water is heated by fire. **Boiler Heating Surface:** The area of the heat transmitting surfaces in contact with the water (or steam) in the boiler on one side and the fire or hot gases on the other. **Boiler Horsepower:** The equivalent evaporation of 34.5 lbs. of water per hour at 212° F. to steam at 212° F. This is equal to a heat output of 33,475 Btu per hour, which is equal to approximately 140 sq. ft. of steam radiation (EDR) . **British Thermal Unit (Btu):** The quantity of heat required to raise the temperature of 1 lb. of water 1°F. This is somewhat approximate but sufficiently accurate for any work discussed in this book.

Bucket Trap (Inverted): A float trap with an open float. The float or bucket is open at the bottom. When the air or steam in the bucket has been replaced by condensate the bucket loses its buoyancy and when it sinks it opens a valve to permit condensate to be pushed into the return. **Bucket Trap (Open):** The bucket (float) is open at the top. Water surrounding the bucket keeps it floating and the pin is pressed against its seat. Condensate from the system drains into the bucket. When enough has drained into it so that the bucket loses its buoyancy it sinks and pulls the pin off its seat and steam pressure forces the condensate out of the trap. **Calorie (Small):** The quantity of heat required to raise 1 gram of water 1°C (approx.). **Calorie (Large):** The quantity of heat required to raise 1 kilogram of water 1°C (approx.). **Centigrade:** A thermometer scale at which the freezing point of water is 0° and its boiling is 100°. **Central Fan System:** A mechanical indirect system of heating, ventilating, or air conditioning consisting of a central plant where the air is heated and/or conditioned and then circulated by fans or blowers through a system of distributing ducts. **Chimney Effect:** The tendency in a duct or other vertical air passage for air to rise when heated due to its decrease in density.

Backpressure.

Coefficient of Heat Transmission (Over-all)-U-: The amount of heat (Btu) transmitted from air to air in one hour per square foot of the wall, floor, roof, or ceiling for

a difference in temperature of one degree Fahrenheit between the air on the inside and outside of the wall, floor, roof, or ceiling. Column Radiator: A type of direct radiator. This radiator has not been sold by manufacturers since 1926. Comfort Line: The effective temperature at which the largest percentage of adults feel comfortable. Comfort Zone (Average): The range of effective temperatures over which the majority of adults feel comfortable. Concealed Radiator: See Convector. Condensate: Water formed by cooling steam. The capacity of traps, pumps, etc., is sometimes expressed in lbs. of condensate they will handle per hour. One pound of condensate per hour is equal to approximately 4 sq. ft. of steam heating surface (240 Btu per hour per sq. ft.). Conductance (Thermal)-C-: The amount of heat (Btu) transmitted from surface to surface, in one hour through one square foot of a material or construction for the thickness or type under consideration for a difference in temperature of one degree Fahrenheit between the two surfaces. Conduction (Thermal): The transmission of heat through and by means of matter. Conductivity (Thermal)-k-: The amount of heat (Btu) transmitted in one hour through one square foot of a homogenous material one inch thick for a difference in temperature of one degree Fahrenheit between the two surfaces of the material. Conductor (Thermal): A material capable of readily transmitting heat by means of conduction. Convection: The transmission of heat by the circulation (either natural or forced) of a liquid or a gas such as air. If natural, it is caused by the difference in weight of hotter and colder fluid. Convector: A concealed radiator. An enclosed heating unit located either within, adjacent to, or exterior to the room or space to be heated, but transferring heat to the room or space mainly by the process of convection. A shielded heating unit is also termed a convector. If the heating unit is located exterior to the room or space to be heated, the heat is transferred through one or more ducts or pipes. Converter: A piece of equipment for heating water with steam without mixing the two. It may be used for supplying hot water for domestic purposes or for a hot water heating system.

Cooling Leg: A length of uninsulated pipe through which the condensate flows to a trap and which has sufficient cooling surface to permit the condensate to dissipate enough heat to prevent flashing when the trap opens. A thermostatic trap may require a cooling leg to permit the condensate to drop enough in temperature to permit the trap to open.

Float & Thermostatic Trap:

A float trap with a thermostatic element for permitting the escape of air into the return line. Float Trap: A steam trap which is operated by a float. When enough condensate has drained (by gravity) into the trap body the float is lifted. In turn, the pin lifts off its seat. This permits the condensate to flow into the return until the float has been sufficiently lowered, to close the port. Temperature does not affect the operation of a float trap. Furnace: That part of a boiler or warm air heating plant in which combustion takes place. Complete heating unit of a warm air heating system.

Gauge Pressure: The pressure above that of the atmosphere. It is the pressure indicated on an ordinary pressure gauge. It is expressed as a unit pressure such as lbs. per sq. in. gauge. Head: Unit pressure usually expressed in ft. of water or mil-inches of water. Heat: That form of energy into which all other forms may be changed. Heat always flows from a body of higher temperature to a body of lower temperature. See also: Latent Heat, Sensible Heat, Specific Heat, Total Heat, Heat of the Liquid. Heat of the Liquid: The heat (Btu) contained in a liquid due to its temperature. The heat of the liquid for water is zero at 32° F. and increases 1 Btu approximately for every degree rise in temperature. Heat Unit: In the foot-pound-second system, the British Thermal Unit (Btu) in the centimeter-gram-second system, the calorie (cal.). Heating Medium: A substance such as water, steam,

or air used to convey heat from the boiler, furnace, or other source of heat to the heating units from which the heat is dissipated. Heating Surface: The exterior surface of a heating unit. See also Extended Heating Surface. Heating Unit: Radiators, convectors, base boards, finned tubing, coils embedded in floor, wall, or ceiling, or any device which transmits the heat from the heating system to the room and its occupants.

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. In a plant where the value of steam is \$4.50 per thousand pounds (\$/1,000 lbs), an inspection program indicates that a trap on a 150 psig steam line is stuck open. The trap orifice is 1/8 inch in diameter. The table shows the estimated steam loss as 75.8 lbs/hr.

By repairing the failed trap, annual savings are:

$$\text{Savings} = 75.8 \text{ lbs/hr} \times 8,760 \text{ hrs/yr} \times \$4.50/1,000 \text{ lbs} = \$2,988/\text{yr}$$

CONCLUSION & SUMMARY

1. Cost-Effective Power Generation aspect

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 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. Thermodynamically, the steam turbine still behaves the same way as it would in a conventional Rankine power cycle, achieving isentropic efficiencies of 20 to 70 percent.

2. Suggested Actions

Steam traps are tested primarily to determine whether they are functioning properly and not allowing live steam to blow through. Establish a program for the regular systematic inspection, testing, and repair of steam traps. Include a reporting mechanism to ensure thoroughness and to provide a means of documenting energy and dollar savings. 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.

Economically the turbine generates power at the efficiency of your steam boiler (modern steam boilers operate at approximately 80 percent efficiency), which then must be replaced with an equivalent 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 percent. Greater efficiency means less fuel consumption; backpressure turbines can produce power at costs that are often less than 3 cents/kWh. Energy savings are often sufficient to completely recover the cost of the initial capital outlay in less than 2 years.

This paper describes modern STs in all phases of a CC project: from the initial selection through construction, startup, and testing. The STs include all the major manufacturers, such as Alstom, GE, Mitsubishi, Siemens Westinghouse, and Toshiba, in several CC configurations. The paper presents several CC projects that have been completed or are in advanced stages of construction. These projects employ the new generation of GTs and STs.

CYCLE SELECTION AND OPTIMIZATION

In the last 10 years, STs in CC applications have had to evolve significantly, from small 80 MW dual admission nonreheat configurations to multiple-pressure-admission reheat turbines with outputs reaching the 350 MW range. Because of this rapid evolution, many original small turbine designs have had to be modified or adjusted to compete in performance and capacity. Significant basic differences exist between STs designed for CCs and conventional anking cycle (RC) applications.

This approach allows the EPC contractor to build a plant that best suits the owner's operating goals. A single ST for multiple GTs is less costly than a separate ST for each GT. However, multiple 1 x 1 configuration trains offer some significant advantages, as outlined below.

- ☐ Phased construction flexibility. Owners can add units as dictated by market conditions.
- ☐ Speed to market. As the construction duration of a 1 x 1 configuration is shorter than a 3 x 1 configuration, the first train can be brought on line more quickly and start generating revenues, while the remaining units are still undergoing construction.
- ☐ Closer matching with dispatch demand. A site with multiple 1 x 1 trains using supplemental duct firing can better and more efficiently match dispatch requirements.
- ☐ Greater plant redundancy. Each unit is completely redundant.
- ☐ Optimized spare parts inventory. Identical components are used for all trains.

STEAM PATH OPTIMIZATION AND SECTIONS

While ST design is a mature technology, manufacturers continue to improve the output and efficiency of their equipment through improved blade designs and superior materials to accommodate higher main and reheat steam temperatures. Computational fluid dynamics (CFD) techniques coupled with rig and field tests have been extensively applied to develop three-dimensional blades, vanes, and passages. Competitive

EQUIPMENT SELECTION

Before selecting equipment from different suppliers, a thorough investigation is necessary to ensure that the owner's pro forma objectives are met for power output, heat rate, startup times, reliability and availability, etc.

The process includes an independent technology assessment of the equipment's operating history and quality control for the engineering and manufacturing processes. In addition, the performance offered by the original equipment manufacturers (OEMs) for a specific project is normalized and reconciled with past performance of the same equipment in a

similar configuration, as achieved on other projects. Bechtel maintains a performance database of all past projects that is routinely updated with information from field tests. Special consideration is given to cogeneration plants where selection of cycle pressures and locations of the steam extractions is limited by the commercial availability of STs that can meet the full range of specified conditions. Another decision needed on most cogeneration projects involves the ability to cold start the ST while the plant continues to supply full process steam requirements to the host. At the other extreme, it is also critical to determine whether to design the ST and associated steam cycle equipment for the maximum steam case when no steam is required for the process. In this scenario, a larger LP section and an increased capacity for downstream electrical equipment (transformer, isophase bus, etc.) are required. In making the selection, careful consideration should be given to economic benefits to be realized from the availability of the extra power and operational constraints due to possibly infrequent occurrences of such conditions (Ref 2). Equipment selection requires the unique expertise and value-added service that only an experienced EPC contractor can provide to the customer.

EVALUATION OF THE EXHAUST SYSTEM: (AXIAL, DOWNWARD, OR LATERAL)

With the high LP flows associated with CC STs, greater emphasis is placed on the last-stage blade (LSB) dimensions and material. One of the major loss mechanisms in the ST is the kinetic energy of the steam as it leaves the LSBs—the lower the kinetic energy that can be achieved, the higher the resulting ST efficiency. The amount of loss is proportional to the ratio of the volumetric steam flow rate through the LSBs and the annular area of the turbine exit. To decrease this loss, a larger turbine exit annulus is required (Ref 4). Numerous challenges face designers, who must marry complex 3D aerodynamic designs with robust mechanical features in this erosion-prone environment. One typical example deals with aeroelastic instability, which is one of the more challenging design problems for very large LSBs. The axial exhaust design is preferred because of its superior thermodynamic performance through lower pressure losses, greater pressure recovery in the diffuser, and simpler and less expensive construction. Because of the compact design and lower elevation, the capital cost of the ST and the associated turbine building can be reduced by 40 percent over using a double flow LP module with a bottom exhaust arrangement (Ref 1).

REFERENCES AND FOOTNOTES

- “Consensus Operating Practices for Control of Feedwater/Boiler Water Chemistry in Modern Industrial Boilers”, published by the ASME, 1994.
- “Recommended Rules for the Care and Operation of Heating Boilers”, Section VI of the ASME Boiler and Pressure Vessel Code, 1995.
- “Recommended Guidelines for the Care of Power Boilers”, Section VII of the ASME Boiler and Pressure Vessel Code, 1995.
- Energy Conversion, Kenneth C. Weston, December 2000
- Improving Steam System Performance, a sourcebook for industry The United States Department of Energy Office of Industrial Technologies Prepared by: Lawrence Berkeley National Laboratory Washington, DC Resource Dynamics Corporation Vienna, VA
- Written schemes of examination INDG178(rev1) HSE Books, 2002
- Pressure Equipment Regulations 1999 (SI 1999 No 2001), The Stationery Office.