FEDERAL TECHNOLOGY ALERTS

(Photo courtesy of TLV Corporation)

Steam Trap Performance Assessment

Advanced technologies for evaluating the performance of steam traps

Abstract

Various types of performance assessment equipment can be used as part of a proactive steam trap maintenance program to significantly reduce energy losses in steam distribution systems. Approximately 20% of the steam leaving a central boiler plant is lost via leaking traps in typical space heating systems without proactive maintenance programs.[1] Relatively simple equipment and programs can easily cut losses in half. Intermediate equipment and programs can cut losses in half again. The best equipment and programs can reduce losses to less than 1%.[2]

The potential impact in the Federal sector is enormous. In the Army alone, the annual savings associated with implementing intermediate steam trap performance assessment equipment and programs are estimated to be about $20 million. Based on investment costs of only $8 million, the average payback period is less than half a year. The total present value of savings over a 25-year period was estimated to be about $200 million. Department of Defense (DoD) and Federal sector impacts are probably about three and four times as great, respectively, as the Army impacts.

Steam trap performance assessment has traditionally been based on three basic methods: sight, sound, and temperature. This *Federal Technology Alert* focuses on ultrasonic sound measurement equipment and equipment utilizing a fourth method based on conductivity. A sight glass specifically designed for steam trap performance assessment is also included.

The first two sections present background material that describes the basic types of steam traps and performance assessment methods. The next section describes the technologies included in this *Federal Technology Alert* in more detail. Subsequent sections describe how to use the technologies and the experiences of Federal sector users. Details regarding development of the Army impacts noted above and the results of a specific program initiated at three Veterans Administration hospitals are also documented. Finally, Appendix A provides detailed information on manufacturers and their products, and Appendix B gives Federal life-cycle costing procedures.

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About the Technology

The focus of this *Federal Technology Alert* (FTA) is on advanced technologies for evaluating the performance or working condition of steam traps. However, prior to discussing techniques and equipment for evaluating steam traps, a brief overview of steam trap functions, designs, and operating characteristics is provided. At least a rudimentary understanding of steam trap principles is necessary to understand how the various evaluation approaches work and why some are more likely to produce a better evaluation than others. Those not familiar with steam traps are also referred to several references listed at the end of this FTA that provide a more detailed discussion.

Steam Trap Overview

Steam traps are automatic valves used in every steam system to remove condensate, air, and other non-condensable gases while preventing or minimizing the passing of steam. If condensate is allowed to collect, it reduces the flow capacity of steam lines and the thermal capacity of heat transfer equipment. In addition, excess condensate can lead to "water hammer," with potentially destructive and dangerous results. Air that remains after system startup reduces steam pressure and temperature and may also reduce the thermal capacity of heat transfer equipment. Non-condensable gases, such as oxygen and carbon dioxide, cause corrosion. Finally, steam that passes through the trap provides no heating service. This effectively reduces the heating capacity of the steam system or increases the amount of steam that must be generated to meet the heating demand.

The objective of the steam trap is not an easy task and condensate pressures and flow rates vary significantly at various points in a steam distribution system. As a result, many different types of steam traps have been developed. Steam traps are commonly classified by the physical process causing them to open and close. The three major categories of steam traps are 1) mechanical, 2) thermostatic, and 3) thermodynamic. In addition, some steam traps combine characteristics of more than one of these basic categories.

The operation of a mechanical steam trap is driven by the difference in density between condensate and steam. The denser condensate rests on the bottom of any vessel containing the two fluids. As additional condensate is generated, its level in the vessel will rise. This action is transmitted to a valve via either a "free float" or a float and connecting levers in a mechanical steam trap. One common type of mechanical steam trap is the inverted bucket trap, shown in Figure 1. Steam entering the submerged bucket causes it to rise upward and seal the valve against the valve seat. As the steam condenses inside the bucket or if condensate is predominately entering the bucket, the weight of the bucket will cause it to sink and pull the valve away from the valve seat. Any air or other non-condensable gases entering the bucket will cause it to float and the valve to close. Thus, the top of the bucket has a small hole to allow non-condensable gases to escape. The hole must be relatively small to avoid excessive steam loss.

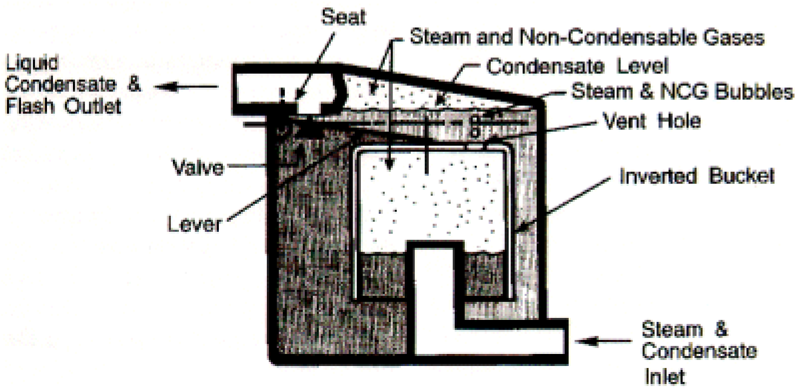

Figure 1. Inverted bucket steam trap.
(Illustration courtesy of Yarway Corporation)

As the name implies, the operation of a thermostatic steam trap is driven by the difference in temperature between steam and sub-cooled condensate. Valve actuation is achieved via expansion and contraction of a bimetallic element or a liquid-filled bellows. Bimetallic and bellows thermostatic traps are shown in Figures 2 and 3. Although both types of thermostatic traps close when exposure to steam expands the bimetallic element or bellows, there are important differences in design and operating characteristics. Upstream pressure works to open the valve in a bimetallic trap, while expansion of the bimetallic element works in the opposite direction. Note that changes in the downstream pressure will affect the temperature at which the valve opens or closes. In addition, the nonlinear relationship between steam pressure and temperature requires careful design of the bimetallic element for proper response at different operating pressures. Upstream and downstream pressures have the opposite effect in a bellows trap; an increase in upstream pressure tends to close the valve and vice versa. While higher temperatures still work to close the valve, the relationship between temperature and bellows expansion can be made to vary significantly by changing the fluid inside the bellows. Using water within the bellows results in nearly identical expansion as steam temperature and pressure increase, because pressure inside and outside the bellows is nearly balanced.

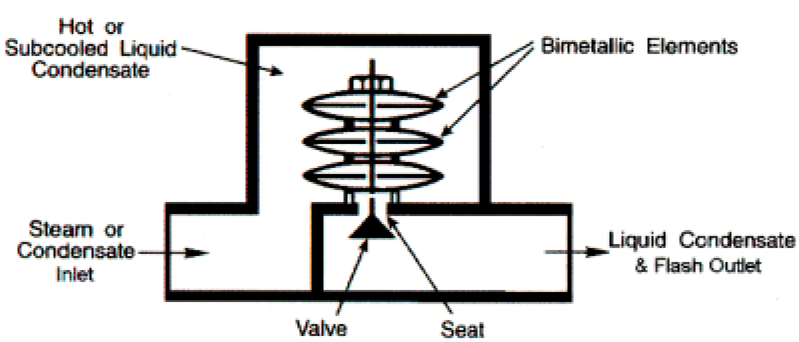

Figure 2. Bimetallic steam trap.
(Illustration courtesy of Yarway Corporation)

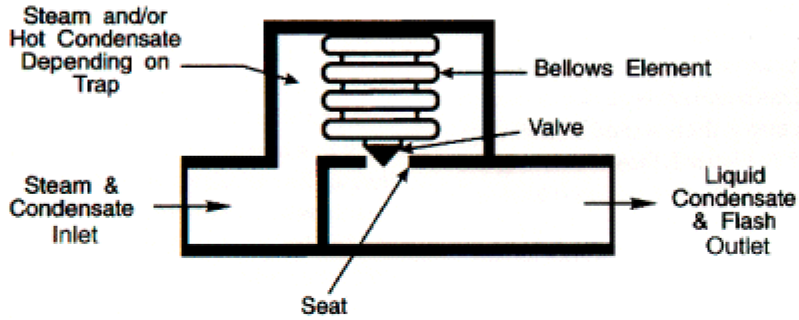

Figure 3. Bellows steam trap.

(Illustration courtesy of Yarway Corporation)

In contrast to the inverted bucket trap, both types of thermostatic traps allow rapid purging of air at startup. The inverted bucket trap relies on fluid density differences to actuate its valve. Therefore, it cannot distinguish between air and steam and must purge air (and some steam) through a small hole. A thermostatic trap, on the other hand, relies on temperature differences to actuate its valve. Until warmed by steam, its valve will remain wide open, allowing the air to easily leave. After the trap warms up, its valve will close, and no continuous loss of steam through a purge hole occurs. Recognition of this deficiency with inverted bucket traps or other simple mechanical traps led to the development of float and thermostatic traps. The condensate release valve is driven by the level of condensate inside the trap, while an air release valve is driven by the temperature of the trap. A float and thermostatic trap is shown in Figure 4.

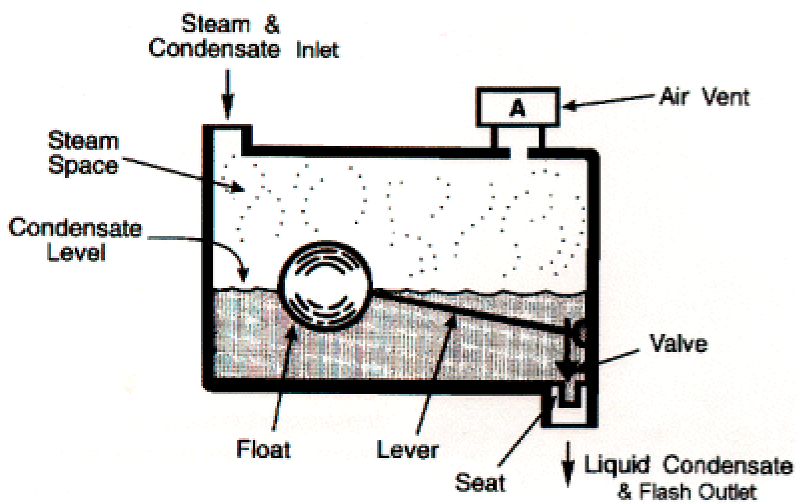

Figure 4. Float and thermostatic steam trap.

(Illustration courtesy of Yarway Corporation)

Thermodynamic trap valves are driven by differences in the pressure applied by steam and condensate, with the presence of steam or condensate within the trap being affected by the design of the trap and its impact on local flow velocity and pressure. Disc, piston, and lever designs are three types of thermodynamic traps with similar operating principles; a disc trap is shown in Figure 5. When subcooled condensate enters the trap, the increase in pressure lifts the disc off its valve seat and allows the condensate to flow into the chamber and out of the trap. The narrow inlet port results in a localized increase in velocity and decrease in pressure as the condensate flows through the trap, following the 1st law of thermodynamics and the Bernoulli equation. As the condensate entering the trap increases in temperature it will eventually flash to steam because of the localized pressure drop just described. This increases the velocity and decreases the pressure even further, causing the disc to snap closed against the seating surface. The moderate pressure of the flash steam on top of the disc acts on the entire disc surface, creating a greater force than the higher pressure steam and condensate at the inlet, which acts on a much smaller portion of the opposite side of the disc. Eventually, the disc chamber will cool, the flash steam will condense, and inlet condensate will again have adequate pressure to lift the disc and repeat the cycle.

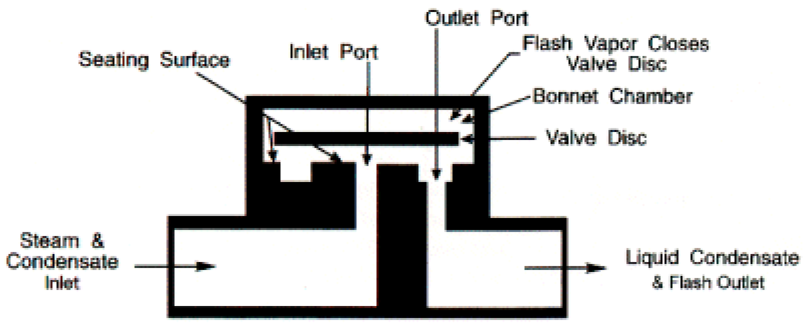

Figure 5. Disc steam trap.
(Illustration courtesy of Yarway Corporation)

Performance Assessment Methods

Steam trap performance assessment is basically concerned with answering the following two questions:

1. Is the trap working correctly or not?
2. If not, has the trap failed in the open or closed position?

Traps that fail open result in a loss of steam and its energy. Where condensate is not returned, the water is lost as well. The result is significant economic loss, directly via increased boiler plant costs, and potentially indirectly, via decreased steam heating capacity. Traps that fail closed do not result in energy or water losses, but can result in significantly reduced heating capacity and/or damage to steam heating equipment.

***There are three basic methods for evaluating a steam trap that are commonly discussed in the literature: sight, sound, and temperature*.** The three are discussed below in the general order of reliability. At least two of the three methods should be used to increase the chances of correctly identifying the condition of a steam trap. ***A less commonly discussed method is based on fluid conductivity*.** Although this method should be at least as reliable as sonic-based methods, it is discussed less frequently in the literature, and no general consensus on its relative reliability was evident.

Sight Method

The sight method is usually based on a visual observation of the fluid downstream of the trap. This is possible if there is no condensate recovery system or if test valves have been installed to allow a momentary discharge of the downstream fluid from the condensate recovery system. In either case, the steam trap evaluator must be able to distinguish between "flash" steam, which is characteristic of a properly working trap, and "live" steam, which is characteristic of a trap that has failed open and is leaking or blowing a significant amount of steam. Flash steam is created when a portion of the condensate flashes to vapor upon expansion to atmospheric pressure. Flash steam is characterized by a relatively lazy, billowy plume. Live steam, on the other hand, will form a much sharper, higher velocity plume that may not be immediately visible as it exits the test valve or steam trap. The difference between live steam and flash steam is illustrated in Figure 6.

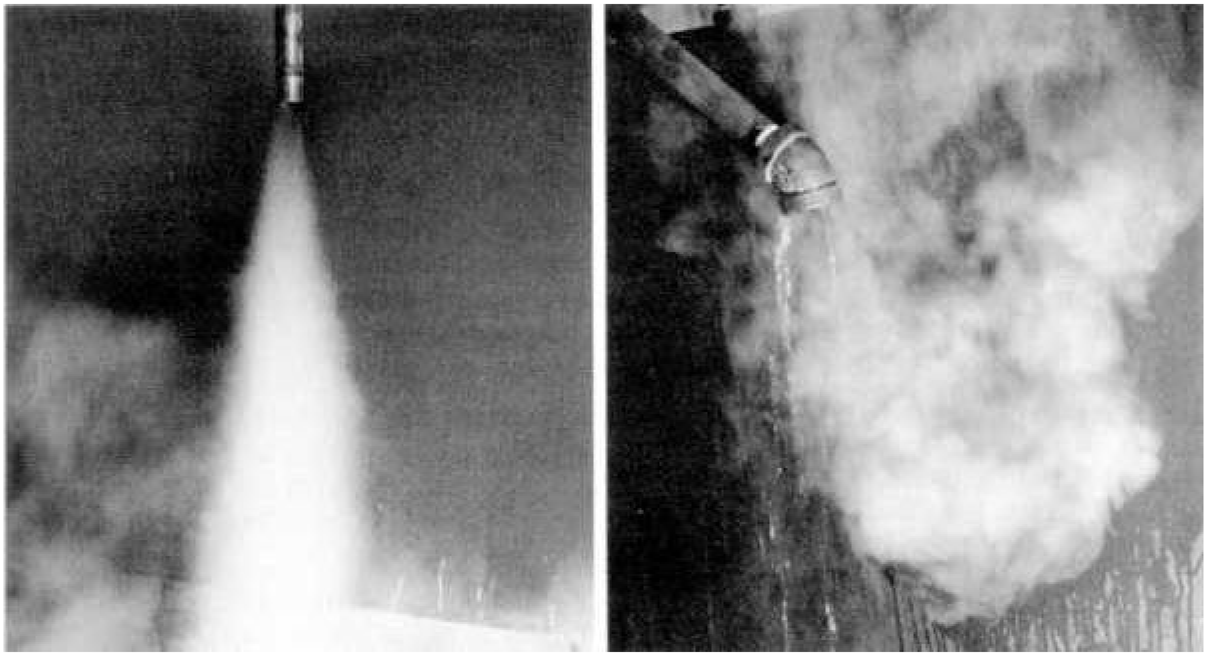

Figure 6. Live steam versus flash steam. (Illustration courtesy of Yarway Corporation)

Sight glasses can also be used for a visual observation, but have some drawbacks that must be overcome or avoided. First, steam and condensate are both expected to exist upstream and downstream of the trap (live steam on the upstream side and flash steam on the downstream side). Second, the view through a sight glass tends to deteriorate over time because of internal or external fouling. Third, both steam and condensate will appear as clear fluids within the pipe. In response to the first and third concerns, sight glasses have been developed with internal features that allow the proportion of steam and condensate to be identified. Incorporation of a sight glass into a pipe is shown in Figure 7a. Normal and abnormal operating conditions viewed through a sight glass are illustrated in Figures 7b, 7c, and 7d for a sight glass installed on the upstream side of the trap. In Figure 7b normal operation results in a condensate level that is just above the internal flow baffle. Moderate to high rates of steam flow past the baffle (indicating a leaking or blowing steam trap) will sweep out most of the condensate, as shown in Figure 7c. A completely flooded baffle, shown in Figure 7d, could be caused by excess condensate formed during startup, a steam trap that is undersized for normal condensate loads, blockage in the condensate return system, or a steam trap that has failed closed or nearly so. Additional investigation is required to determine which of the alternative causes is the likely source of the problem.

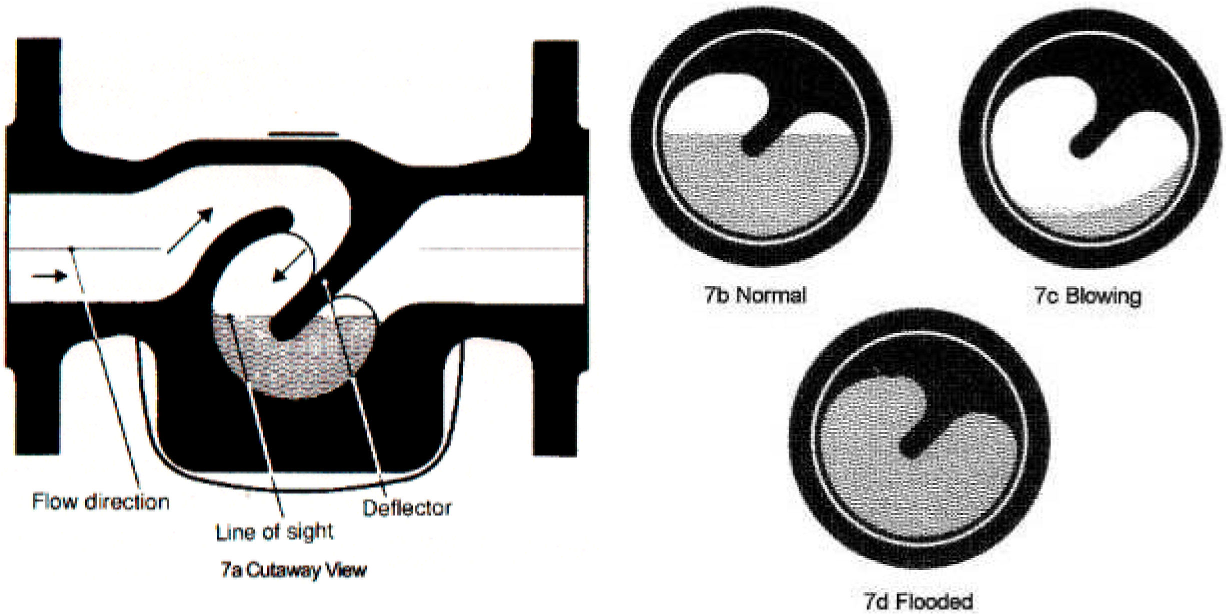

Figure 7. Sight glass evaluation. (Illustration courtesy of GESTRA, Inc.)

Sound Method

Mechanisms within steam traps and the flow of steam and condensate through steam traps generate sonic (audible to the human ear) and supersonic sounds. Proper listening equipment, coupled with the knowledge of normal and abnormal sounds, can yield reliable assessments of steam trap working condition. Listening devices range from a screwdriver or simple mechanic's stethoscope that allow listening to sonic sounds to more sophisticated electronic devices that allow "listening" to sonic or sonic and ultrasonic sounds at selected frequencies. The most sophisticated devices compare measured sounds with the expected sounds of working and non-working traps to render a judgment on trap condition. A typical ultrasonic test kit is shown in Figure 8.

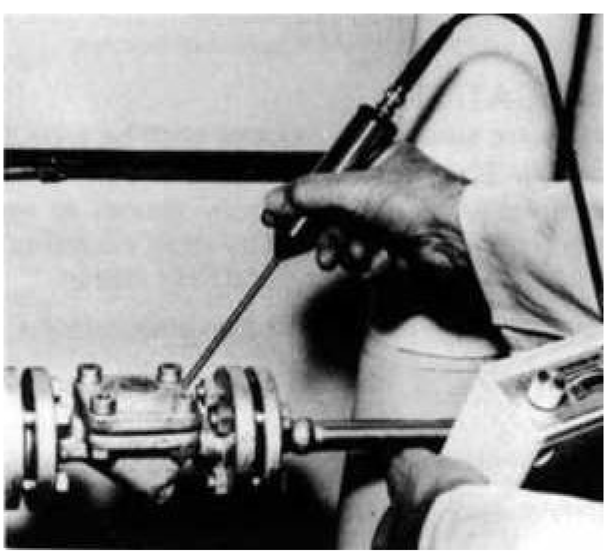

Figure 8. Ultrasonic test kit.
(Illustration courtesy of GESTRA, Inc.)

Temperature Method

Measuring the temperature of the steam trap is generally regarded as the least reliable of the three basic evaluation techniques. Saturated steam and condensate exist at the same temperature, of course, so it's not possible to distinguish between the two based on temperature. Still, temperature measurement provides important information for evaluation purposes. A cold trap (i.e., one that is significantly cooler than the expected saturated steam temperature) indicates that the trap is flooded with condensate, assuming the trap is in service. As described above for the visual test via a sight glass, a flooded trap could mean several things, but barring measurement during startup, when flooding can be expected, generally indicates a problem that needs to be addressed. Downstream temperature measurement may also yield useful clues in certain circumstances. For example, the temperature downstream of a trap should drop off relatively quickly if the trap is working properly (mostly condensate immediately past the trap). On the other hand, the temperature downstream of the trap will be nearly constant if significant steam is getting past the trap. Care must be taken not to use this technique where other traps could affect downstream conditions, however.

Temperature measurement methods, like sound measurement, vary tremendously in the degree of sophistication. At the low-end, spitting on the trap and watching the sizzle provides a general indication of temperature. For the more genteel, a squirt bottle filled with water will serve the same purpose. Alternatively, a glove-covered hand can provide a similar level of accuracy. More sophisticated are various types of temperature-sensitive crayons or tapes designed to change color in different temperature ranges. Thermometers, thermocouples, and other devices requiring contact with the trap offer better precision. Finally, non-contact (i.e., infrared) temperature measuring devices provide the precision of thermometers and thermocouples without requiring physical contact. Non-contact temperature measurement makes it easier to evaluate traps that are relatively difficult or dangerous to access closely. An infrared temperature measuring "gun" is shown in Figure 9.

Figure 9. Infrared temperature gun.
(Illustration courtesy of Raytek Corporation)

Conductivity Method

Conductivity-based diagnostics are based on the difference in conductivity between steam and condensate. A conductivity probe is integrated with the steam trap or just upstream of the steam trap in a sensing chamber. Under normal operation, the tip of the conductivity probe is immersed in condensate. If the steam trap leaks excessively or is blowing, steam flow will sweep away the condensate from the test probe tip and conductivity corresponding to steam will be measured. Thus, the sensing chamber and the existence of steam and condensate under normal and leaking or blowing conditions are similar to that described above and shown in Figure 7 for the sight glass.

Conductivity measurement must be accompanied by temperature measurement to ensure a correct diagnosis. For example, an indication of steam and a trap that has failed open could occur if a trap has not been used recently and has filled with air. The conductivity of air is similar to steam, but a trap filled with air would be close to ambient temperature, in contrast to a trap filled with steam. Similarly, the presence of condensate could mean the trap is working properly, but could also mean that 1) the trap has flooded, either because the trap has failed closed or something else is blocking the line, 2) the trap is undersized, or 3) the heat transfer equipment served by the trap is warming up to its normal operating temperature and generating an unusually large amount of condensate for a short period. These alternative conditions would be indicated by low temperature in conjunction with the presence of condensate.

Application Domain

Steam trap monitoring equipment should be employed wherever steam heating systems and steam traps are used. Steam can be used for space and process heating. Space-heating with steam is more common in the Federal sector than other sectors, which can be attributed to a tendency for Federal buildings to be larger, grouped closely together in campus-like arrangements, or constructed in an era when central boiler systems were the preferred heating system. The Department of Defense has about 5,000 miles of steam distribution systems, not including piping within buildings. Larger forts or bases can easily have more than 10,000 steam traps. Proactive steam trap maintenance programs are believed to be the exception, rather than the rule, in the Federal sector due to a shortage of maintenance staff. On the other hand, essentially all studies of steam trap maintenance programs reported in the literature suggest that energy savings far exceed implementation costs. Thus, the potential incremental application of steam trap performance evaluation equipment is significant when measured by either the size or fraction of the market.

Energy-Saving Mechanism

Monitoring and evaluation equipment does not save any energy directly, but identifies traps that have failed and whether failure has occurred in an open or closed position. Traps failing in an open position allow steam to pass continuously, as long as the system is energized. The rate of energy loss can be estimated based on the size of the orifice and system steam pressure using the relationship illustrated in Figure 10. This figure is derived from Grashof's equation for steam discharge through an orifice (Avallone and Baumeister 1986) and assumes the trap is energized (leaks) the entire year, all steam leak energy is lost, and that makeup water is available at an average temperature of 60°F. Boiler losses are not included in Figure 10, so must be accounted for separately. Thus, adjustments from the raw estimate read from this figure must be made to account for less than full time steam supply and for boiler losses.

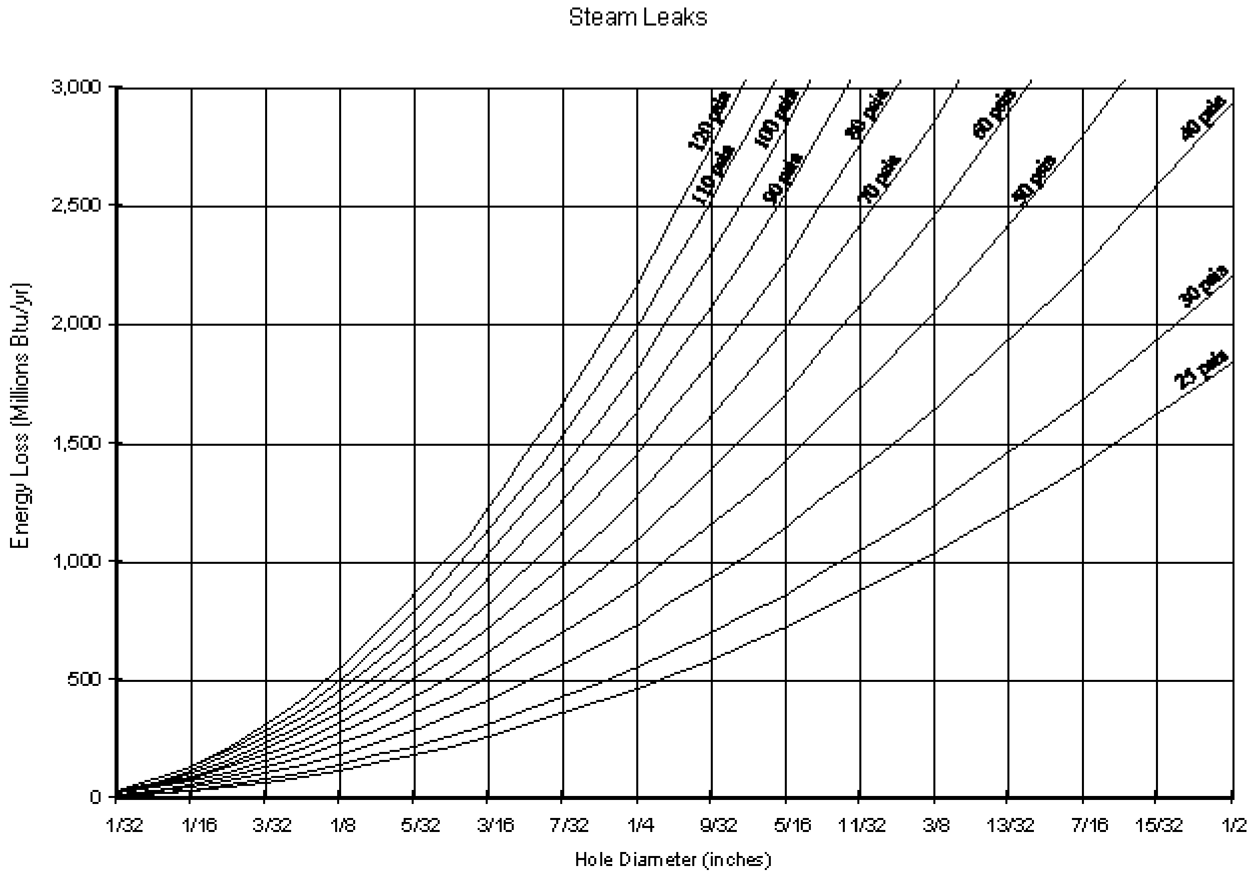

Figure 10. Energy loss from leaking steam traps.

The principal uncertainty in using the Figure 10 energy loss rates is estimating the equivalent hole diameter for a trap suspected of leaking or blowing steam. Vendor advice can be solicited to identify the orifice size for a trap when fully open. However, not all traps fail in this mode. Rather than being stuck open, the trap valve may no longer seal properly, resulting in a smaller hole. Intermediate failure modes are also possible. Whether a trap has lost its seal or is stuck fully open, the flow of condensate through the orifice reduces the area available for steam flow. Fischer (1995) estimates that condensate flow reduces steam flow by 1/3 to 1/2 of that expected without condensate. The variation depends on the sizing of the trap relative to expected condensate load. In addition, steam trap internals create flow restrictions that reduce losses relative to unimpeded flow through an orifice.

The maximum steam loss rate occurs when a trap fails with its valve stuck in a fully opened position. While this failure mode is relatively common, the actual orifice size could be any fraction of the fully opened position. Therefore, judgment must be applied to estimate the orifice size associated with a specific malfunctioning trap. Lacking better data, assuming a trap has failed with an orifice size equivalent to one-half of its fully-opened condition is probably prudent. Additional advice on estimating losses from individual traps can be found in Pychewicz (1985), David (1981), and Tuma and Kramer (1988).

The use of Figure 10 is illustrated via the following example. Inspection and observation of a trap led to the judgment that it had failed in the fully open position and was blowing steam. Manufacturer data indicated that the actual orifice diameter was 3/8 inch. The trap operated at 60 psia and was energized for 50% of the year. Boiler efficiency was estimated to be 75%. Calculation of annual energy loss for this example is illustrated in the sidebar below.

Other Benefits

Where condensate is not returned to the boiler, water losses will be proportional to the energy losses noted above. Feedwater treatment costs will also be proportionately increased. In turn, an increase in make-up water increases the blowdown requirement and associated energy and water losses. Even where condensate is returned to the boiler, steam bypassing a trap may not condense prior to arriving at the deaerator, where it may be vented along with the non-condensable gases. Steam losses also represent a loss in steam-heating capacity, which could result in an inability to maintain the indoor design temperature on winter days or reduce production capacity in process heating applications. Traps that fail closed do not result in energy or water losses, but can also result in significant capacity reduction (as the condensate takes up pipe cross-sectional area that otherwise would be available for steam flow). Of generally more critical concern is the physical damage that can result from the irregular movement of condensate in a two-phase system, a problem commonly referred to as "water hammer."

Estimating steam loss using Figure 10
Assume: 3/8-inch-diameter orifice steam trap, 50% blocked, 60 psia saturated steam system, steam system energized 4,380 h/yr (50% of year), boiler efficiency 75%.

- Using Figure 10 for 3/8 inch orifice and 60 psia steam, steam loss = 2,500 million Btu/yr
- Assuming trap is 50% blocked, annual steam loss estimate = 1,250 million Btu/yr
- Assuming steam system is energized 50% of the year, energy loss = 625 million Btu/yr
- Annual fuel loss including boiler losses = [(625 million Btu/yr)/(75% efficiency)] = 833 million Btu/yr

Installation

Installation requirements are essentially nil for portable test equipment, which includes ultrasonic systems with or without built-in diagnostic capability. Some training will be required for the ultrasonic systems without built-in diagnostics, however, for the user to correctly interpret the signals received. The conductivity-based systems generally require a test chamber plumbed into the pipeline just upstream from the steam trap, although some steam traps have an integrated test chamber. Continuous monitoring requires the installation of power and control wiring to connect individual test probes to a central monitoring terminal. Otherwise, a portable monitoring device can be periodically connected to each test probe. Sight glasses must also be plumbed into the pipeline just upstream from the steam trap.

Federal Sector Potential

Steam heating systems are relatively common in the Federal sector. Total boiler capacity, boiler energy consumption, steam piping length, and the number of traps in the Federal sector are not directly available from databases, but can be estimated from related data and rules-of-thumb.

Estimated Savings and Market Potential

Implementation of a proactive steam trap program (i.e., a program based on regular maintenance checks rather than only replacing steam traps when failure creates an intolerable operating condition) can save significant energy. The results of several steam trap programs described in the literature suggest that failed steam traps leak approximately 20% of the steam leaving the boiler in predominately space-heating systems lacking a proactive maintenance program. The same sources suggest that the loss rate would be reduced to about 6% by the average proactive maintenance program. If the average loss rate for a proactive program is 6%, then a minimal program (using rudimentary test equipment) might reduce losses to about 8% and an intermediate program (using good portable equipment and more frequent testing) should yield better results, reducing losses to perhaps 4%. With an advanced program (using hard-plumbed and wired equipment allowing continuous monitoring), the loss rate should approach 0%.

In general, each increment of improvement in the steam trap loss rate requires an increased investment in labor and equipment. Equipment costs are negligible for either the minimal or intermediate programs, but would increase significantly for the advanced program, which requires the installation of new hardware, including retrofit of the existing steam piping. The significant investment associated with the advanced program is probably not justified in most Federal applications, which are predominately for building space heating. Compared to typical industrial process heating applications, end-use heat exchanger condensate loads are small for typical space heating applications. Thus, smaller steam traps are used, and the potential loss from a single trap probably does not warrant the expense of an advanced program. This generalization should be revisited in any site-specific analysis, however.

The estimated savings and market potential were estimated by evaluating the cost-effectiveness of implementing either a minimal or intermediate proactive steam trap maintenance program. 80% of Federal sites were assumed not to have a proactive maintenance program. 15% were assumed to have a minimal program and 5% an intermediate program. No Federal sites were presumed to have an advanced program.

The costs of implementing a minimal or intermediate program, or upgrading from a minimal program to an intermediate program, were estimated from rules-of-thumb provided in publications describing proactive steam trap maintenance programs. Program requirements include an initial identification of all steam trap locations, purchase of test equipment, training, trap testing, trap replacement, and engineering management.

Estimated costs for the two programs, as a function of the total trap population, are shown in Table 1. The minimal program is presumed to use whatever testing equipment is already available, so no expenditure for equipment or equipment-use training is required. Traps are presumed to be tested once a year for the minimal program and twice a year for the intermediate program, which explains the difference in trap testing and engineering management costs for the two programs. The intermediate program is presumed to do a better job of assessing trap condition; a higher percentage of traps that have failed are identified as having failed and a lower percentage of traps that are working correctly are misidentified as having failed. Thus, a lower percentage of steam traps are still leaking after completing a test and repair cycle with the intermediate program. In addition, subsequent failures accumulate for only six months for the intermediate program compared to a year for the minimal program. The combined effect is presumed to cut energy losses for the intermediate program in half compared to the minimal program.

Table 1. Steam trap proactive maintenance program cost estimates.[3]

Cost Element	Minimal Program	Intermediate Program

Trap Identification	$15/trap once	$15/trap once
Equipment and Training	$0 total once	$4000 total once
Trap Testing	$5/trap per year	$10/trap per year
Trap Replacement	$40/trap first year	$40/trap first year
	$15/trap thereafter	$15/trap thereafter
Engineering Management	$5000 + $2/trap/year	$5000 + $4/trap/year
Total Initial Cost	$55/trap	$4000 + $55/trap
Total Annual Cost	$5000 + $22/trap	$5000 + $29/trap

Consider a hypothetical facility with 100,000 lb/hr of steam generating capacity, 500 traps, annual steam production of 219,000,000 lb, and a marginal cost of steam production of $5/thousand pounds. Implementation of the minimal program would save 26,280,000 lb of steam valued at $134,000 every year for an initial cost of $27,500 plus annually recurring costs of $16,000. Implementation of the intermediate program would save 35,040,000 lb of steam valued at $175,200 every year for an initial cost of $31,500 plus annually recurring costs of $19,500. The payback periods for the minimal and intermediate programs are 0.23 and 0.20 years, respectively.

The calculations in the previous paragraph provide the economic justification to proceed with trap identification and testing, resulting in a more accurate assessment of trap conditions and steam losses, hence trap replacement costs and energy savings. The life-cycle cost calculations should be repeated once this additional information is available to determine if trap replacement is still economically justified. Note that money already spent for trap identification and initial testing are "sunk" and should not be included in the subsequent calculation.

The potential economic and environmental impacts of implementing cost-effective steam trap maintenance programs in the Army are shown in Table 2. The results are quite impressive. Annual energy savings could be about 5 trillion btu, with the present value of annual savings (annual energy savings less annual program costs) and the net present value (after paying for initial program investment costs) both in excess of $200 million. The data required for accurate estimates were not available, but DoD and Federal sector impacts are probably about three and four times as great, respectively, as the Army impacts.

Table 2. Potential Army impacts of proactive steam trap maintenance programs

Criteria	Result
Net Present Value ($)	203,991,245
Installed Cost ($)	7,850,779
Present Value of Savings ($)	211,841,024
Energy Savings (million Btu/year)	5,197,636
SO_2 Emissions Reduction (lb/year)	3,624,870

NO_x Emissions Reduction (lb/year)	1,215,219
Particulate Emissions Reduction (lb/year)	68,721
CO Emissions Reduction (lb/year)	354,341
CO_2 Emissions Reduction (tons/year)	368,695
Hydrocarbon Emissions Reduction (lb/year)	8,163

Laboratory Perspective

The cost-effectiveness of proactive steam trap maintenance is well documented in the literature. In general, it's far more important to ensure that steam traps are evaluated on a regular basis than to worry about which specific type of testing equipment is used. A more careful analysis of the costs and benefits is justified, however, if some of the more expensive options requiring hardware installation are considered. Still, the efficiency improvement offered by these more sophisticated systems may be justified for systems with larger steam traps that lose much more steam upon failure. The pervasive existence of steam heating systems coupled with relatively few proactive steam trap maintenance programs in the Federal sector presents a substantial opportunity for energy savings and related benefits.

Application

This section describes in more detail the technical considerations regarding implementation of a proactive steam trap maintenance program and selection of steam trap testing equipment. The first few paragraphs describe the conditions and characteristics where a maintenance program and specific types of equipment should be applied and situations that should probably be avoided. Subsequent sections focus on equipment integration impacts, including installation requirements, equipment and installation costs, and maintenance requirements.

Application Screening

Some type of steam trap performance assessment program should be implemented anywhere steam heating systems and steam traps are used. Even for smaller systems with only a handful of traps, some type of steam trap program will be cost-effective. The use of temperature and sound measurement equipment currently available in your maintenance shop, even if limited to a gloved hand and a screwdriver, is better than having no regular assessment program at all. The most important decision is to implement a steam trap performance assessment program. Selection of the specific performance assessment equipment is a secondary consideration.

Where to Apply

The steam trap performance assessment equipment described in this FTA varies significantly in initial cost and moderately in operating cost and assessment effectiveness. For smaller steam systems with relatively few traps and/or for energy managers with exceptionally small budgets, a simple ultrasonic gun (without built-in diagnostics) is probably the best investment. However, where many different staff may be called upon to conduct tests, the incremental investment in an ultrasonic gun with built-in diagnostics makes the most sense. The built-in diagnostic capability practically eliminates the need for training, which is essential to achieving good results without built-in diagnostics, but would be expensive if a large group had to be trained. Conductivity-based assessment equipment offers the best performance improvement and lowest operating costs via continuous, remote monitoring, but installation of the sensing chambers and wiring make this the most capital-intensive steam trap assessment system. The extra investment is most likely to be cost-effective in steam systems serving heating equipment with relatively large loads and, hence, relatively large steam traps. Larger steam traps, when failed open, result in larger, more expensive leaks. Industrial process heating applications would be most attractive for this type of assessment system, but space-heating applications should not be excluded from consideration.

What to Avoid

The retrofit of sight glasses or test valves allowing a visual assessment of steam trap performance should be carefully considered. While visual assessment is judged by the majority of steam trap experts to be the best assessment technique, the cost of retrofitting this type of equipment is significantly greater than any portable temperature or sonic test equipment and comparable to conductivity-based test equipment. The latter has the advantage of being wired for continuous, remote monitoring, however, which should reduce operating costs and improve steam system efficiency for a relatively modest incremental investment, compared to sight glasses or test valves.

Equipment Integration

Portable steam trap test equipment, which includes all of the ultrasonic devices described in this FTA as well as most temperature-measuring equipment, requires no integration with the steam distribution system. On the other hand, conductivity-based and visual-based test equipment must be plumbed into the distribution system. Some steam traps have built-in conductivity sensor chambers, but most utilize a separate sensor chamber. Either approach requires isolation of the steam trap and surrounding piping and insertion of a new device (either a new steam trap with a sensing chamber or a separate sensing chamber). Sight glasses and test valves require a similar retrofit. Conductivity chambers, sight glasses, and test valves are generally available in models allowing threaded, flanged, or welded connections to suit pipeline-specific requirements, but all require at least a moderate amount of pipefitting labor to install.

Maintenance Impact

All steam trap performance assessment equipment will require incremental labor to collect and evaluate test data. Much of this incremental labor is associated with walking from one trap to another with portable test equipment. This requirement can be eliminated with hard-wired, remotely accessed, conductivity-based systems, however, with incremental labor limited to periodic review and evaluation of the centrally collected data. Steam trap replacement costs will increase, of course, compared to not having a proactive steam trap maintenance program. Otherwise, maintenance of the performance assessment equipment itself is generally expected to be negligible. A notable exception would be sight glasses, which may require periodic removal and cleaning to maintain clarity.

Equipment Warranties

A one-year warranty is standard for most steam trap performance equipment and manufacturers covered in this FTA. An exception to this generalization is the Ultraprobe™ ultrasonic system manufactured by UE Systems, Inc., which is warranted for five years.

Costs

The costs of steam trap performance-assessment equipment vary significantly, depending on the type, its features, and its size (for sight glasses and conductivity-based equipment that must be plumbed into the existing pipeline). Fixed frequency ultrasonic meters can be purchased for $600 or less up to about $2,000. Tunable ultrasonic test systems can usually be purchased for $3,000 to $5,000. The purchase cost of conductivity-sensing chambers and sight glasses varies from less than $100 to more than $1,000 per trap, depending on pipe diameter, pipe material, and the type of connection (welded, flanged, or threaded). Installation costs for conductivity test chambers and sight glasses are also significant and variable, although not generally as expensive or variable. Depending on pipe size and connection type, an additional $50Ð200 per trap can be expected.

Rough estimates of other costs associated with a proactive steam trap maintenance program are shown in Table 1.

Technology Performance

Ultrasonic testing equipment, applicable to a wide-range of technologies besides steam traps, has been used extensively in the Federal and private sectors. Conductivity-based test equipment and sight glasses, both more peculiar to steam trap assessment, have been used less frequently, but have still seen significant use. All of the steam trap performance assessment equipment included in this FTA could be described as mature. In all cases, hundreds or thousands of units or systems have been sold. In general, a substantial fraction of sales have been to the Federal sector, but specific sales data for Federal and non-Federal sectors and customer references were not always available. The specific experiences of available references are documented in this section. Contact information is provided in Appendix A.

Ted Tomaliwski of the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, uses the CTRL Ultraphonic™ ultrasonic tester. Ted works at the central steam, chilled water, and compressed air plant at the NIST facility. Steam produced at the central plant is primarily used for space heating. Ted uses the Ultraphonic to check for air leaks and malfunctioning steam traps. Ted told us the Ultraphonic "works well and is easy to use." Ted also uses a contact temperature probe to evaluate steam trap performance.

Charles McMullin has responsibility for exterior steam lines at Whiteman Air Force Base in Knobnoster, Missouri. Charles has used TLV's TrapMan™ (an integrated ultrasonic and temperature measurement system with built-in diagnostics) for about 4 years, and considers it an improvement over temperature measurement devices that were previously used to evaluate steam traps. Charles notes that performance data are recorded by the system, so it takes very little time to conduct the tests. Overall, Charles says that he is "well satisfied" with the TrapMan system.

CIS Services operates the Electric Power Research Institute's Monitoring and Diagnostics Center. CIS provides instruction on the inspection of transformers, valves, and steam traps. They use Triple 5 Industries' ultrasonic leak detector for all of these applications. George Spencer of CIS says that Triple 5 Industries' ultrasonic leak detector is "the best system you can buy." In particular, George likes the battery-powered portability of the system, and claims the system is substantially faster than using temperature systems for assessing steam traps.

Peter Palamidis is the Preventive Maintenance Coordinator at Brookhaven National Laboratory in Upton, New York. Peter uses UE Systems' Ultraprobe™ 2000 to survey approximately 2,500 steam traps at his facility. Peter says the Ultraprobe is a "good system," and he was especially enthusiastic about the support that UE Systems provides its customers.

Case Study

Steam trap management programs were recently initiated at three Veterans Administration (VA) medical centers in the Northeast with the help of FEMP's SAVEnergy Program. The three VA hospitals were located in Providence, Rhode Island, and Brockton and West Roxbury, Massachusetts. Steam trap inspection and evaluation was included as part of broader audit of the steam generation, distribution, and end-use equipment at these three facilities. Steam traps were identified and evaluated to determine their performance and the value of steam losses from malfunctioning traps. Malfunctioning traps were designated for either repair or replacement. In addition, VA maintenance crews received trap-testing training as part of the continuing steam trap management program.

Facility Description

The key facility-level characteristics for a steam trap management program are the steam system pressure or pressures, the hours per year that the steam system is energized, and the marginal cost of producing steam that is lost in faulty traps. The steam pressure affects the rate of steam loss through a leaking trap as shown in Figure 10. Losses occur continuously at a constant rate (independent of end-use demand) whenever the steam system in energized, so care must be taken to estimate this factor correctly. Individual pieces of steam-heated equipment or sections of a system may be energized for different portions of the year. For example, space-heating lines may be shut off during the summer while domestic water heating is required year round. In addition, the use of automated control valves (or not) will significantly affect the fraction of time that a steam trap is energized. The marginal cost of steam will equal fuel cost divided by boiler efficiency at a minimum. Makeup water treatment costs should also be included for that fraction of the leaking steam that fails to return to the boiler feed water tank.

Multiple steam pressures were found at each of the three medical centers. The specific pressures were 110, 80, 40, and 15 psig at Providence; 120, 40 and 5 psig at Brockton; and 100, 55 and 5 psig at West Roxbury. Steam uses at all three facilities include space heating, water heating, food preparation, equipment sterilization, and laundry. Steam usage ranged from 12Ð52 weeks per year for the various processes. Steam losses were valued at $5.25 per 1,000 pounds of steam at Providence and $4.25 per 1,000 pounds of steam at Brockton and West Roxbury.

Existing Technology Description

Trap-specific characteristics must be collected via inspection and evaluation to accurately estimate annual steam loss. The size, type, manufacturer, and model should be identified. This information is used to identify the effective orifice size if the trap has failed in a fully open condition. Interpretation of trap operating condition via one of the methods previously described is required to judge whether a trap is operating correctly or not, if it has failed in an open or closed position, and the degree of failure if less than fully open. Accurately determining the effective orifice size for a trap determined to have failed in an open or partly open position requires detailed knowledge of the trap design (acquired from the trap vendor) and experience evaluating traps. Thus, it may be more cost-effective to hire the services of a company that specializes in trap testing and evaluation than to conduct the assessment with in-house personnel. Sites with larger steam systems and more traps are more likely candidates for developing their own capabilities, but availability of maintenance staff is often the limiting factor.

The trap inspection and evaluation company contracted for the VA assessment identified the trap location, manufacturer, type, model (in some cases), nominal pipe diameter, inlet and outlet pressure, steam supply control, and steam service for each steam trap. Again, knowledge of steam service (e.g., water heating, space heating, equipment sterilization, main and header drip legs, etc.) and steam supply control to the service is essential for estimating the number of hours a year that each trap will be energized and potentially leaking. The balance of the information collected is oriented toward determining the leak rate.

Providence has by far the greatest number of traps of the three facilities with 1109 units. Brockton and West Roxbury have 202 and 95 traps, respectively. Unfortunately, the trap inspection was conducted in the spring at Providence and summer at Brockton and West Roxbury when most, if not all of the traps servicing space-heating equipment were not in use. Thus, it was not possible to test approximately 70% of the traps at Providence and approximately 40% of the traps at Brockton and West Roxbury. Of the remaining traps, 51, 47, and 5 were found to have failed in the open position at Providence, Brockton, and West Roxbury, respectively. Among those determined to have failed opened, each was classified as leaking at a low, medium, or high rate relative to the leak rate for each trap if it failed fully open. Thus, the estimated annual leak rate is a function of the trap orifice if fully open, the degree of openness of the failure, the differential pressure across the trap, and the number of hours the trap is energized.

New Technology Equipment Selection

The energy savings in this case study come from repairing and replacing steam traps that have failed in a fully or partly open position and were leaking steam into the condensate system. No change in steam trap technology was considered. Instead, a change in maintenance practice was recommended. Selection of the steam trap testing equipment is not nearly as important as the decision to conduct testing. Using the most rudimentary trap testing equipment will probably cut trap-related steam losses by more than 50%. Using any of the testing equipment described in this *Federal Technology Alert* will probably cut trap-related steam losses by at least 75%. In general, more sophisticated testing equipment and more frequent testing is warranted for larger traps operating at higher pressures, where the potential steam loss rate is the highest.

Savings Potential

The savings potential for each trap can be calculated from an estimate of the orifice size associated with a leaking trap (i.e., the size of the hole that steam is leaking through, which will be less than or equal to its orifice size when a trap is fully open), the steam pressure, the fraction of the year that the trap is energized, and the boiler efficiency. Figure 10 shows how annual energy losses vary with equivalent hole (orifice) diameter and steam pressure.

Annual steam losses were estimated to be 3,561, 16,591, and 733 thousand pounds per year at the Providence, Brockton, and West Roxbury medical centers, respectively. Steam was valued at $5.25 per thousand pounds at Providence and $4.25 per thousand pounds at Brockton and West Roxbury. Thus, the total annual costs of the losses (and the expected annual savings if fixed) were estimated to be $18,695 at Providence, $70,511 at Brockton, and $3,117 at West Roxbury.

Life-Cycle Costs

Trap inspection and evaluation at the VA medical centers was included as part of broader energy audits addressing other components of the steam generation and distribution systems. The trap-related portion of the energy audit costs were estimated by the contractor to average $9.70 per trap, while trap replacement was estimated to cost $94 each.[4] Thus, total trap replacement costs were estimated to be $5076, $4512, and $470 at Providence, Brockton, and West Roxbury, respectively. Combining these investment costs with the annual savings estimates noted above yields payback periods of 0.27, 0.06, and 0.15 years for the three medical centers in the same order. Note that "sunk" cost associated with trap testing does not figure into the economic assessment affecting the decision to replace the traps or not. Also note that this assessment focuses on the costs and savings of the traps identified as failed and needing replacement. The estimated savings for these traps will continue until these traps start to fail. The average trap lasts for about 5 years, with some lasting longer and some failing sooner.

The Technology in Perspective

Proactive steam trap management programs have proven themselves to be cost-effective. The most important decision is making a commitment to implement a program; the specific testing equipment chosen is of lesser importance. Still, site-specific steam system and maintenance resource characteristics (e.g., number and size of traps, availability of capital and labor) will affect the preferred testing technology. In the future, continued improvement of performance assessment technologies should allow even greater cost-effective energy savings.

The Technology's Development

Sight, sound, and temperature measurements have been used to assess the performance of steam traps since steam traps were invented, but the measuring technology has evolved over the years. Equipment using a fourth method, based on the conductivity of the fluid at a specific point in the pipeline, has been developed in recent years.

In steam systems without condensate return, steam leaking past a trap is directly visible. With condensate return, a test tee and two valves (one to isolate the trap being tested from the influence of other traps, the other to provide an outlet for viewing the fluid downstream of the trap being tested) are all that's required. Thus, the standard technology for conducting a visual test has remained unchanged since steam traps were invented. Sight glasses provide an alternative approach to visual assessment that can be used without affecting system operation, but are prone to fouling in some service conditions.

Sound measurement has progressed from a screwdriver to a more comfortable mechanic's stethoscope to ultrasonic listening devices. The former two assist with hearing sounds in the normal audible range of the human ear, while the latter detects normally inaudible sounds of higher frequency and converts the signal into audible sounds. Simpler ultrasonic listening devices are tuned to a fixed frequency or frequency range, while more advanced models allow tuning to a specific frequency or frequency range. More recently, acoustic signatures representative of properly working and failed traps have been stored in the memory of ultrasonic listening devices for comparison with current readings. This allows the ultrasonic instrument to provide a diagnosis of trap condition without relying on the experience of the instrument user.

Temperature measurement tools have also progressed significantly over the years. Although a gloved-hand or squirt bottle may be adequate in some situations, much better accuracy can be easily achieved. Temperature measurement has progressed from these original "ballpark" approaches to temperature-sensitive materials that change color with temperature to several types of contact and non-contact devices. Earlier instruments were generally thermometers (i.e., devices that measure temperature based on the thermal expansion of various materials). More advanced contact devices are now based on either the thermoelectric potential of two dissimilar metals (thermocouple) or the variation in electrical resistance of a metal with temperature (thermistor). Contact temperature measurement is often coupled with ultrasonic measurement to provide an integrated steam trap testing unit. Non-contact devices allow the freedom and comfort of measuring temperature from a distance based on the thermal radiation emitted from an object's surface. The radiation entering a non-contact pyrometer is either focused on a heat-sensitive element such as a thermocouple or thermistor (radiation or infrared pyrometer) or its intensity is compared to that of reference element (optical pyrometer).

Conductivity measurement is a relatively new approach for evaluating steam traps. A probe inserted into the pipeline can easily distinguish between the conductivity of steam or condensate. The probe must be positioned at a location where normally it would be covered by condensate, but failure would cover it with steam or vice versa. Special sensing chambers create a flow path and precise point for inserting a probe. Conductivity probes, also often coupled with contact temperature measurement devices, can be wired to a central, remote monitoring device that receives signals from many probes. This minimizes subsequent data collection efforts, but does cost more to purchase and install than ultrasonic test equipment, which is portable.

Technology Outlook

Steam trap testing equipment is relatively mature, but evolutionary progress is expected to continue. Advances in electronics have spurred the development of new steam trap testing equipment and reduced the cost of basic ultrasonic and temperature measurement instruments. This trend is expected to continue. Future advances in ultrasonic measurement might reduce costs enough to allow meters to be permanently attached to individual steam traps like conductivity probes and sensing chambers. This would allow central, remote monitoring of ultrasonic measurements.

Manufacturers

The number of technologies that could potentially be applied to the evaluation of steam trap performance is extensive. In general, the manufacturer list that follows was limited to those making technologies that are peculiar to the evaluation of steam traps. This excluded, for example, all temperature-measuring devices. An exception to this general exclusion was made for ultrasonic testing equipment, however.

Steam trap evaluation technologies and associated manufacturers were identified by contacting steam trap and ultrasonic testing equipment manufacturers listed in product directories published by *Thomas Register, Chemical Engineering, Energy Products, Heating/Piping/Air-Conditioning, Energy User News*, and *Consulting Specifying Engineer*. We also conducted searches of Internet web sites and library databases. Despite our efforts, it is practically impossible to ensure that all manufacturers of steam trap performance assessment equipment have been identified. In fact, given the broad scope of potentially applicable equipment, some manufacturers have surely been missed. To those, we extend our apologies.

The search process identified 13 products offered by 10 companies in four generic categories. The four categories were 1) ultrasonic listening devices (with or without accompanying temperature-measuring devices) with built-in diagnostic capability, 2) conductivity measuring devices (with or without accompanying temperature-measuring devices) with built-in diagnostic capability, 3) ultrasonic listening devices (tunable or fixed frequency bandwidth, with or without accompanying temperature-measuring devices) without built-in diagnostic capability, and 4) a sight glass for visual determination of steam trap condition. A detailed description of each product, including manufacturer contact information, is presented in Appendix A.

The 10 companies offering these steam trap products are:
- Armstrong International, Inc.
- CTRL Systems, Inc.
- Electronics For Industry, Inc.
- GESTRA, Inc.
- Mitchell Instrument Co.
- Spirax Sarco, Inc.
- Superior Signal Company, Inc.
- TLV CORPORATION
- Triple 5 Industries, LLC.
- UE Systems, Inc.

Who is Using the Technology

Thousands of ultrasonic listening devices (without built-in steam trap diagnostics) have been sold to Federal and non-Federal customers. However, these devices can be used for evaluating an extremely broad range of other equipment, so the number used for evaluating steam traps is unknown. Approximately 150 ultrasonic testing systems with built-in steam trap diagnostics also have been sold. Again, the specific number of Federal applications is unknown. Sales data for sight glasses and conductivity-based testing systems were unavailable. The following Federal contacts were identified by the manufacturers listed above as users of one or more of the steam trap monitoring technologies described in this *Federal Technology Alert*.

Ted Tomaliwski
National Institute of Standards and Technology
Quince Orchard and Clopper Road
Gaithersburg, Maryland
301-975-6983

George Spencer
CIS Services
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Eddystone, Pennsylvania
800-745-9981

Charles McMullin
Whiteman Air Force Base
Building 410
Knobnoster, Missouri
660-687-5095

Peter Palamidis

Brookhaven National Laboratory
Building 097
Upton, New York
516-344-2462

For Further Information

Associations

International District Energy Association
1200 19th Street, N.W. Suite 300
Washington, DC 20036-2412
Tel: 202-429-5111
Fax: 202-429-5113
Web Page URL: www.energy.rochester.edu/idea/

American Boiler Manufacturers Association
950 N. Glebe Road
Suite 160
Arlington, VA 22203-1824
Tel: 703-522-7350
Fax: 703-522-2665
Web Page URL: www.abma.com

Council of Industrial Boiler Owners
6035 Burke Centre Parkway
Suite 360
Burke, VA 22015
Tel: 703-250-9042
Fax: 703-239-9042
Web Page URL: www.cibo.org

Clearinghouse

Steam Challenge Clearinghouse
P.O. Box 43171
925 Plum Street, SE
Olympia, WA 98504-3171
Tel: 800-862-2086
Fax: 360-586-8303
Web Page URL: Steamline@energy.wsu.edu

Other Web Sites

U.S. Department of Energy, Office of Industrial Technologies Steam Challenge Program
Web Page URL: www.oit.gov/steam

Alliance to Save Energy
Web Page URL: www.ase.org

Armstrong Steam Library
Web Page URL: www.armstrong-intl.com/university/su.html

Guides and Handbooks

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Naval Facilities Engineering Service Center. 1998. *Steam Traps—An Overview*. Port Hueneme, California.

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Appendixes

Appendix A: Steam Trap Monitoring Equipment Information

Appendix B: Life-Cycle Costing Procedures and the BLCC Software

Contacts

General Contacts

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Produced for the U.S. Department of Energy by the Pacific Northwest National Laboratory

July 1999

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