Best Practices for Heat Tracing Pilot Plants

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Heat tracing a pilot plant is a difficult task, but with proper design and careful installation, the tracing system can operate safely and effectively.

Pilot plants frequently need to operate at elevated temperatures. Achieving and maintaining the desired process temperature can be challenging due to the small size of the equipment, the often congested space, and the poor heat-transfer characteristics of many surfaces. In addition, some industrial heating methods are too difficult or costly to use on the pilot-plant scale. For example, wrapping small pipe and tubing with heat tracing is rarely feasible; many tracers are larger than the tubing and contact between them is poor, which leads to heating problems. And, as shown in Figures 1 and 2, a pilot plant's piping system is complex, with proportionally more heat sinks, such as supports, valves, and piping branches, than are found in an industrial facility.

Effectively heat tracing a pilot plant requires a good understanding of these issues. This article provides best practices for selecting and working with the major types of heat tracing used in pilot plants: self-limiting, constant wattage, steam, and hot oil tracing, as well as tubular resistance heaters and heated enclosures. It concludes with some comments on safety, design, and operations that apply regardless of which specific heat-tracing method is selected.

▲ **Figure 1.** A steam tracing system in a pilot plant is often complex.

Self-limiting electric tracers

Self-limiting electric heat tracing is one of the easiest and safest methods of tracing. This technology consists of a polymer matrix between two conductors. As the line temperature rises, the resistance of the polymer increases, which reduces the power output until eventually the tracer shuts off.

When using self-limiting heat tracing, make sure that the heat output is at the desired operating temperature. If the tracing is incorrectly specified based on the power output at room temperature (rather than at the operating temperature of the process), the system may be undersized and struggle to maintain or even reach the desired process temperature. Since the power output is a function of the operating temperature and not the amount of tracing applied, undersized systems cannot be corrected by adding more tracing — the additional tracing will just reach the same temperature.

The maximum temperature that the self-limiting heat tracing can reach is usually much lower than the maximum temperatures quoted, since the wattage delivered decreases with increasing temperature. Also, the maximum temperature the tracing can produce is typically much lower than the temperature it can withstand; be sure not to confuse the two values. In addition, small pilot-plant systems can experience heat losses in excess of published values, which typically apply to larger, less-complicated tubing runs.

Self-limiting heat tracing draws significantly more power when started up at lower temperatures, as the resistance is lower and the power (and current) draw higher. Hence, starting this type of heat tracing at a much lower temperature than it was designed for may trip a circuit breaker and prevent the system from heating. Manufacturers publish the maximum length of self-limiting heat tracing as a function of starting temperature for common breaker sizes. Unfortunately, some installations have been designed to be energized initially at a higher temperature (such as 60°F) but will then trip when started unexpectedly at a lower temperature (*e.g.,* 40°F). Make sure the system is sized to match the intended operation. A best practice is to size the maximum length per breaker for the coldest possible startup temperature. Relying on someone to remember to turn on the tracing when the ambient air reaches a certain temperature can be problematic.

Significant conservatism is usually required when applying self-limiting heat tracing. It is generally as wide as or wider than much of the pilot-plant-scale tubing to which it is attached, and it is often improperly secured to the tubing around bends, valves, struts, and transitions. Both of these factors contribute to reduced heat-transfer performance. To overcome these limitations, pilot plants should derate the power output at actual operating temperatures by 20–30% (*e.g.,* assume a 10-W/ft tape will deliver only 7 W/ft).

Apply self-limiting heat tracing generously. Be sure to wrap supports, dead legs, gages, instruments, and similar heat sinks.

Heat-transfer cement and heat-transfer tapes (adhesive-tape-like material designed to be affixed over the tracing to help distribute the heat more evenly) are rarely effective with self-limiting heat tracing. They do help and they may be useful for dealing with marginal shortfalls, but it is usually more cost-effective to simply use a higher-wattage tracer.

Constant-wattage heat tapes

Constant-wattage electric heat tapes come in a wide range of styles and are available from a variety of sources. They typically consist of two conductors inside a fabric (or, less commonly, polymer) cover.

The quality of these tapes varies widely, from good to poor. Many lower-cost, generic, laboratory-supply-house models are non-uniform and have a short service life. Heavier-duty (and more-expensive) industrial tapes typically perform better and last much longer. In-house testing is recommended before standardizing on a particular style or model.

The temperature that constant-wattage heat tracing can reach is not limited. As a result, connected components can easily get hot enough to create a burn hazard (>140°F). Additional insulation (to keep the component surfaces below 140°F) may be required; standoffs and insulation barriers (to prevent heating of the associated equipment) can also be used.

Installation of these tapes in an electrically classified area can be tricky, because their heater wires frequently exceed autoignition temperatures (AITs) regardless of how low the control temperature is set. In any traced system, leaks from fittings, valve packing, or similar locations are likely to pass over the heater wire. This presents a significant fire hazard.

One way around this is to purchase higher-voltage tape and run it at a lower voltage, for example, operate a 240-VAC tape at 120 VAC. This can limit the heater wire temperature to below 80% of the AIT. However, this also reduces power by as much as 75% from rated values, which can make it difficult to maintain the desired temperature. The reduction in heater wire temperature depends on many factors and is difficult to calculate, so testing before use is recommended. Also, take care to ensure that any insulation added later does not inadvertently lead to higher — even potentially unsafe — temperatures.

Another possible solution is to install a variable transformer to limit the voltage, or a phase-angle fired silicon controlled rectifier (SCR) to limit the amperage. However, many popular, low-cost SCRs cannot limit either current or amperage (instead, they control power by limiting the amount of time the heater wire is at a specified temperature), and they allow the heater wire to reach operating temperatures. Although this limits the overall power applied, the heater wire temperature is often intermittently hot enough to ignite many materials. While it may be tempting to place a thermocouple directly on the heater wire as a preventive measure, practically this is almost impossible to accomplish.

Poor wrapping of constant-wattage heat tracing can create hazards. Crossing or doubling can allow overlapped areas to overheat and ignite. Shorting to, and even through, piping has occurred in some instances. Hence, it is important

▲ **Figure 2.** Heat tracing often needs to accommodate a wide range of piping configurations, such as these steam-traced feed funnels.

to leave space between successive wraps (Figure 3).

Many constant-wattage heat tapes, particularly the less-expensive models, are both non-uniform and high-power, which can cause significant temperature variation.

These issues suggest that constant-wattage heat tracing should be limited to installations that can tolerate larger temperature fluctuations. Some trial-and-error testing — for instance, rewrapping with more space between wraps, and adding or removing insulation in certain areas — may help to minimize problems, although it is time-consuming and often of limited effectiveness.

Because constant-wattage tracing operates at higher heater temperatures than other types of tracing, burns are, unfortunately, much more common. Hot spots that can cause burns are often difficult to identify in advance and are recognized only after someone receives a burn. As a result, extreme care in initial testing and operation is required. Thermal imaging can be very useful for identifying unknown or unrecognized hot spots.

Heat-transfer cement and heat-transfer tapes are rarely cost-effective with this type of tracing.

Steam and hot oil tracing

Steam and hot oil tracing systems employ a high-temperature fluid flowing inside tubing attached to the piping to be heated. Heat is transferred from the steam or oil, across the contact area, to the process.

The process piping is traced in small sections (zones) to limit the pressure drop through each section's tracing to reasonable limits. The tracing can be assembled in the field from standard tubing and fittings, or purchased as prefabricated bundles with the process tubing, tracing, and insulation already installed (Figure 4).

Modifications are costly, so it is wise to design for extra zones at the outset. Adding spare taps during initial construction, providing oversized supply and return headers, and oversizing the delivery system allow more zones to be added later. It is also prudent to limit tracer runs to reasonable lengths and to use no more than 50% of the available pressure drop. Such measures allow additional length to be added easily to any zone that is operating below the desired temperature, thereby avoiding significant rework (such as adding a complete new zone).

Cool areas often form at the end of long zones, where all the steam has condensed or the hot oil's temperature driving force has been exhausted. Hydraulic problems can also arise in long zones.

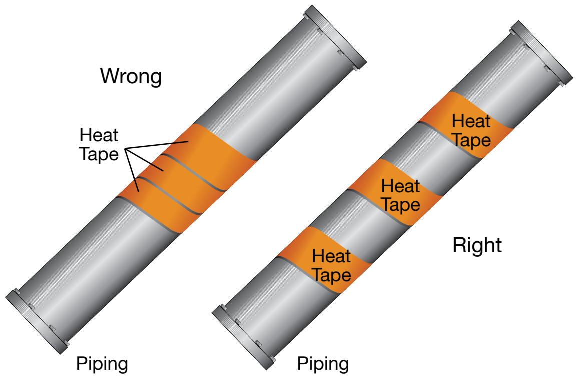
Leakage is a potential problem in both steam and oil systems. To minimize leaks, locate all joints outside the insulation, where they are more accessible for inspection and repair. Weld or braze connections instead of using fittings; the extra time required for their assembly is almost always well worth the savings during startup and shutdown.

Heat-transfer cements can improve the effectiveness of steam or oil tracing, particularly on larger components such as vessels, tanks, etc. They are somewhat less effective on smaller tubing and piping.

In some instances, jacketing may be more effective than tracing. Although jacketing is more expensive, whether purchased or fabricated in-house (for example, from tubing), it is significantly more effective due to the larger and more-uniform heat-transfer area. Since it is not feasible to jacket fittings, this approach is most cost effective for longer runs with few or no fittings.

For steam systems, a dedicated steam trap should be provided for each zone. When multiple zones are served by a common trap, some zones will inevitably not work properly. It is also important to recognize that steam traps need routine maintenance, so accessibility is required.

Hot oil systems use heating fluids that usually break



▲ **Figure 3.** Overlapping tape can short or catch on fire. Be sure to leave a gap between wraps.

▲ **Figure 4.** Pretraced and insulated tubing bundles connected to a steam feed manifold make for a much smaller and neater installation. Simply remove the bundle from a roll, then connect it to the process and to the tracing supply and return.

down over time. Follow the manufacturer's recommendations on the timing for testing and replacing the fluid. Since many high-temperature fluids are hazardous (or become so over time), evaluate before construction how to safely change out degraded fluids; this may require additional piping and/or safeguards (ventilation, closed transfers, etc.).

Tubular resistance heaters

Tubular resistance heaters typically consist of two conductors inside a stainless steel sheath with an insulating powder filling the annular area. As with constant-wattage heat tracing, components and supports can get hot enough to create a burn hazard, and the skin temperature of the sheath can easily exceed AITs and create an ignition hazard. Solutions similar to those discussed for constant-wattage tracing can minimize these risks.

Alternatively, attaching a thermocouple to each tubular heater and controlling the system to below the AIT is feasible, but not simple. This approach, depicted in Figures 5 and 6, requires separate control and alarm thermocouples as well as a separate controller and alarm. Hence, it is expensive. In addition, finding the hottest point on the heater may require testing after installation; predicting the location in advance is difficult to impossible.

When installing tubular resistance heaters, lay the tubular heater against the piping. Wrapping the heater around the tubing with a bend radius that is too tight can cause fatigue failure and/or break the heater. Reuse (*i.e.,* wrapping-unwrapping-rewrapping) of this type of tracing is not recommended, as it commonly leads to fatigue failure.

Secure all tubular resistance heaters with numerous, closely spaced ties. These heaters tend to pull away from the tubing when they get hot, which reduces heat transfer. A tie spacing of 2–4 in. is recommended.

Tubular resistance heaters are difficult to wrap around supports, instruments, and other heat sinks. To prevent the formation of cold spots, take care to cover these components as well. Care is also necessary in the piping design. Rather than supporting the piping and insulating the piping and support, it is usually better to insulate the tubing and support the insulation. This eliminates the support as a heat sink.

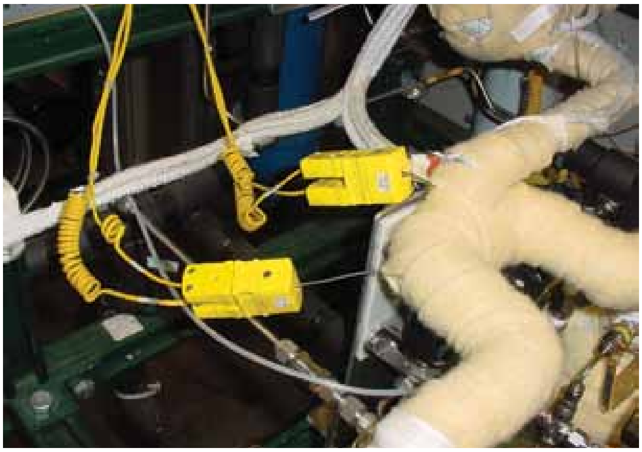
Heat-transfer cement can be slightly more effective with tubular resistance heaters than other types of tracing, as these heaters are often the same size or smaller than the tubing. However, unless the heater is installed with numerous close-fitting supports to severely limit thermal expansion, the cement usually has a short life because it easily cracks and breaks off during thermal cycling. Heat-transfer tapes offer only marginal improvement, mainly because the heater's higher heat flux exceeds the tape's capacity. In addition, many tapes separate from the heater over time, which reduces their effectiveness.

Heated enclosures

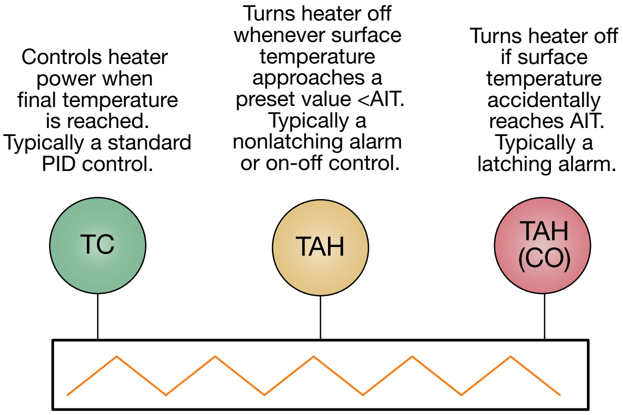
Heated enclosures (Figure 7, next page) are common in pilot plant work. Their major advantage is their separation from the process — because nothing is affixed to the piping, the process can be easily modified. However, retrofitting an enclosure on existing piping and equipment is difficult to impossible; hence, it is important to carefully evaluate this approach before starting construction.

A best practice is to use commercial strip heaters to heat the enclosure. These have a much longer service life and lower cost than most homemade alternatives.

Temperature uniformity within the enclosure is primarily a function of air circulation. Providing a high air circulation rate helps to minimize temperature gradients. Effective circulation patterns can be obtained in several ways. Installing the heaters at the bottom of the box and relying on the rising heat is often sufficient for small enclosures (roughly



▲ **Figure 5.** This electric heat tracing system includes two thermocouples, one for control and an independent one for over-temperature protection.



▲ **Figure 6.** A control system such as this can be used to meet a Class I or II area electrical classification.

8 ft^3 or smaller). Placing holes or slots that allow cool air to flow in at the bottom and hot air to flow out near the top of the box is often effective for moderate-size (about 8–50 ft^3) and/or lower-temperature (below 150°F) enclosures. Larger enclosures generally require air amplifiers (for temperatures higher than about 250°F) or internal fans (for temperatures below 250°F).

Consider how valves and other components will be actuated. This may require additional care in layout to ensure that all components are accessible from outside of the box. When access is needed infrequently, it is sometimes practical to carefully reach in through strategically located doors. A better practice, however, is to extend valve handles through the box wall. With higher-temperature enclosures, longer extensions may be required to allow for cooling. Make sure the mechanism that connects the extended handle to the valve cannot loosen with repeated heating and cooling. Pins or brackets are usually better than set screws in this regard, although high-temperature locking fluids can often help to reduce loosening — but rarely eliminate it. In other cases, remote actuation may be required.

Meeting a hazardous area electrical classification is relatively straightforward with a heated enclosure. It is often possible to purchase a higher-voltage heater and operate it at a lower voltage as discussed earlier.

Testing before use is recommended, and is usually successful because these heaters are much larger and tend to distribute the heat more evenly than other tracing methods.

Limiting the voltage or amperage is also much easier, because attaching a surface thermocouple or resistance temperature detector (RTD) to the skin of a commercial strip heater is generally straightforward.

Finally, purging the entire enclosure in accordance with NFPA 496, Standard for Purged and Pressurized Enclosures for Electrical Equipment, allows the heater to operate at temperatures above the AIT. In some cases (for instance, if the interior of the enclosure has numerous potential leakage sources), purging with inert gas rather than air might be required.

Burn hazards, while significantly less of a problem, can still exist. Common problem areas include doors and panel clearances, valve handle extensions immediately next to the heated enclosure, process lines immediately next to the heated enclosure, and structural supports. Potential hot spots such as these are usually easily identified during commissioning, but some care in initial operation is required. Thermal imaging devices can be very useful in easily and effectively identifying these areas.

▲ **Figure 7.** These two ovens are being used as heated enclosures.

Less-effective practices

A discussion of best practices would not be complete without some mention of less-effective approaches.

Preheaters are usually only viable if the section to be heated is very short (*e.g.,* a reactor) and the preheater can be located immediately upstream of the heated component. Heat lamps are limited to very-low-temperature applications (typically 120°F or lower) and to general-purpose areas; their effectiveness is also very limited. Forced hot air systems are usually limited to low temperatures (typically 200°F or lower); otherwise, system complexity increases significantly.

Safety

Make sure the method you are considering can meet the required area electrical classification. In general, self-limiting and steam tracing are inherently safer than other methods. And, hot oil systems can often be designed for low enough temperatures to meet area electrical classification requirements.

Constant-wattage and tubular resistance tracing require careful over-temperature protection. Both types of tracing should have independent temperature control and over-temperature shutdown sensors, and their over-temperature system should be completely separate from the main pilot

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plant control system. Careful placement at the hottest point is also required.

Heated enclosures are generally recommended for higher-temperature applications (above 350°F), as they can most easily be designed to minimize cold spots and meet area electrical classification requirements than other types of heat tracing.

Expansion and contraction following heating and cooling can significantly increase the frequency and amount of process leakage. Consider eliminating joints by welding or using single lengths of tubing. Alternatively, it might be prudent to always keep the pilot plant hot, even when it is not in operation, to avoid leakage caused by thermal cycling. Make routine leak testing an integral part of the startup procedure, and be sure it is well thought-out and carefully done.

Proper wiring and grounding is critical to avoid shock hazards. Lockout/tagout procedures need to be enforced consistently. Just as importantly, pay careful attention to lockout/tagout during the design phase to make sure it can be done easily and safely. Remember that all electric tracing requires ground fault interrupt (GFI) protection as prescribed by the National Electric Code.

Personnel protection needs careful consideration. To avoid burns, check insulation regularly and make any necessary repairs promptly.

Design and operations

It is important to be realistic about how to provide over-temperature protection. Many proposals are inherently risky and difficult to implement safely and effectively. Finding the hottest spot to monitor temperature almost always requires post-construction testing (and often modification!).

Be skeptical of published heat loss values based on larger installations, components, or piping. Heat losses in pilot plants are often much larger because of the higher density of valves and supports. In addition, pilot plant insulation is rarely as good as insulation in a full-scale plant. Consider the need for standoffs to isolate heated components from supports.

Carefully review the need for access to the process piping during the design. It often dictates how certain sections or components can most effectively be heat traced. CEP