Prevention is better than cure

Brandon T. Vincent and **Thomas C. Willingham** of Controls Southeast, Inc discuss the importance of adequate heating to prevent plugging and corrosion problems in sulphur tail gas lines and compare the economics of ControTrace versus tube tracing.

Throughout the world, refineries and natural gas plants utilise large-bore piping systems to transport hot tail gas. Tail gas is a by-product of an equilibrium-limited Claus reaction designed to convert H_2S to elemental sulphur. Its chemistry generally includes N_2, H_2O, CO_2, and a variety of sulphur compounds such as H_2S, SO_2, S_x, COS, and CS_2. Tail gas flows from the last sulphur condenser to the tail gas unit (TGU); during upset conditions, tail gas can bypass the TGU to go directly to the incinerator. Tail gas processing can be frustrated by plugging and corrosion in the piping. Figure 1 shows a tail gas line failure due to plugging at a butterfly valve. Figure 2 shows a tail gas line from another plant which failed due to extreme corrosion. Corrosion in a tail gas line can be quite aggressive, and rates as high as 0.75 mm/month have been recorded. Tail gas processing varies from plant to plant due to differences in licensed technology, feedstock chemistry, and site operations. This variability contributes to a lack of industry consensus on the root cause mechanisms of tail gas line failures. However, it is generally agreed that inadequate heating is a contributing factor to tail gas line failure.

Pipe heating system

It is considered an industry best practice to heat tail gas lines via a pipe heating system using 3.5 to 10 barg saturated steam. Pipe heating systems are typically designed to maintain either the process temperature or the pipe wall temperature. In process applications which feature liquid flow (such as molten sulphur), a common thermal requirement is to maintain a minimum bulk process temperature to preserve its flow-ability. Vapour processes, on the other hand, generally require that the pipe wall temperature be maintained above the vapour dew-point to prevent condensation. If saturated tail gas contacts a cooler pipe wall, it will condense on the pipe wall. If the pipe wall temperature is below ~120°C, solid sulphur can build up on the pipe wall and can begin an aggressive iron/sulphur corrosion process. Regardless of the heating technology employed, the technology provider must have the capability to predict the temperature profile within the pipe wall and to engineer a system to maintain the minimum wall temperature at or above the incoming tail gas temperature. Particular attention must be applied to flange pairs and pipe supports since these components act as heat sinks and can create local cold spots at the pipe wall.

Tail gas lines are most commonly heated using ControTrace bolt-on jacketing or tube tracing. Both technologies feature heating elements which run alongside of and are attached to the piping. Steam flows through the heating elements and transfers its heat to the piping. ControTrace heating elements have a 50-mm X 25-mm rectangular cross section. One of the 50-mm surfaces is formed with a concave radius. The radius matches the outside diameter of the process piping, thus ensuring good contact

Fig 1: **Tail gas line failure due to plugged butterfly valve**

Fig 2: **Tail gas line failure due to extreme corrosion**

Fig 3: **ControTrace heating system for 900 mm tail gas line**

Fig 4: **Tube tracing for 750 mm tail gas line**

Fig 5: **Baseline tail gas piping system**

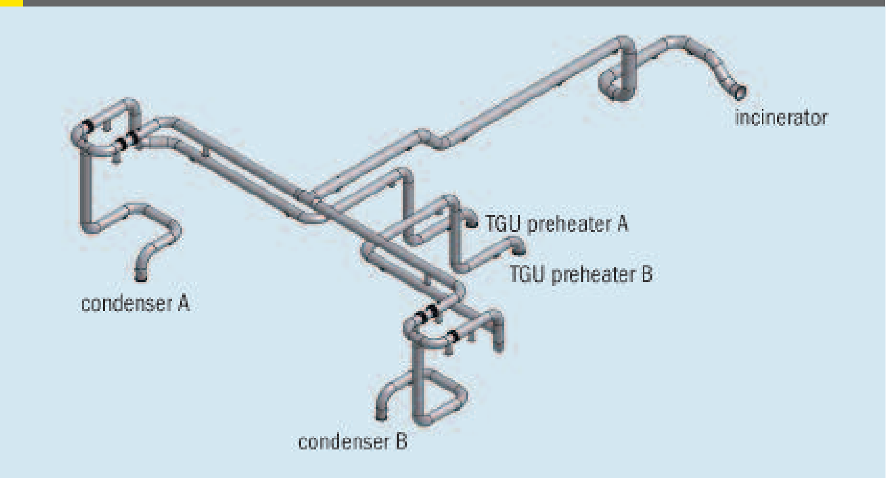
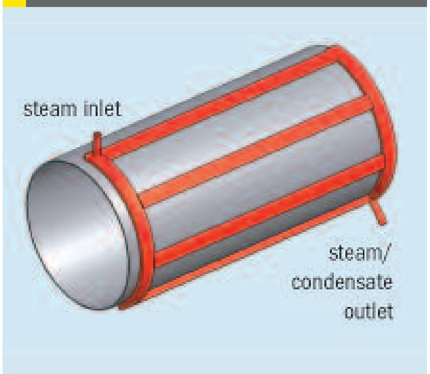


Fig 6: **ControTrace panel consisting of multiple heating elements**



For illustrative purposes only, the mirror panel on the back side of the pipe is not shown.

between the heating element and the pipe. Tube tracing, on the other hand, is 10-mm or 13-mm diameter tubing and at most contacts the piping at a single point. Enhanced tube tracing features the application of heat transfer cement between the trace and the pipe to widen the heat transfer contact area. In either technology, the number of heating elements is varied based upon the process temperature/properties, flow conditions, piping materials, insulation type/thickness, and ambient conditions. Fully jacketed piping is a third heating option, but it is generally recognised as quite expensive and even cost-prohibitive at pipe sizes above 300 mm. Examples of ControTrace and tube tracing applications on tail gas lines are shown in Figs 3 and 4, respectively.

When selecting a tail gas pipe heating system, one should consider both performance history and cost. The three major cost components are:

- the capital expenditure for the heating system;
- capital expenditures for the utilities infrastructure to supply steam to the heating system;
- on-going operational expenditures to maintain the system/utilities.

Unfortunately, only the capital cost of the heating system is typically considered. The cost of the utilities infrastructure is a significant portion of the system costs, and neglecting it during technology selection can lead to a poor economic decision. The ongoing operational expenditures for a steam system are not well quantified. However, it seems reasonable that reducing the total number of components within a system leads to reduced operating costs, particularly when steam trap surveys commonly report that a third of a plant's trap population does not function properly.

Economic analysis

An economic analysis was performed to compare the total capital costs of ControTrace and 13-mm tube tracing for a tail gas piping system. Both tube tracing and enhanced tube tracing were considered. The piping system was chosen from a survey of over ten refineries and is representative in both its routing and distance. The system, shown in Fig. 5, features two parallel trains from the condensers to the TGU pre-heaters along with a common bypass line from the condensers to the incinerator. Total length of piping in the system is 300 m. Four different pipe size scenarios were considered: 450/600 mm, 600/750 mm, 900/1,050 mm, and 1,500/1,800 mm. (The first dimension represents the pipe size in all but the common bypass line, and the second dimension represents the bypass pipe size.) Since tail gas technologies feature a variety of process temperatures off the condenser,

Table 1: **Number of heating elements and circuits for each scenario**

	450 mm			600 mm			900 mm			1500 mm		
3.5 barg steam	CT	TTe	TT	CT	TTe	TT	CT	TTe	TT	CT	TTe	TT
Quantity of elements	6	14	31	8	17	32	10	23	46	14	32	76
Quantity of circuits	28	136	304	28	172	322	56	226	460	84	320	758
10 barg steam	CT	TTe	TT	CT	TTe	TT	CT	TTe	TT	CT	TTe	TT
Quantity of elements	4	9	18	6	11	23	8	15	32	10	21	52
Quantity of circuits	12	67	152	12	79	162	12	107	225	20	149	368

two thermal scenarios were considered: 135°C saturated tail gas maintained by 3.5 barg steam and 157°C saturated tail gas maintained by 10 barg steam. Finite-difference computer modeling was performed on the piping system to determine the number of heating elements around the pipe circumference required to prevent tail gas condensation at the pipe wall. Multiple ControTrace panels and tube tracing runs were connected in series to form a steam circuit. Steam supply and condensate return locations for the circuits were designed to allow steam to flow from a high to low elevation without pocketing and to resupply steam prior to excessive loss in steam pressure. Pressure drop calculations were performed to assess the steam pressure loss for ControTrace. For tube tracing, circuit lengths were established at 45 and 60 m for 3.5 and 10 barg steam, respectively, based on typical tube tracing specifications. Finally, additional flange and pipe support heating was included in the ControTrace systems but not in the tube tracing systems. (Flange and pipe support heating is very difficult with tube tracing, so it is often ignored.) This had the result of increasing the cost and circuit count for the ControTrace systems.

Table 1 shows the number of heating elements and circuits for each scenario. ControTrace (CT) requires the least number of elements due to its greater contact area with the pipe. Enhanced tube tracing (TTe) requires 2.5 times more elements, and bare tube tracing (TT), due to its minimal point contact with the pipe, requires over 6 times more. For ControTrace, multiple elements on each side of the pipe are connected into a single panel with one inlet and one outlet, as shown in Figure 6. This yields two heating panels for each section of piping and, therefore, two circuits for each supply/return location. For tube tracing, each tracing element is a separate circuit, resulting in significantly more circuits in the total system. There is a unique steam trap required for each circuit. Figure 7 shows the

Fig 7: **Quantity of steam traps required at 3.5 barg steam**

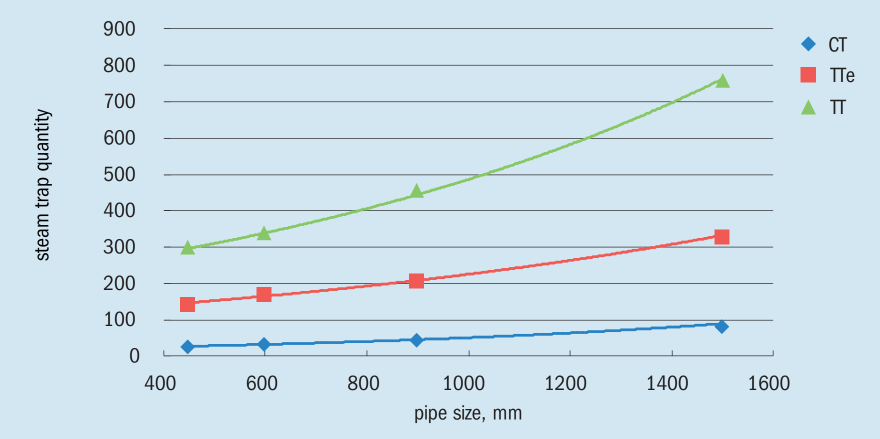


Fig 8: **Total length of tracing to install at 3.5 barg steam**

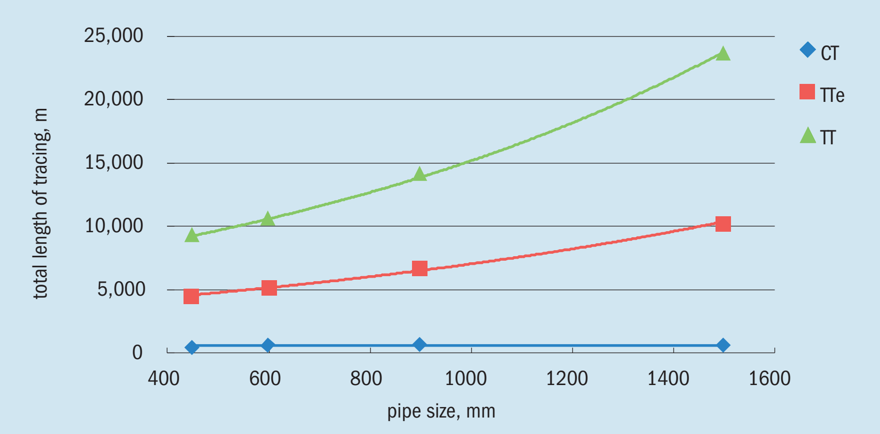
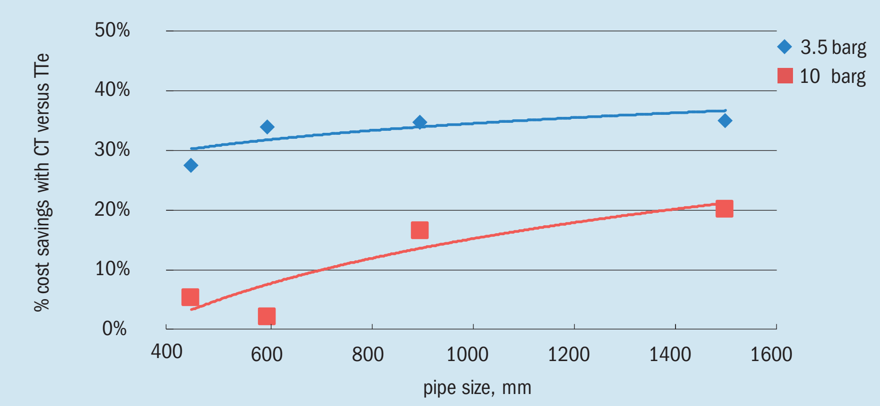


Fig 9: **Cost savings with ControTrace versus tube tracing**



steam trap quantities required for each scenario at 3.5 barg, and Fig. 8 shows the total length of tracing to be installed for each system. While ongoing operational costs cannot be easily quantified, it is generally agreed that a 10-20 times difference in the length of tracing to be installed and a 5-10 times difference in the number of traps to maintain translates to significant differences in system robustness.

Total system costs were based on the design configurations in Table 1 combined with industry standard installation practices and current pricing for materials and field labor. Once received on site, each meter of ControTrace or tube tracing must be attached to the piping. Each supply/return location requires supply/return manifolds complete with valves and steam traps. Field labour is required to set these manifolds in position and to run an average of 25 m of pre-insulated tubing from the supply/return port on the manifold to the circuit. A summary of all cost assumptions is provided in $US in Table 2.

Table 2: **Summary of material and labour cost assumptions**

Tube trace: 13 mm SS welded, 0.9 mm wall, $/m	8.37
HTC and channel for enhanced tube trace, $/m	18.37
Banding for trace installation, $/m	3.28
Pre-insulated tubing: 19mm SS welded, $/m	17.36
Pre-insulated tubing: 13mm SS welded, $/m	14.57
Manifold to tubing connection, $	23.47
Tubing to tubing connection, $	30.05
Steam supply manifold, $ per port	537.35
Condensate return manifold, $ per port	975.35
Labor rate, $/hr	42.00
Tube trace installation rate (m/hr)	2.13
Enhanced tube trace installation rate (m/hr)	1.58
ControTrace installation rate (panel/hr)	0.33
Pre-insulated tubing installation rate (m/hr)	2.74

Total system costs

The total system costs for ControTrace and tube tracing for the 450 mm scenario at 3.5 barg steam are compared in Table 3. Neglecting infrastructure costs, enhanced tube tracing offers 30% savings over ControTrace, and historical economic considerations have stopped at this point. But, when infrastructure costs are included, ControTrace offers 28% cost savings over enhanced tube tracing. This dramatic shift is due to the fact that tube tracing requires significantly more utilities infrastructure than ControTrace. Approximately 20% of the total ControTrace system cost is in infrastructure compared to 60% for tube tracing. This also renders tube tracing more sensitive to potential price escalation in materials, field labour rates, and field productivity. From Table 3, it can also be seen that bare tube tracing (without heat transfer cement) is terribly cost-prohibitive.

Table 3: **System cost comparison for 450 mm piping system at 3.5 barg steam**

	CT	TTe	TT
Trace material, $	309,481	127,441	110,547
Trace install, $	35,154	112,817	186,840
System Subtotal, $	344,635	240,258	297,387
Pre-insulated tubing, $	22,218	90,576	202,464
Pre-insulated tubing install, $	19,600	47,600	106,400
Manifolds, $	45,381	215,407	481,640
Tubing connections, $	1,795	6,865	14,751
Infrastructure subtotal, $	88,994	360,448	805,255
Grand total, $	433,629	600,706	1,102,642

ControTrace offers cost savings over enhanced tube tracing that increase with larger pipe sizes and lower steam pressures, as shown in Fig. 9. Systems which utilise a lower steam pressure feature a smaller temperature difference between the steam and the process. This results in a smaller heat transfer rate than would be achieved with a higher steam pressure, requiring more elements to achieve the thermal objective. The increased element count increases the infrastructure requirements, which increases the cost savings. Element count also increases with pipe size, further increasing the cost savings. At a 450 mm pipe size (the smallest tail gas piping of any of the refineries surveyed for this analysis) and 10 barg steam pressure, ControTrace and enhanced tube tracing are near cost parity. Total cost savings of up to 35% are possible at larger TGU capacities.

Conclusion

Historically, the most common technology used on tail gas lines was tube tracing. Superior operational performance with ControTrace over the last decade across a wide spectrum of refineries and extreme operational conditions has reversed that trend. But, some designers still lean toward the use of tube tracing for its perceived cost benefit over ControTrace and fully jacketed piping. Such an assessment neglects the cost of required utilities infrastructure and leads to a faulty economic decision. When all capital costs are considered, an engineered ControTrace system can offer up to a 35% cost savings over tube tracing. Compared to tube tracing, ControTrace minimises the quantity of equipment to install and steam traps to maintain. It also renders the total system cost less sensitive to potential price escalation in materials, field labor rates, and field productivity. In addition to these economic benefits, ControTrace offers a technically superior product due to its increased heat transfer contact area, more robust construction (3 mm wall thickness), panel configuration that is easier to handle/install, ability to adequately heat flange pairs and pipe supports, and system design which ensures a certain wall temperature distribution based on heat transfer computer modeling and pressure drop calculations. An additional feature of a ControTrace system is custom designed field construction drawings which eliminate the potential for installation ambiguity. Considering the wide variability in tail gas technology licensing, feedstock chemistry, and site operations, ControTrace provides an economic means of increasing plant robustness against costly process interruptions.