TECHNICAL REPORT

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EFFICIENT STEAM TRAPS FOR ENERGY CONSERVATION

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All of us are familiar with terms such as energy conservation, high fuel costs, inflation, recession and many others, and their implication of knowledge and experience in regard to a plant's overall profitability. However, these same terms are often disregarded when considering the smaller, yet equally important aspect of proper equipment utilization in a system. In particular, the amount of steam energy lost from a system which uses steam to perform a wide range of functions is overlooked. This preventable waste is somewhat understandable as most maintenance crews control the operation of an established steam system and consequently order steam traps according to price and ease of installation rather than technical qualifications and performance. This type of situation is most often true in tracer line use. These lines and their related products, such as valves, traps, and strainers, are often regarded as necessary, but not very significant pieces of equipment. Tracer lines do not have a direct relationship with the final product, however they still play a very vital role in getting the final product on the market. Carefully chosen equipment and a well-managed maintenance program for tracer lines can save many barrels of oil every day. At the relatively high cost of a kilogram of steam, these additional savings will immediately lower the total overhead of the plant and raise the profit level. Maintenance alone cannot do the job; the product selected must be suitable for the application. In every tracer line there is an automatic unit controlling the discharge of condensate at changes of elevation, predetermined lengths or at the end of each tracer line. This automatic device, the steam trap, is often the vital link which controls whether or not the tracing system is brought up to temperature as quickly as possible without backing up the condensate or passing live steam. Since the steam trap does not directly improve the end product, it is often ignored. We should not forget that this automatic device helps the tracer line obtain maximum thermal efficiency. The tracer line, having maximum thermal efficiency output, maintains the product at a temperature which keeps the process fluid flowing. Taking this into consideration, it becomes very reasonable to be more attentive to this device which, with its comparatively low cost, enables the system to operate at maximum efficiency.

Many types of traps have been tried in this industry. Several criteria have been set to establish what a good trapping device should do. However, one criterion on which no one has ever put much emphasis concerns heat loss. The heat loss can be related to either the subcooling of the condensate ahead of the steam trap or the loss of live steam through the orifice. Most of the time this automatic device is purchased on physical size and price only which often results in high profit losses. Until recently, not very much was known about the heat loss or the kilocalorie inefficiency of a steam trap. Before studying this question further, let us look at what to expect from a steam trap.

A steam trap must discharge the formed condensate and hold back the live steam. It should retain the kilocalories of latent heat, but pass on the few kilocalories which are in the sensible heat. It should discharge the condensate formed at the line pressure with its equivalent temperature and not let this condensate back up in the tracer line. If this occurs, the thermal efficiency from the tracer line to the product is lost in the area where the condensate is backed up, and the tracer line does not perform its job. It should also be remembered that it is the condensing of live steam, not the condensate, which contains the large amount of kilocalories. You will note from the steam tables that only one kilocalorie is transferred for every °C the condensate temperature drops. However, 500 kcal of energy are released in the change of phase when steam is converted from a gas into a liquid.

A second important part in the total thermal efficiency of a tracer line and the heat loss of a trap is that a trap should not discharge any live steam. It is just as detrimental when the trap discharges a certain amount of live steam with the condensate as it is when it backs up the condensate before discharging, allowing it to **subcool.** This discharged steam still contains the latent heat which failed to perform its work in the tracer line. In other words, the return lines become hot instead of the equipment. Other aspects could be mentioned in steam trap selection such as materials, easy installation, capacities, etc., but basically the most important point is how much work does the trap perform at the lowest cost?

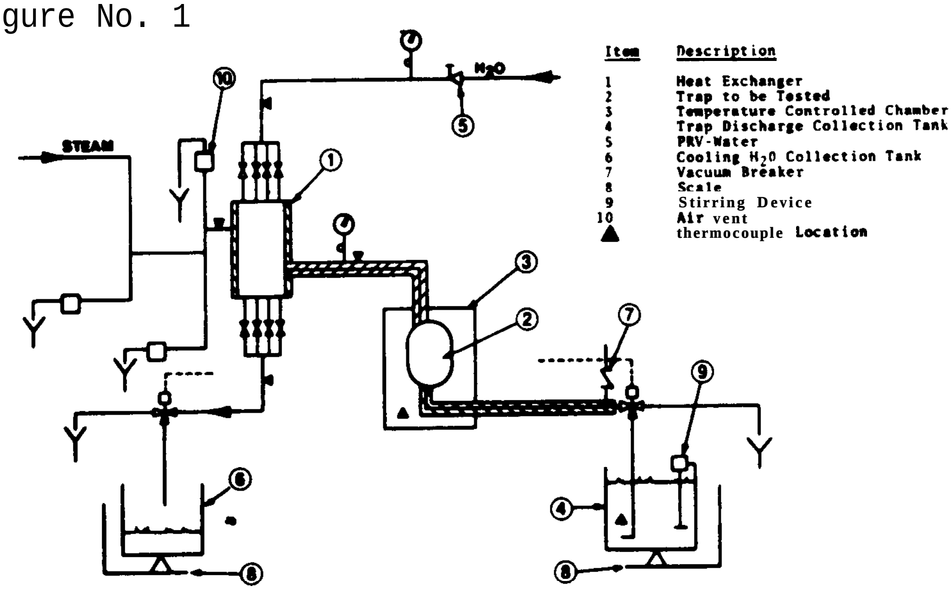
Heat loss can be summed up by these two factors: the waste of live steam and the degree of subcooling which the unit allows before performing its function. For these reasons it can be stated that the final cost of a trap is determined by either the number of kilocalories it discharges or consumes in its operation, or the kilocalories of sensible heat it gives off before discharging. Taking all of this into consideration, it becomes readily apparent that a trap should not be purchased on price and ease of installation alone.

Testing the heat loss of a trap on every piece of steam using equipment would be quite an involved and lengthy experiment. Therefore, a test was set up using two types of commonly used traps, thermodynamic and inverted bucket. Since it was difficult to test these two types of traps on process equipment, it was decided to conduct all tests on one particular application. Tracer lines were chosen because of the large number of traps used in this application. A marketing study revealed that most tracer lines were designed for use between 7 - 12 kg/cm^2. Capacities of the units were between 10 - 100 kg/hr. The average outside temperature was difficult to establish, but was set at -45° C which is equal to 0° C with a wind chill factor of 15 km/hr. With these standards established, the following experiment was set up in our laboratory to perform a heat loss test on the steam trap. Steam is supplied via a separator through a calorimeter into the shell of the heat exchanger. The heat exchanger, containing four cooling water tubes, is so designed that it will operate with one or more tubes in an open position. Closing all the tubes will give us a near no-load condition. The cooling water is collected in a tank. The steam and condensate from the shell of the heat exchanger is then supplied to the testing chamber. The testing chamber is which the to-be-tested trap is installed is kept at a constant temperature. The condensate discharged by the trap is fed into a second tank. Two three-way valves are installed on the cooling water outlet and the trap discharge outlet and are used to stabilize the total system on start-up. Temperatures are taken at six different points; namely, the incoming cooling water, the incoming steam, the outgoing cooling water, the steam and condensate supply line to the testing chamber, the condensate collection tank and the testing chamber. A vacuum breaker is installed on the condensate return so that no vacuum can pull the condensate out of the tank and into the supply line when the steam supply is shut down at the completion of the test. Also, a stirring device is installed in the condensate tank to avoid stratification and to assure an accurate temperature reading. The following procedure was used to test each type of trap.

First, the temperature in the testing chamber is set. Then the cooling water flow rate and the number of open tubes are set to generate a specific load from the heat exchanger. The initial weight of the partially filled condensate collection tank is established. This tank is kept partially filled with water so that any flash steam entering the tank will be condensed. At **the** same time, the initial weight of the cooling water collection tank is established. The system is then allowed to stabilize with the trap discharging to drain and the cooling water flowing to drain. The steam pressure, the ambient temperature and the initial temperature of the water in the condensate collection tank are then recorded. The test is started by simultaneously diverting the trap discharge and the cooling water into each specific tank. The timer is started at that point. A multi-point temperature recorder continually monitors the steam temperature, cooling water inlet and outlet temperatures across the heat exchanger and the temperature in the testing chamber. The temperature in the collection tank is also monitored. The test is ended when the condensate collection tank temperature is the same amount above room temperature as it was below room temperature at the start of the test. This is to minimize any radiation heat transfer between the tank and the room. At the end of the test, the trap discharge and cooling water are again diverted to drain and the timer is stopped. Final weight and temperature of the collection tanks are then recorded. The temperature plots from the multi-point recorder are averaged for each of the points monitored and recorded. The steam trap evaluation test setup is pictured below.

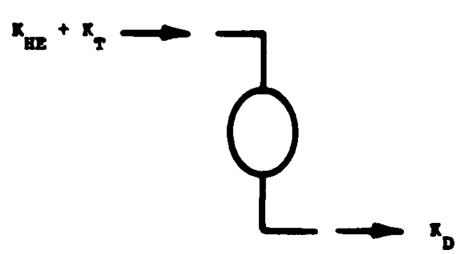
TEST TO ESTABLISH THE ENERGY CONSUMPTION OF A STEAM TRAP

Figure No. 1



The test data is then converted to meaningful results by performing a number of calculations.

Figure No. 2



The basis for the calculation of the total steam loss of the trap is a mass balance across the trap. The condensate load generated in the heat exchanger plus a quantity of steam (total steam loss of the trap) flow to the trap. This equals the load discharged by the trap into the collection tank.

$K_D = K_{HE} + K_T$

or (Law of Conservation of Mass)

$K_T = K_D - K_{HE}$

Where:

K_T = Total steam loss of trap (kg/hr)

K_D = Load discharged by trap (kg/hr)

K_{HE} = Condensate load generated in heat exchanger (kg/hr)

The load discharged is calculated as follows:

$K_D = (W_E - W_S)(60/t)$ (kg/hr)

Where:

K_D = Load discharged (kg/hr)

W_S = Initial weight H_2O & container (kg)

W_E = Final weight H_2O & container (kg)

t = Length of test (min)

The condensate load generated in the heat exchanger is calculated using the equations that follow:

$K_{HE} = q_H/r$ (kg/hr) (Saturated Steam supplied to Heat Exchanger)

also

$q_H = K \cdot c_p \cdot \Delta T$ (kcal/hr)

and

$K = \Delta W\ (60/t)$ (kg/hr)

Therefore:

$$K_{HE} = \frac{60 \cdot \Delta W \cdot c_p \cdot \Delta T}{r \cdot t} \quad \text{(kg/hr)}$$

Where:

K_{HE} = Load generated in heat exchanger (kg/hr)

q_H = Heat transferred in heat exchanger (kcal/hr)

K = Mass flow rate cooling H_2O (kg/hr)

c_p = Specific heat cooling H_2O at temp. average (kcal/kg/^oC)

ΔT = Temp. H_2O out - temp H_2O in (^oC) (temp. out $\leqslant 100^o$ C)

ΔW = Cooling H_2O collected (kg)

t = Length of test (min)

r = Latent heat at steam temp. (kcal/kg)

The condensate load to the trap equals the load generated in the heat exchanger plus the load generated by piping losses between the heat exchanger and the trap. The magnitude of this loss is extremely small because this pipe is short in length and is well insulated. Since this loss is nearly identical for every trap tested, it cancels when comparing the results.

After the total trap steam loss has been determined, the total trap heat loss is calculated as follows:

$Q_{TL} = K_T \bullet i''$ (kcal/hr)

Where:

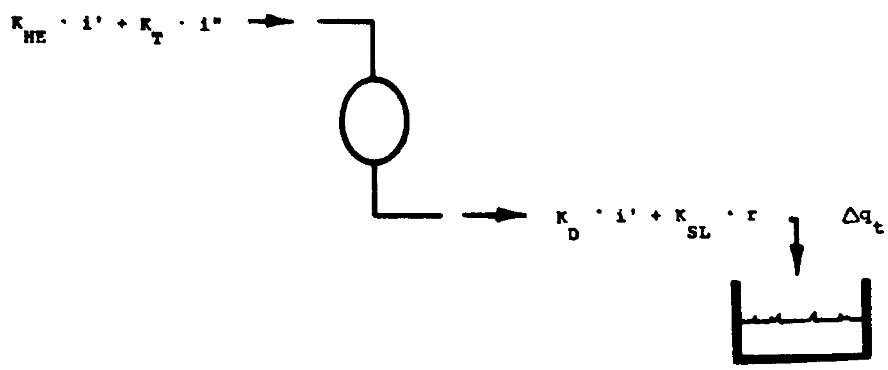
Q_{TL} = Total heat loss of trap (kcal/hr)

K_T = Total steam loss of trap (kg/hr)

i'' = Specific enthalpy of saturated steam (kcal/hr)

The total trap losses which have been determined, represent the quantity of steam that passed through the heat exchanger without performing any useful work. These total losses are composed of two parts. The first part is attributed to the condensate generated within the trap as a result of convection and radiation losses from the trap body. The second part is live steam which has passed through the trap's orifice. To further evaluate the performance of the trap, the magnitude of this live steam loss is determined. The basis for this calculation is a heat balance between the trap and the trap discharge collection tank.

Figure No. 3



(Assuming the trap discharges saturated condensate plus possibly some live steam.)

$$\Delta q_t = K_D \cdot i' + K_{SL} \cdot r \quad \text{(kcal/hr)}$$ (Law of Conservation of Energy)

Where:

Δq_t = Heat collected in trap discharge tank (kcal/hr)

K_{SL} = Live steam loss of the trap (kg/hr)

K_D = Load discharged by trap (kg/hr)

i' = Enthalpy of condensate at steam temperature (kcal/kg)

r = Latent heat saturated steam (kcal/kg)

The heat collected in the tank equals the change in total enthalpy of the tank and water during the time period of the test.

$$\Delta q_t = (i'_F - i'_I)\ (60/t)$$

Where:

i'_F = Total enthalpy at the end of test (kcal)

i'_I = Total enthalpy at the beginning of test (kcal)

t = Length of test (min)

To calculate the total enthalpy or heat of the tank-water system, the water equivalent weight of the tank is first calculated. This is necessary because it obviously requires fewer kilocalories to raise the temperature of the metal tank 1° c than to raise the temperature of the water 1° C.

$$W_e = W_c \cdot c_{pc}/c_{pw} \quad \text{(kg)}$$

Where:

W_e = Water equivalent weight of tank (kg)

W_c = Weight of tank (kg)

c_{pc} = Specific heat container (kcal/kg/$^\circ$C)

c_{pw} = Specific heat water (kcal/kg/$^\circ$C)

$W_e = .117\ W_c$

(Container is stainless steel; water in 10 - 60° C range: container temp. $\approx$ H_2O temp.)

And:

$$W_I = W_S - W_c + W_e$$

$$= W_S - W_c + .117\ W_c$$

$$= W_S - .883\ W_c\ \text{(kg)}$$

$$W_F = W_E - W_c + W_e$$

$$= W_E - .883\ W_c\ \ \text{(kg)}$$

Where:

W_I = Initial weight H_2O + H_2O equiv. container (kg)

W_F = Final weight H_2O + H_2O equiv. container (kg)

W_S = Initial weight H_2O + container (kg)

W_E = Final weight H_2O + container (kg)

The initial total enthalpy and the final total enthalpy of the tank-water system are as follows:

$$i'_I = W_I \cdot i'_{ISP}\ \ \text{(kcal)}$$

Where:

i'_{ISP} = Specific enthalpy of H_2O at initial temp. (kcal/kg)

$i'_F = W_F \cdot i'_{FSP}$ (kcal)

Where:

i'_{FSP} = Specific enthalpy of H_2O at final temp. (kcal/kg)

Again, the heat added to the trap discharge collection tank is as follows:

$$\Delta q_t = (i'_F - i'_I)\,(60/t)$$

$$= (W_F \cdot i'_{FSP} - W_I \cdot i'_{ISP})\ (60/t)$$

But it was previously stated that:

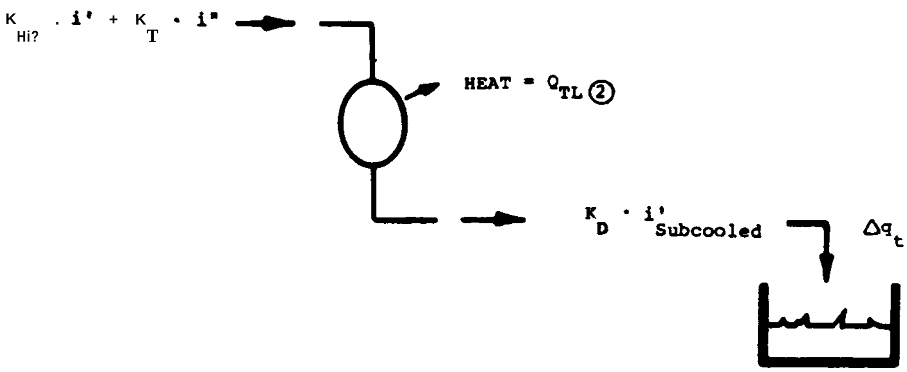
$$\Delta q_t = K_D \cdot i' + K_{SL} \cdot r$$

Therefore, the live steam loss is determined as follows:

$$K_{SL} = \frac{\Delta q_t - K_D \cdot i'}{r}$$

Some traps back up condensate allowing it to cool below saturation temperature before it is discharged. When this condition exists, the assumption that the trap discharges saturated condensate plus possibly some live steam (which was made in the previous calculation of live steam loss), is invalid. As a result, the calculated live steam loss will appear negative. Obviously, the magnitude of the trap's live steam loss cannot be less than 0. When a trap discharges subcooled condensate only, the total trap heat loss can be evaluated as follows:

Figure No. 4



$$K_{HE} \bullet \text{j\_t}+K_T \bullet \text{j\_@l=Q}_{TL\,(2)} + K_D \cdot i'_{Subcooled}$$

But:

$$K_D \cdot i'_{Subcooled} = \Delta q_t$$

So:

$$K_{HE} \cdot i' + K_T \cdot i'' = Q_{TL\,(2)} + \Delta q_t$$

Or:

$$Q_{TL\,(2)} = K_{HE} \bullet i'+K_T \cdot i'' - \Delta q_t$$

Where;

$Q_{TL\,2}$ = Total trap heat loss (subcooling) (kcal/hr)

K_{HE} = Condensate load generated in heat exchanger as previously calculated (kg/hr)

K_T = Total steam loss of trap as previously calculated (kg/hr)

K_D = Load discharged by trap as previously calculated (kg/hr)

Δq_t = Heat collected in trap discharge tank (kcal/hr)

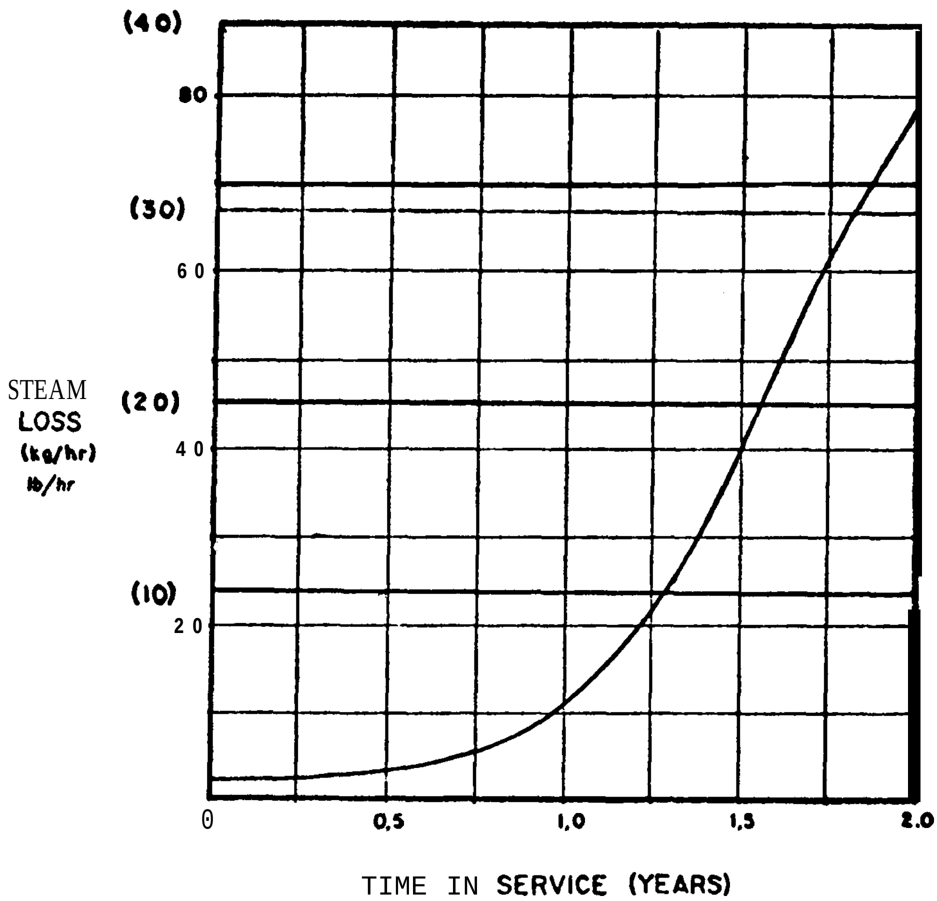
$i'_{Subcooled}$ = Specific enthalpy of subcooled condensate (kcal/hr)

i' = Specific enthalpy of saturated condensate (kcal/hr)

1" = Specific enthalpy of saturated steam (kcal/kg)

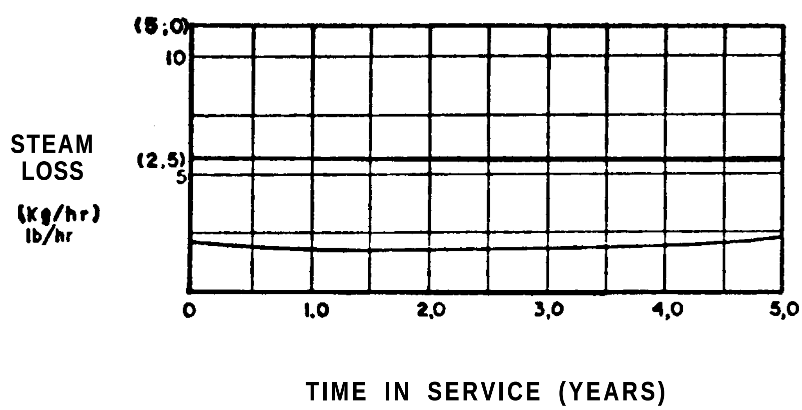
The length of the test (60/t) can make a big difference in the results of the test. Therefore, it was established that a test should be a minimum length of 15 minutes to lessen the margin of error in the total calculations. Each trap was tested at least four times and the results, if not the same, were averaged. All the traps, no matter which manufacturer or make, were tested under the same load conditions from 10 - 100 kg/hr with a constant pressure at the inlet of 11 bar and an outlet pressure of 1 bar. The testing chamber was kept at -45° C which was computed at 0° C with a wind chill factor of 15 km/hr. Similar tests were conducted under higher ambient temperatures, however no substantial difference in the steam loss could be seen. The following curves represent the average line of the test results.

Thermodynamic Type Traps



For the first six months, the energy characteristics of these traps can be termed acceptable, however any trap that was in service for more than six months was cycling faster than a new trap of the same type from the same manufacturer. Because of this increased cycling, the wear of this unit increased quite rapidly producing the results as seen on the curve. By the end of the first year, it may be losing 5 kg/hr which could mean a monthly average of about 2,5 kg/hr. However, during the remainder of the trap's life, it will very likely be losing 30 kg/hr which would mean a monthly average of 10 kg/hr.

Inverted Bucket Type Trap



The total steam or kilocalorie loss of this type of trap remains the same for a life cycle of about five years. By subtracting the live steam loss from the total steam loss, it is concluded that most of the trap losses were due to radiation and convection and not to loss through the orifice, which was typical of the thermodynamic type trap after its initial six month period of operation.

Looking at these two curves and relating them to the profitability of a plant, it's apparent that greater efficiency in your tracing system can be obtained by using a type of trap which does not lose live steam through the orifice and which does not subcool the condensate before discharging. By multiplying the average steam loss times steam cost for 1.000 kilograms of steam and then by the number of total units, it becomes obvious this low cost unit is of vital importance to the total profitability of your plant.