STEAM AND CONDENSATE SYSTEMS

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Introduction

- Nearly half of the energy used by industry goes into the production of process steam, approximately the same total energy usage as that required to heat all the homes and commercial buildings in America.

Introduction

- Steam is one of the most abundant, least expensive, and most effective heat-transfer media obtainable.
- Water is found everywhere, and requires relatively little modification from its raw state to make it directly usable in process equipment.
- During boiling and condensation, if the pressure is held constant and both water and steam are present, the temperature also remains constant.
- By maintaining constant pressure, which is a relatively easy parameter to control, excellent control of process temperature can also be maintained.

Components of Steam and Condensate Systems

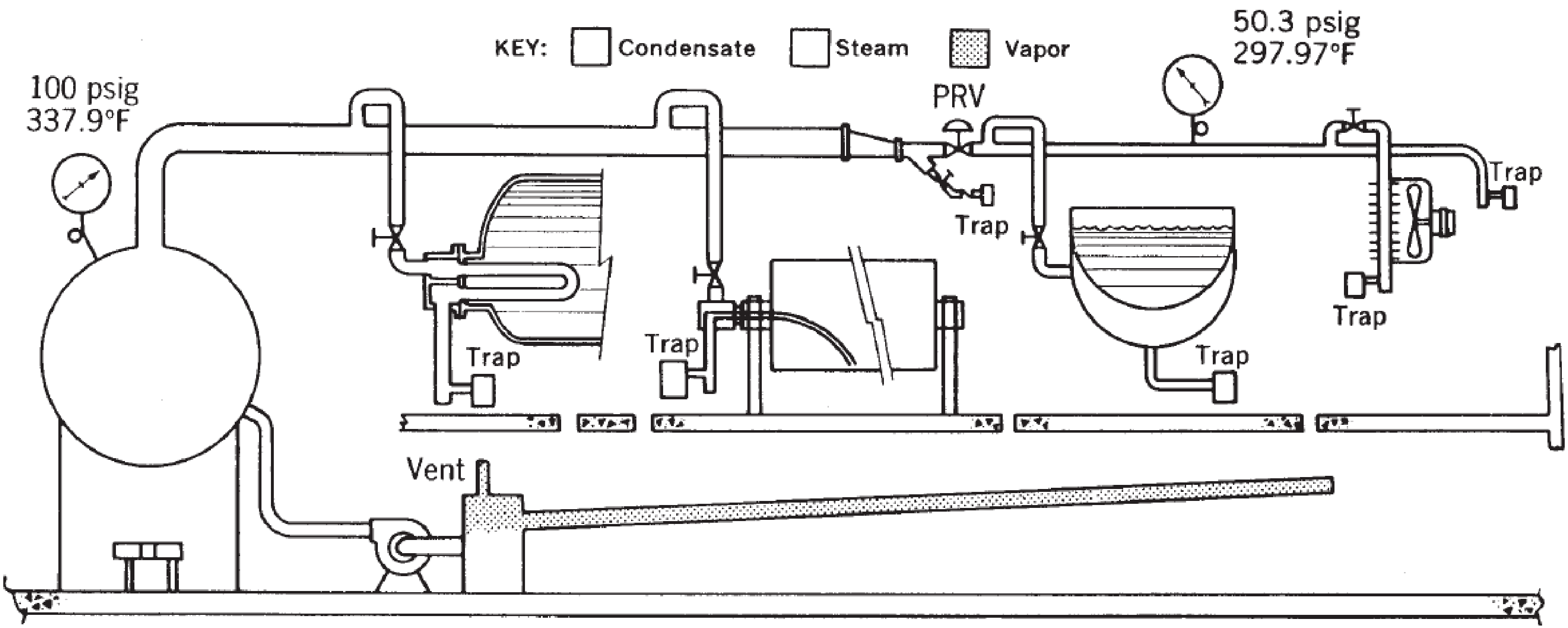

Fig. 6.1 Typical steam system components.

Energy Conservation Opportunities in Steam Systems

Table 6.1 Checklist of Energy Conservation Opportunities in Steam and Condensate Systems

General Operations

1. Review operation of long steam lines to remote single-service applications. Consider relocation or conversion of remote equipment, such as steam-heated storage tanks.
2. Review operation of steam systems used only for occasional services, such as winter-only steam tracing lines. Consider use of automatic controls, such as temperature-controlled valves, to assure that the systems are used only when needed.
3. Implement a regular steam leak survey and repair program.
4. Publicize to operators and plant maintenance personnel the annual cost of steam leaks and unnecessary equipment operations.
5. Establish a regular steam-use monitoring program, normalized to production rate, to track progress in reduction of steam consumption. Publicize on a monthly basis the results of this monitoring effort.
6. Consider revision of the plant-wide steam balance in multipressure systems to eliminate venting of low-pressure steam. For example, provide electrical backup for currently steam-driven pumps or compressors to permit shutoff of turbines when excess low-pressure steam exists.
7. Check actual steam usage in various operations against theoretical or design requirement. Where significant disparities exist, determine the cause and correct it.
8. Review pressure-level requirements of steam-driven mechanical equipment to evaluate feasibility of using lower pressure levels.
9. Review temperature requirements of heated storage vessels and reduce to minimum acceptable temperatures.
10. Evaluate production scheduling of batch operations and revise if possible to minimize startups and shutdowns.

Energy Conservation Opportunities in Steam Systems

Steam Trapping

1. Check sizing of all steam traps to assure they are adequately rated to provide proper condensate drainage. Also review types of traps in various services to assure that the most efficient trap is being used for each application.
2. Implement a regular steam trap survey and maintenance program. Train maintenance personnel in techniques for diagnosing trap failure.

Condensate Recovery

1. Survey condensate sources presently being discharged to waste drains for feasibility of condensate recovery.
2. Consider opportunities for flash steam utilization in low-temperature processes presently using first-generation steam.
3. Consider pressurizing atmospheric condensate return systems to minimize flash losses.

Energy Conservation Opportunities in Steam Systems

Mechanical Drive Turbines

1. Review mechanical drive standby turbines presently left in the idling mode and consider the feasibility of shutting down standby turbines.
2. Implement a steam turbine performance testing program and clean turbines on a regular basis to maximize efficiency.
3. Evaluate the potential for cogeneration in multipressure steam systems presently using large pressure-reducing valves.

Insulation

1. Survey surface temperatures using infrared thermometry or thermography on insulated equipment and piping to locate areas of insulation deterioration. Maintain insulation on a regular basis.
2. Evaluate insulation of all uninsulated lines and fittings previously thought to be uneconomic. Recent rises in energy costs have made insulation of valves, flanges, and small lines desirable in many cases where this was previously unattractive.
3. Survey the economics of retrofitting additional insulation on presently insulated lines, and upgrade insulation if economically feasible.

- **Example:** A 100-ft run of 6-in. steam piping carries saturated steam at 95 psig. Tables obtained from an insulation manufacturer indicate that the heat loss from this piping run is presently 110,000 Btu/hr. With proper insulation, the manufacturer’s tables indicate that this loss could be reduced to 500 Btu/hr. How many pounds per hour of steam savings does this installation represent, and if the boiler is 80% efficient, what would be the resulting fuel savings?

- **Example:** Suppose, in the preceding example, that the steam line is carrying superheated steam at 250 psia (235 psig) and 500°F. For the same reduction in heat loss (109,500 Btu/hr), how many pounds per hour of steam is saved?

Table 6.4 Orders of Magnitude of Convective Conductances

Heating Process	Order of Magnitude of h (Btu/hr ft^2 • F)
Free convection, air	1
Forced convection, air	5-10
Forced convection, water	250-1000
Condensation, steam	5000-10,000

$$q = U(T_{f1} - T_{f2})$$

Table 6.5 Comparison of Steam and Light Organics as Heat-Exchange Media

Shell-Side Fluid	Tube-Side Fluid	Typical U (Btu/hr ft^2 · °F)	Typical Fouling Resistance (hr ft^2 · °F/Btu)
Steam	Light organic liquid	135-190	0.001
Steam	Heavy organic liquid	45-80	0.002
Light organic liquid	Light organic liquid	100-130	0.002
Light organic liquid	Heavy organic liquid	35-70	0.003

there is a tendency for fluids to deposit "fouling layers" of crystalline, particulate, or organic matter on transfer surfaces, which further impede the flow of heat. This impediment is characterized by a "fouling resistance," which, for design purposes, is usually incorporated as an additional factor in determining the overall conductance.

Estimating Steam Usage and Its Value

- To properly assess the worth of energy conservation improvements in steam systems, it is first necessary to determine how much steam is actually required to carry out a desired process, how much energy is being wasted through various system losses, and the dollar value of these losses.

Estimating Steam Usage and Its Value

Determining Steam Requirements

- Several approaches can be used to determine process steam requirements.
- The choice of which method is to be used depends on how critical the steam-using process is to the plant's overall energy consumption and how the data are to be used.

Estimating Steam Usage and Its Value

- For applications in which a high degree of accuracy is not required, such as developing rough estimates of the distribution of energy within a plant, steam consumption tables have been developed for various kinds of process equipment.

Table 6.6 Typical Steam Consumption Rates for Industrial and Commercial Equipment

Type of Installation	Description	Typical Pressure (psig)	Steam Consumption in Use (lb/hr)
Bakeries	Dough-room trough, 8 ft long	10	4
	Oven, white bread, 120-ft^2 surface	10	29
Bottle washing	Soft drinks, per 100 bottles/min	5	310
Dairies	Pasteurizer, per 100 gal heated/20 min	15-75	232 (max)
Dishwashers	Dishwashing machine	15-20	60-70
Hospitals	Sterilizers, instrument, per 100 $in.^3$, approx.	40-50	3
	Sterilizers, water, per 10 gal, approx.	40-50	6
	Disinfecting ovens, double door, 50-100 ft^3, per 10 ft^3, approx.	40-50	21
Laundries	Steam irons, each	100	4
	Starch cooker, per 10 gal capacity	100	7
	Laundry presses, per 10-in. length, approx.	100	7
	Tumblers, 40 in., per 10-in. length, approx.	100	38
Plastic molding	Each 12-15 ft^2 platen surface	125	29
Paper manufacture	Corrugators, per 1,000 ft^2	175	29
	Wood pulp paper, per 100 lb of paper	50	372
Restaurants	Standard steam tables, per ft of length	5-20	36
	Steamjacketed kettles, 25 gal of stock	5-20	29
	Steamjacketed kettles, 60 gal of stock	5-20	58
	Warming ovens, per 20 ft^3	5-20	29
Silver mirroring	Average steam tables	5	102
Tire shops	Truck molds, large	100	87
	Passenger molds	100	29

Estimating Steam Usage and Its Value

- A second, and generally more accurate, approach to estimating steam requirements is by direct energy balance calculations on the process.
- Analysis of complex equipment should be undertaken by a specialist. It is, however, possible to determine simple energy balances on equipment involving the heating of a single product.

Table 6.7 Specific Heats of Common Materials

Material	Btu/lb · °F	Material	Btu/lb · °F
		Solids	
Aluminum	0.22	Iron, cast	0.49
Asbestos	0.20	Lead	0.03
Cement, dry	0.37	Magnesium	0.25
Clay	0.22	Porcelain	0.26
Concrete, stone	0.19	Rubber	0.48
Concrete, cinder	0.18	Silver	0.06
Copper	0.09	Steel	0.12
Glass, common	0.20	Tin	0.05
Ice, 32°F	0.49	Wood	0.32-0.48
		Liquids	
Acetone	0.51	Milk	0.90
Alcohol, methyl, 60-70°F	0.60	Naphthalene	0.41
Ammonia, 104°F	1.16	Petroleum	0.51
Ethylene glycol	0.53	Soybean oil	0.47
Fuel oil, sp. gr. 86	0.45	Tomato juice	0.95
Glycerine	0.58	Water	1.00
		Gases (Constant-Pressure Specific Heats)	
Acetone	0.35	Carbon dioxide	0.20
Air, dry, 32-392°F	0.24	Methane	0.59
Alcohol	0.45	Nitrogen	0.24
Ammonia	0.54	Oxygen	0.22

Estimating Steam Usage and Its Value

- **Example:** A paint dryer requires about 3000 cfm of 200°F air, which is heated in a steam-coil unit. How many pounds of 50-psig steam does this unit require per hour?
- Hint: The density of air at temperatures of several hundred degrees or below is about 0.075 lb/ft^3.

Estimating Steam Usage and Its Value

- **Example:** A milk evaporator uses a steam jacketed kettle, in which milk is batch-processed at atmospheric pressure. The kettle has a 1500-lb per batch capacity. Milk is heated from a temperature of 80°F to 212°F, where 25% of its mass is then driven off as vapor. Determine the amount of 15-psig steam required per batch, not including the heating of the kettle itself.
- Hint: the specific heat of milk is 0.90 Btu/lb °F.

Estimating Surface and Leakage Losses

- Figure 6.2 illustrates the annual heat loss, based on 24-hr/day, 365-day/yr operation, for bare steam lines at various pressures. The figure shows, for example, that a 100-ft run of 6-in. line operating at 100 psig will lose about 1400 million Btu/yr. The economic return on an insulation retrofit can easily be determined with price data obtained from an insulation contractor.

Estimating Surface and Leakage Losses

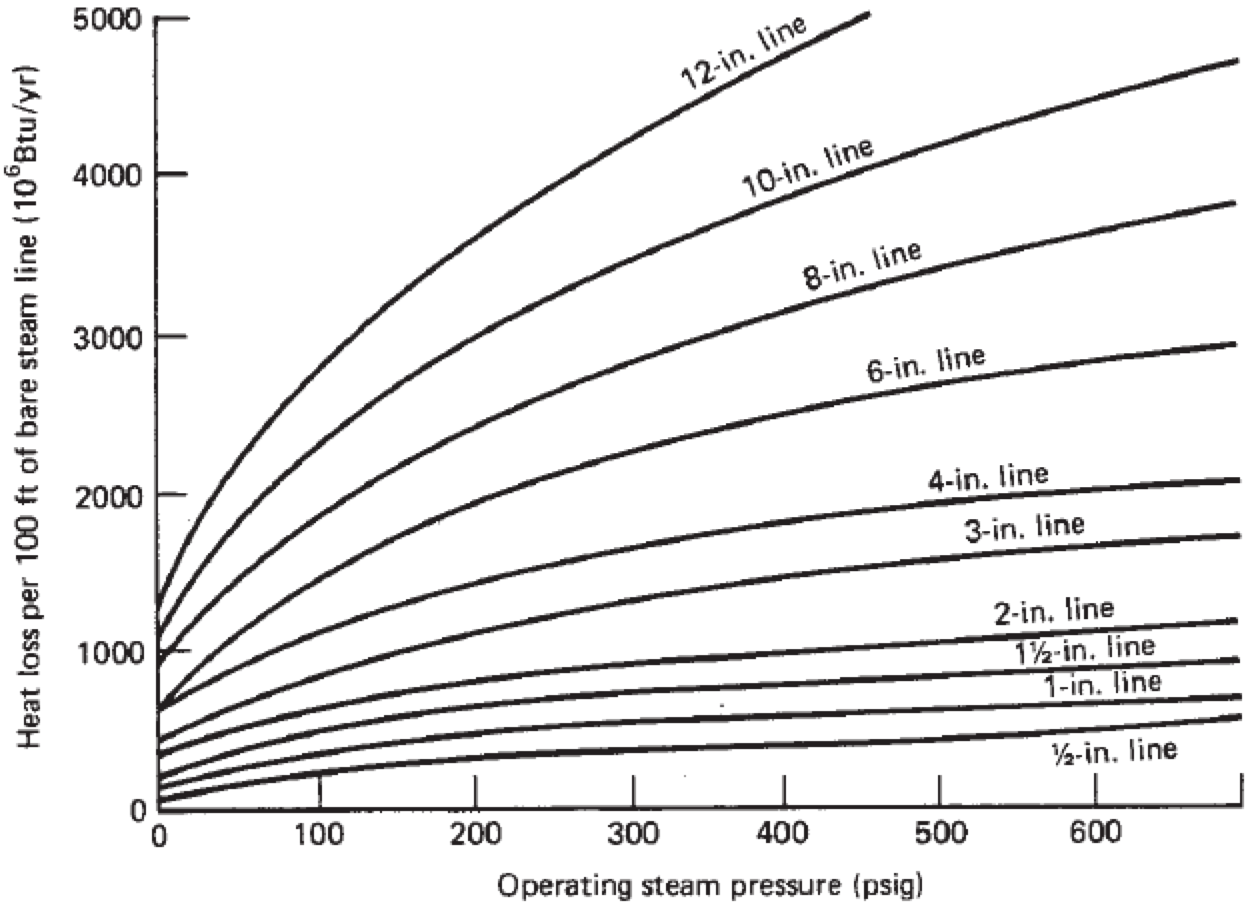

Fig. 6.2 Heat loss from bare steam lines.

Estimating Surface and Leakage Losses

- Figure 6.3 can be used to estimate heat losses from flat surfaces at elevated temperatures, or from already insulated piping runs for which the outside jacket surface temperature is known.

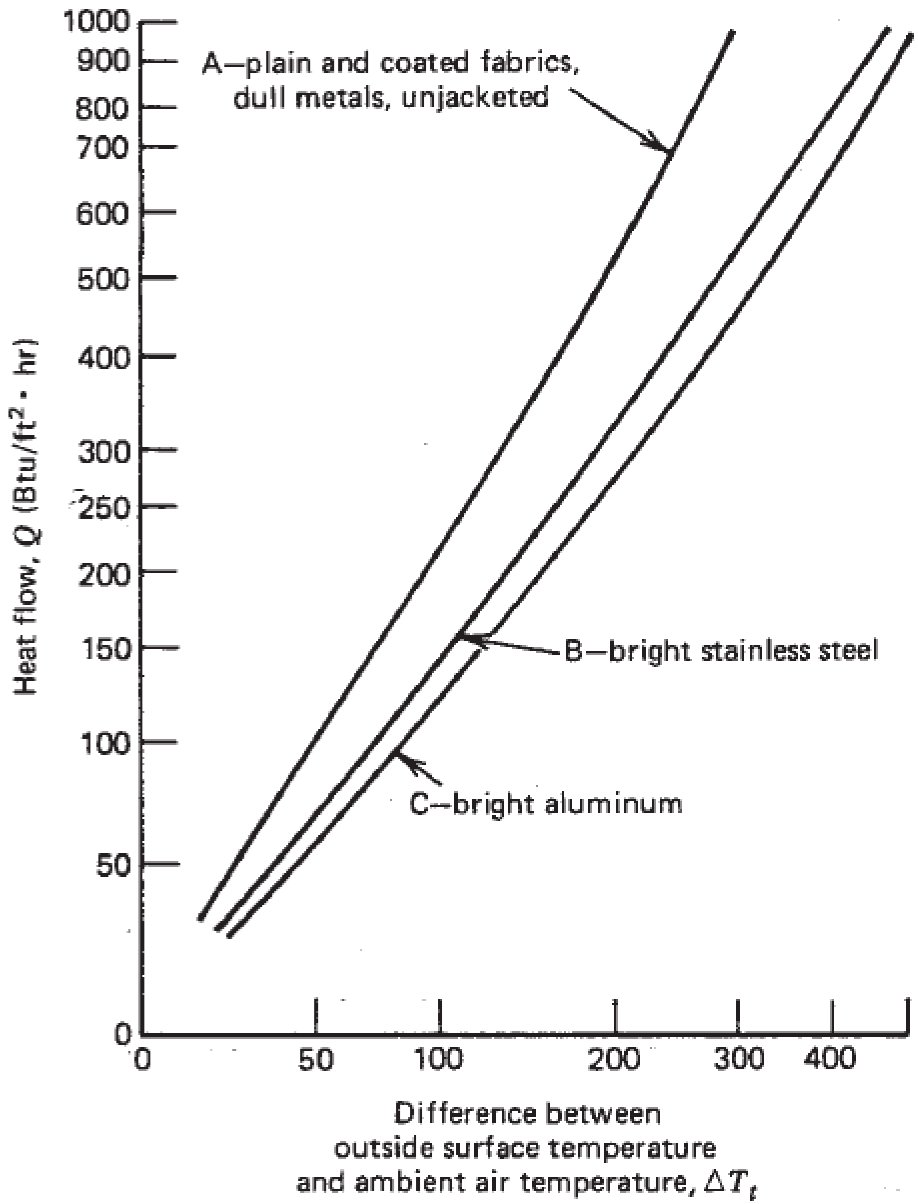

Fig. 6.3 Heat losses from surfaces at elevated temperatures.

Estimating Surface and Leakage Losses

- Figure 6.4 permits estimation of loss of steam at various pressures leaking through holes represented in million Btu/yr, based on full-time operation.
- A stuck-open steam trap with a 1/8-in. orifice would waste about 600 million Btu/yr of steam energy when leaking from a 100-psig line.
- This figure can also be used to estimate magnitudes of leakage from other sources of more complicated geometry.
- It is necessary to first determine an approximate area of leakage (in square inches) and then calculate the equivalent hole diameter represented by that area. The following example illustrates this calculation.

Estimating Surface and Leakage Losses

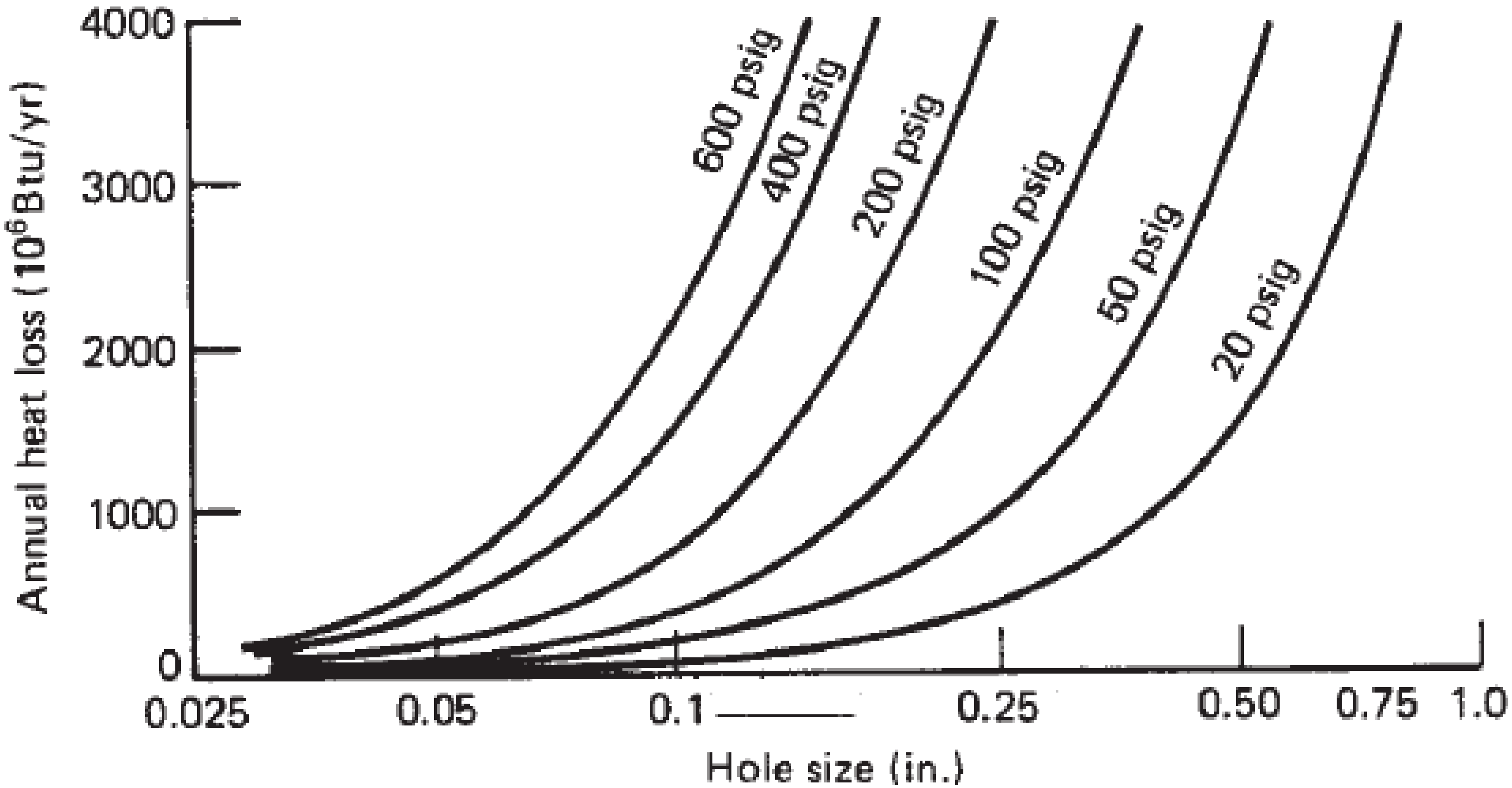

Fig. 6.4 Heat loss from steam leaks.

Estimating Surface and Leakage Losses

- **Example:** A flange on a 200-psig steam line has a leaking gasket. The maintenance crew, looking at the gasket, estimates that it is about 0.020 in. thick and that it is leaking from about 1/8-in. of the periphery of the flange. Estimate the annual heat loss in the steam if the line is operational 8000 hr/yr.

Computing the Dollar Value of Steam

- **Example:** An oil refinery produces 200-psig saturated steam in a large boiler, some of which is used directly in high-temperature processes, and some of which is let down to 30 psig through regulating valves for use at lower temperatures. The feedwater is added to the boiler at about 160°F. The boiler efficiency has been determined to be 82%, and boiler fuel is priced at $2.20 million Btu. Establish the values of 200-psig and 30-psig steam ($/lb).

Example 8-1: In one part of your plant, you are currently heating 4000 litres of water per hour from 10°C to 70°C with gas. A the same time in this area you have noticed that you are venting 70°C (=343°K) steam to the air. How many kg/h of 70°C steam would be required to meet the water heating needs with a 90% efficient steam coil, if the steam leaves the coil at 20°C?

Solution: The amount of heat needed is 4000 litres × 1.00 kg/litre × (70°C - 10°C) = 2,400 kcal/h. Each kg of steam enters with 2,765 kJ/kg, leaves with 2,517 kJ/kg and gives up 248 kJ/kg. So 24,000/(248 × .90) = 107.5 kg/h would be needed.

Example 8-2: Use of flash steam. Given 250 kg/h of condensate at 1400 kPa drops to 30 kPa through a pressure reducing valve. The condensate must quickly go to the boiling temperature at the lower pressure, with the surplus heat causing the lower pressure condensate to turn to steam. This is "flash steam." In this situation, how much low pressure steam would be available if the steam were allowed to flash off?

Answer:	Enthalpy at 1400 kPa	= 2790 kJ/kg
	Enthalpy at 30 kPa	= 2625 kJ/kg
	Heat available for flashing	= 165 kJ/kg
	Latent heat at 30 kPa available for flashing	= 2335 kJ/kg
	Proportion evaporated	= 165/2335 = 7.1%
	Flash steam available	= 250 × .071 = 17.8 kg/h

Steam Leaks

- A major waste of energy associated with steam lines.
- In many environments, steam leaks can be detected by their hissing; in noisy environments, it may be necessary to use an industrial stethoscope or an ultrasonic leak detector.

Cost/yr = (€/MJ × (kg steam lost/h) × MJ/kg) × (operating hours/yr)

- The amount of steam lost can be measured directly, estimated on the basis of experience, or calculated with a formula.

Steam Leaks

- Grashof's formula gives the number of kg of steam lost per hour through an orifice of area A as:

$$kg/h = 0.700 \times 0.000178 \times 3600 \times A \times P^{.97}$$

- where
- 0.70 = coefficient of discharge for hole (for a perfectly round hole, this coefficient is 1)
- 0.000178 = a constant in Grashof's formula
- 3600 = number of seconds in an hour
- A = area of hole in square centimeters = $\Pi(\text{hole radius})^2$
- P = pressure inside steam line in kPa

Steam Leaks

- Using this formula and the steam tables, it is possible to develop tables giving steam and energy losses for any given leak size for a plant whose steam pressure is known.

Table 8-1. Heat losses/energy costs from each leak of 100 kPa steam

Hole diameter (mm)	*Steam loss (kg/h)*	*Heat loss (mJ/h)*	*Energy cost (€/month)*
2	8	21	31
4	32	84	124
6	73	189	279
8	130	336	496
10	203	526	775
12	292	757	1117
14	397	1030	1520
16	519	1346	1985
18	657	1703	2513
20	811	2103	3102

Steam Leaks

- A crude but frequently effective way of evaluating steam leaks was given by Waterland in an early version of the *Energy Management Handbook*.
- It is based on an arbitrary rating system and works as follows: Tour a defined plant area at a weather condition or time of day when leaks are quite prominent, making a note of each steam leak and rating it as a wisp, moderate leak, or severe leak.
- Assign a value of 10 kg/h for each wisp, 50 kg/h for a moderate leak, and 200 to 500 kg/h for the severe leaks. When more than 20 leaks are evaluated, the total leakage determined in this way will usually be within 25% of the actual steam loss.

Steam Traps

- Steam traps and the condensate return system separate condensate from the steam distribution system and thereby perform three important functions:
  1. Prevent water hammer
  2. Return condensate to the boiler
  3. Improve the quality of the steam for further processes
- Steam traps also help in the removal of air and dissolved gases from the steam, thus removing two insulators and sources of inefficiency.

Steam Traps

Steam trap problems and maintenance

- Steam traps can fail open or fail closed.
- If a trap fails open, the effect and the cost are the same as a steam leak.
- If it fails closed, it is not separating condensate from steam, and water hammer, corrosion, and structural failure (caused by the weight of condensate) can result. It can also be subject to freezing, depending on the climate.

Steam Traps

Example 8.3: A recent inspection of your facility has revealed four steam traps with 2 mm orifices that are blowing steam into the condensate return. The steam pressure for the four traps was 1000 kPa, and the condensate return is gravity fed at atmospheric pressure. At €2.50 per GJ, how much are these steam losses costing, assuming continuous operation of the plant?

Solution: If steam is blowing from a trap, its enthalpy in the steam line is 2777.6 kJ/kg, and its enthalpy of the saturated liquid at ambient temperature (assumed to be 20°C) is 87.7 kJ/kg. The amount of heat lost from the steam lines per kg of steam is then 2,690 kJ/kg. To estimate the amount of steam loss, Grashof's formula gives 11.5 kg/h per trap. This gives 11.5 kg/h × 2690 kJ/kg × 4 raps × €2.50/GJ = €30.90 per hour in fuel costs. This is really quite a lot of money, and the amount is probably conservative.

Water treatment

- Scaling has an adverse effect on heat transfer. The more scale buildup, the less heat is transmitted through pipe walls. This scaling can be prevented by proper water treatment, making water treatment one of the essential elements in boiler management.

Tracer Lines

- A tracer line is a small steam line, usually copper or steel, wrapped around pipes, pumps, and instruments used with hot liquids or condensate; its purpose is to maintain the temperature of the liquid.
- Tracer lines are usually attached between the line or pump and the insulation.
- Tracer lines range in diameter from 10 mm to 50 mm, with 10 mm the most common.
- These lines can keep water and other products from freezing even in very cold weather, but the price of maintaining a high temperature in cold weather is the necessity to manage the condensate in the tracer lines.

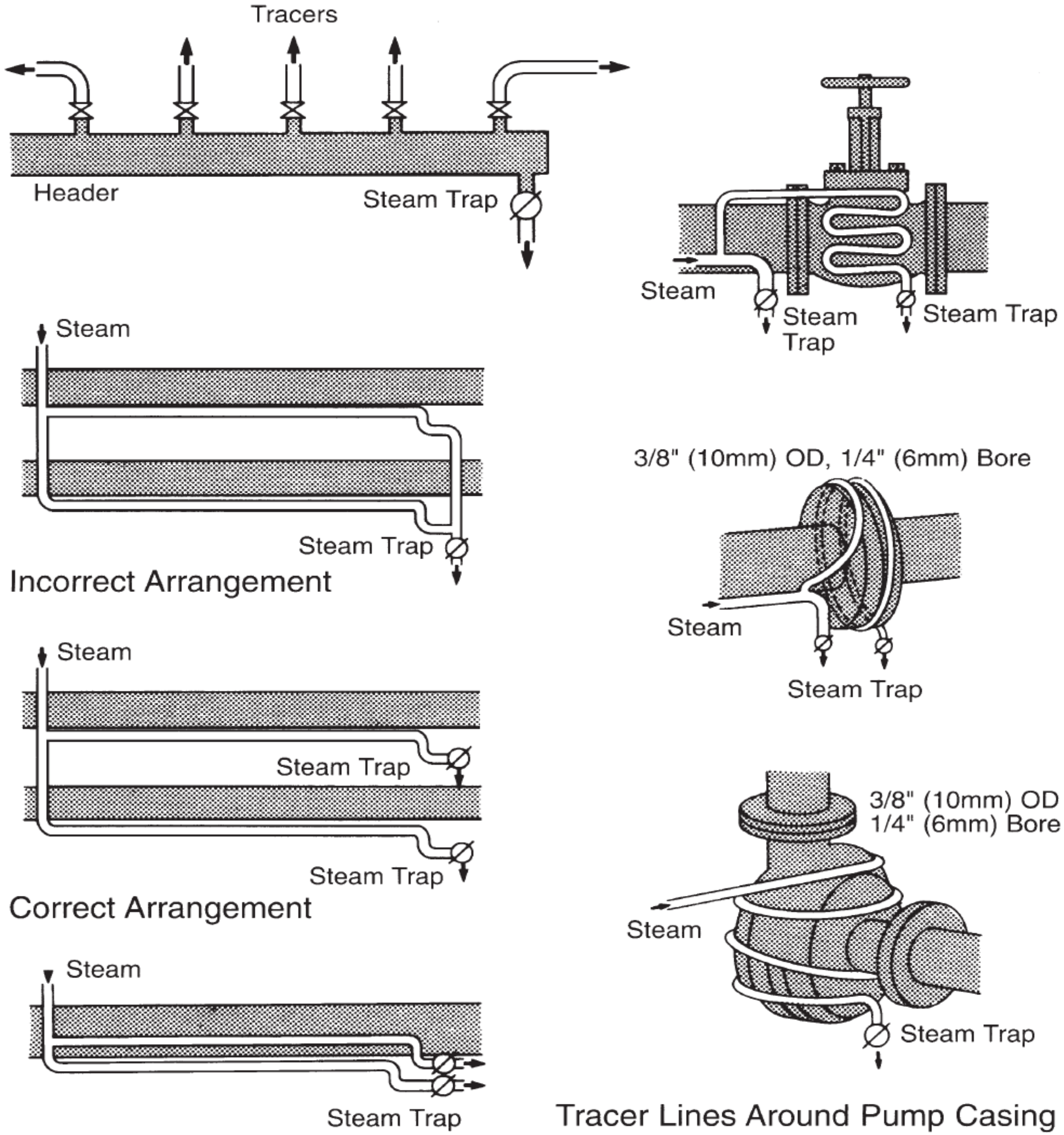

Figure 8-5. Examples of tracer lines (From [5], with permission of Spirax Sarco, Inc.)