5. Process Steam Systems

The chemical manufacturing industry depends heavily on steam for process applications. Given its prominence, it's discussed here in greater detail than other process heating operations. This chapter will focus on best practices in process heat systems; many of these practices yield high-energy savings for minimum initial capital investment.

5.1 Overview

Steam is a principle energy source for chemical industrial processes. It provides energy for process heating, pressure control, mechanical drives, and component separation, and is also a source of water for many industrial operations and chemical reactions. The popularity of steam as an energy source stems from its many advantages, which include low toxicity, transportability, high efficiency, high heat capacity, and low production costs relative to other energy transport mediums. [Steam Source Document DOE]

A 1997 study by the Gas Research Institute indicates that throughout industry steam production has been the second-most energy-intensive of all process applications in manufacturing operations (Figure 5.1).

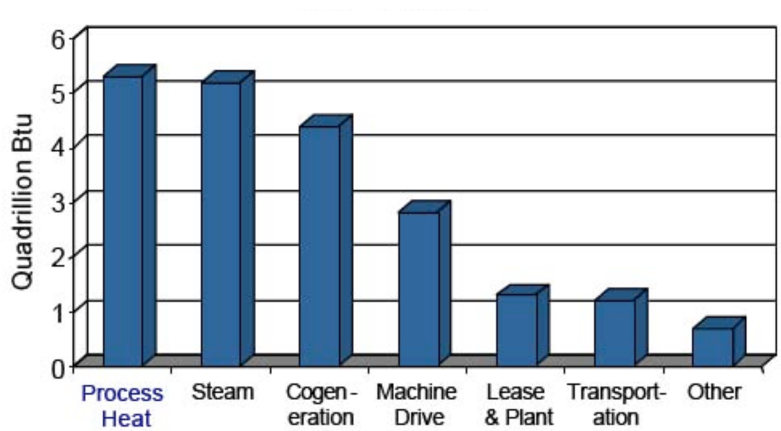

Figure 5.1 Industrial Energy Use by Process Application [GRI, 1997]

According to Figure 5.1, steam production and steam process uses are responsible for the consumption of over 5 quadrillion Btus (quads) of energy within the manufacturing industry. Of this amount, the chemical industry consumes about 1.54 quads, or nearly 30% of the steam energy used by the industry. Natural gas is the dominant fuel source of process steam systems (Figure 5.2). Due to the increased volatility of the fossil fuel market, energy efficiency measures must be taken to ensure steam remains an economically favorable energy source in the future.

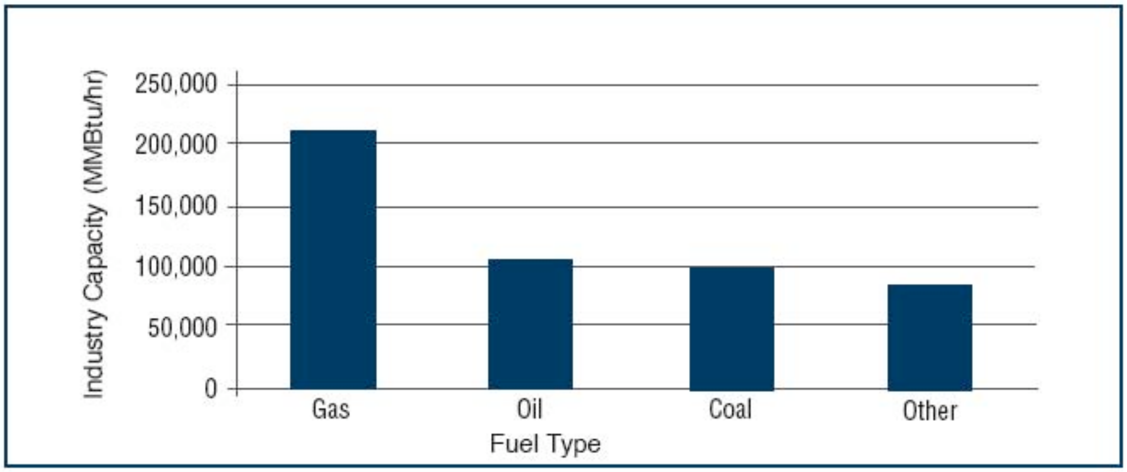

Figure 5.2 Chemical Industry Boiler Capacity by Fuel Type [Steam Asses DOE]

Many manufacturing facilities have older, inefficient equipment. For them, applying energy efficiency measures known as best practices is the easiest way to realize energy savings. With the concurrent use of advanced technologies, new operating practices, and implementation of best practices, reductions of 20 to 30% in energy costs are possible [Steam Overview DOE].

5.2 Explanation of Use

The ability of steam to retain a significant amount of energy on a unit mass basis (between 1,000 and 1,250 Btu/lb) makes it ideal for use as an energy transport medium. Energy can be extracted from the steam in the form of mechanical work through a turbine or as heat for process heating. Since most of the heat contained in steam is in the form of latent heat, large quantities of energy can be transferred efficiently at a constant temperature, which is a useful attribute in many process-heating applications. Steam is also used in contact applications such as the reforming of natural gas for nitrogen fertilizer production. In addition, process steam systems are used to control the pressures and temperatures of many chemical processes, and in applications such as stripping of contaminants, facilitating fractionation of hydrocarbons, and in certain drying operations. [Steam Source Document DOE]

The configuration and operation of process steam systems used by chemical manufacturers are widely ranging. Many facilities do not disclose details of their systems, making it difficult to assess information and pass specific opportunities for savings on to others. This document will discuss four categories of process steam systems and then list best practices based that may be applied to nearly any process steam system. Figure 5.3 represents a typical process steam operation used by a chemical manufacturer.

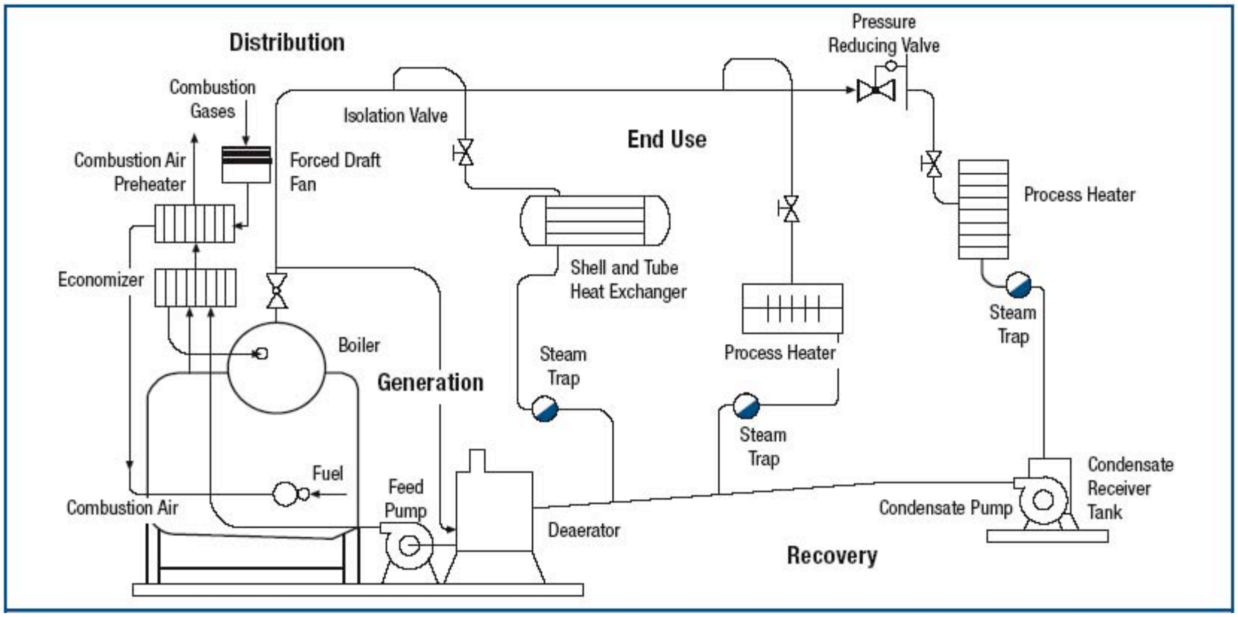

Figure 5.3 A Typical Process Steam System Schematic

A process steam system consists of the four categories listed below:

- generation
- distribution
- end use
- recovery

5.2.1 Generation

Steam is normally generated in a boiler or waste heat recovery device by transferring heat from hot combustion gases or other hot process streams to water. The water absorbs the heat, facilitating the phase change necessary to produce steam. The steam is then transferred under pressure from the boiler to the distribution system. In general, two types of boilers are used to generate steam.

- Firetube boilers—Combustion gases pass through tubes, transferring heat to boiler water flowing over the tubes on the shell side. Benefits of this type of boiler include low initial costs as well as efficiency and durability. The boilers are limited, however, to lower pressure steam production temperatures, generally not exceeding 300 psig, due to the steam being contained in the shell.
- Watertube boilers—Boiler water passes through tubes while hot gases contained on the shell side circulate over the outside of the tubes, transferring heat. The fact that the steam is contained in the tubes and not the shell allows for much higher pressure steam production, on the order of up to 3000 psig is practical. For this reason, and due to their high efficiency, watertube boilers are ideal for applications that require saturated or superheated steam, especially those applications insisting on dry, high pressure, high heat energy steam. About 60% of the steam produced in the chemical industry lies in the range of 300 to 1000 psig. [Steam Assess DOE]

The two boiler types listed are both fuel-fired boilers; in addition, heat recovery devices such as waste heat recovery boilers (WHRB), heat recovery steam generators (HRSG), superheaters, and economizers are used in industry to generate steam.

5.2.2 Distribution

The distribution system is critical because it carries the pressurized steam produced in the boilers to the end-use operations. Systems often have numerous take-off lines that operate at different steam pressures, which are achieved by using isolation valves, pressure regulating valves, and, in some cases, back pressure turbines to separate take-off lines from the original headers. The goal of any distribution system is to deliver to the end-user sufficient quantities of steam at a specified temperature and pressure. An efficient system requires proper pressure balance and regulation, good condensate drainage, and proper insulation. [Steam Source DOE] Typical steam distribution system components include:

- piping
- proper insulation
- valves or turbines
- steam separators, accumulators, and traps

5.2.3 End Use

Steam end-use equipment transfers steam energy into other useful forms of energy that can then be used further in process applications. This document separates process steam end use operations into two categories: steam heat transfer and operational end uses. Steam heat transfer is explained in section 4.2.2.5, Specific Heat Transfer Operations. Section 5.2.3 focuses more on operational end uses that perform applications based on the concept of heat transfer to receive a desired outcome. Table 5.1 lists some of the equipment that is used for process steam operational end uses.

Table 5.1 Key Steam End Use Equipment [Steam Source DOE]

Equipment	Process Application	Industry
Condenser	Steam turbine operation	Aluminum, Chemical Manufacturing, Forest Products, Glass, Metal Casting, Petroleum Refining, and Steel
Distillation tower	Distillation, fractionation	Chemical Manufacturing, Petroleum Refining
Dryer	Drying	Forest Products
Evaporator	Evaporation/concentration	Chemical Manufacturing, Forest Products Petroleum Refining
Process heat exchanger	Alkylation, Process air heating, Process water heating, Gas recovery/Light ends distillation, Isomerization, Storage tank heating Visbreaking/Coking	Aluminum, Chemical Manufacturing, Forest Products, Glass, Metal Casting, Petroleum Refining, and Steel
Reboiler	Fractionation	Petroleum Refining
Reformer	Hydrogen generation	Chemical Manufacturing, Petroleum Refining
Separator	Component separation	Chemical Manufacturing, Forest Products, Petroleum Refining
Steam ejector	Condenser operation, Vacuum distillation	Aluminum, Chemical Manufacturing, Forest Products, Glass, Metal Casting, Petroleum Refining, and Steel
Steam injector	Agitation/blending, Heating	Chemical Manufacturing, Forest Products, Petroleum Refining
Steam turbine	Power generation, Compressor mechanical drive, Hydrocracking, Naphtha reforming, Pump mechanical drive, Feed pump mechanical drive	Aluminum, Chemical Manufacturing, Forest Products, Glass, Metal Casting, Petroleum Refining, and Steel
Stripper	Distillation (crude and vacuum units), Catalytic cracking, Asphalt processing, Catalytic reforming, Component removal, Component separation, Fractionation, Hydrogen treatment, Lube oil processing	Chemical Manufacturing, Petroleum Refining
Thermocompressor	Drying, Steam pressure amplification	Forest Products

Within the chemical manufacturing industry, steam end-use operations vary widely by process application, as demonstrated by Table 5.1. However, despite the specific operation in use, it is obvious these operations are essential to the overall manufacturing scenario and, therefore, directly linked to productivity. Increases in the efficiency of end-use devices often are directly coupled to dramatic reductions in overall energy consumption.

The most common operational end uses employed by chemical manufacturers include: [Steam Asses DOE]

- stripping
- fractionation
- power generation
- mechanical drive
- process heating
- quenching
- dilution
- vacuum draw

- pressure regulation
- injection
- source of process water

The information found in the section 5.2.3 was taken directly from material found in Steam System Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries provided by the Office of Energy Efficiency and Renewable Energy:, U.S. Department of Energy **[Steam Asses DOE]**

Stripping
Steam is often used to facilitate the separation of components. In stripping towers, steam pulls unwanted contaminants from a process fluid. The steam used in these applications is not directly returned because the effluent has too many unwanted substances.

Fractionation
In fractionation towers, steam is used to assist in the separation of chemical products that contain components with different boiling points. Steam is injected in the bottom of the towers along with a feedstock. The steam helps carry the more volatile products up the tower where they condense on trays that are maintained at the condensation temperature of the desired products. The steam provides a mass transport medium, helps prevent deposition on hot surfaces, and provides favorable viscosity properties of the product within the tower.

Power Generation
In power generation, steam is often used to drive turbines, which, in turn, spin electric generators. Many chemical plants meet their electric power needs with a mixture of purchased power and on-site generation. The ratio between purchased power and self-generated power depends on several factors, including cost of electricity, availability, and capacity of on-sited power generation, anonymous on-sited demand for steam.

Mechanical Drive
In many chemical manufacturing facilities, most mechanical drive energy is supplied by electric power; however, steam and natural gas account for a large portion of this energy component. Approximately 11% of the total mechanical drive energy comes from steam-powered turbines.

Steam is used because of its reliability, availability, and favorable economic feasibility under certain conditions. Because either a turbine or a motor can equally serve many processes, deciding which option to use is typically based on relative economic advantages. Important factors are the cost of steam and net electricity price (accounting for both energy and demand charges). In many critical applications, plants incorporate redundancy by installing both types of drives, thus preventing failure in one power source from causing a costly shutdown.

Process Heating
Steam is used in many chemical process heating applications. Favorable characteristics for these applications include:

- constant temperature heat delivery

- effective temperature control through regulation of steam pressure
- large heat content per unit mass

Steam provides an excellent heat source for applications that require temperatures between 250-500˚F. Competing sources of process heat include direct-fired furnaces and process fluid heat recovery heat exchangers. Although steam is used in applications with temperatures up to 700˚F, the pressure requirement for it often makes its generation and distribution impractical. Direct-fired furnaces can typically achieve higher temperatures than steam can feasibly provide and are, therefore, widely used in many chemical industry applications. In addition, many chemical production processes involve exothermic reactions that provide opportunities for process heating with fluid-to-fluid heat exchangers.

Quenching
An important part of controlling chemical reactions is the regulation of the reaction temperature. In many applications, steam controls process temperature by quenching. Many chemical processes involve exothermic reactions and the heat released affects the temperature of the reaction. Steam is often directly injected to regulate such processes. Steam has a large latent heat capacity and can often be separated from process streams in subsequent steps, especially with chemicals that have a low solubility in water.

Dilution
Steam is often used to dilute a process gas, which, in turn, reduces coke formation on the surfaces of heat exchanger. Many chemical products, particularly hydrocarbons, tend to form deposits on high-temperature surfaces, thus reducing heat transfer. Because these deposits are difficult to remove, steam is often injected with process chemicals to minimize their surface formation. Steam helps by diluting these chemicals and by reducing localized hot spots.

Steam ejectors may be used in certain process equipment to produce a vacuum. Other equipment that serves this purpose includes motor-driven vacuum pumps. The amount of steam used for this purpose varies from plant to plant, depending on the manufacturing operation.

Pressure Regulation
Steam is often used to control the partial pressure of a reaction. When steam is injected with reactants in a fixed-volume vessel, it can increase the pressure and cause a desired shift in the reaction. This use of steam is particularly effective when the reactants have low solubility in water. An example of this use is found in ethylene production, where steam is injected in the pyrolysis furnace to inhibit unwanted reactions.

Injection
Steam is often directly injected into a process to help transport products. Steam effectively serves in these applications by providing a source of pressure or by acting as an entrainment medium. A favorable characteristic in such an application is the ability to separate water from the product in subsequent steps.

Source of Process Water

Steam is also a source of water as a solvent and a feedstock. As a solvent, steam provides both heat and solubility. As a feedstock, it provides a source of pressure, temperature, and hydrogen (e.g., as in steam methane reforming in the ammonia industry).

5.2.4 Recovery

The purpose of the recovery system and its components is to collect and return the condensate back to the generation sector of the system. The benefits of using a condensate system are two-fold. The water returned by the condensate system, which has previously been chemically treated, can be reused as boiler feedwater within the process steam system, lowering the cost of treating new boiler feedwater. Second, the thermal gain of using condensate water instead of makeup boiler feedwater reduces energy consumption since the temperature of condensate water is considerably higher than makeup water. The cost savings from not purchasing, heating or treating the boiler makeup water often make investments in condensate recovery systems economically feasible. [Steam Source DOE]

Another benefit of a condensate recovery system is the use of flash steam vessels to produce low-quality steam. The low quality steam is produced by flashing the above ambient pressure condensate return water in a flash chamber at ambient pressure. It can then be used for operations such as space heating or the heating of water for personal use.

A typical condensate can and often does contain the following seven components.

- condensate return piping
- proper insulation
- condensate return tanks
- pumps
- flash steam vessels
- condensate meters
- filtration/cleanup equipment

5.3 Process Steam Systems Best Practices

Table 5.2 is intended to be used as a first step to identify opportunities for possible reductions in energy consumption and improved efficiency for nearly all process steam systems. The table lists opportunities for improvement in energy generation, distribution, and recovery. In general, optimizing the efficiency of steam-supplied end uses requires a case-by-case assessment and is therefore not included in Table 5.2. The remainder of Chapter 5 will provide more detailed information describing the best practices found in Table 5.2 and elaborate further on additional energy efficiency measures, including those for steam end use operations.

Table 5.2 Common Performance Improvement Opportunities of Process Steam Systems

Opportunity	Description
	Generation
Minimize excess air	Reduces the amount of heat lost up the stack, allowing more of the fuel energy to be transferred to the steam
Clean boiler heat transfer surfaces	Promotes effective heat transfer from the combustion gases to the steam
Install heat recovery equipment (feedwater economizers and/or combustion air preheaters)	Recovers available heat from exhaust gases and transfers it back into the system by preheating feedwater or combustion air
Improve water treatment to minimize boiler blowdown	Reduces the amount of total dissolved solids in the boiler water, which allows less blowdown and therefore less energy loss
Recover energy from boiler blowdown	Transfers the available energy in a blowdown stream back into the system, thereby reducing energy loss
Add/restore boiler refractory	Reduces heat loss from the boiler and restores boiler efficiency
Optimize deaerator vent rate	Minimizes avoidable loss of steam
	Distribution
Repair steam leaks	Minimizes avoidable loss of steam
Minimize vented steam	Minimizes avoidable loss of steam
Ensure that steam system piping, valves, fittings, and vessels are well insulated	Reduces energy loss from piping and equipment surfaces
Implement an effective steam-trap maintenance program	Reduces passage of live steam into condensate system and promotes efficient operation of end-use heat transfer equipment
Isolate steam from unused lines	Minimizes avoidable loss of steam and reduces energy loss from piping and equipment surfaces
Utilize backpressure turbines instead of PRVs	Provides a more efficient method of reducing steam pressure for low-pressure services
	Recovery
Optimize condensate recovery	Recovers the thermal energy in the condensate and reduces the amount of makeup water added to the system, saving energy and chemicals teatment
Use high-pressure condensate to make low-pressure steam	Exploits the available energy in the returning condensate

5.3.1 Institute Process Steam System Standard Operating Procedures

All steam systems must have a documented Standard Operation Procedure (SOP) to ensure proper operation. The instructions in the SOP should enable a user to complete a job safely, with no adverse impact on the environment (thus meeting compliance standards), and in a way that maximizes operational and production requirements. Planning, writing, and initiating should be the first steps in attempting to implement any best practice provided in this manual for process steam systems.

For many years, Quality Assurance people at large companies have been creating SOPs to help workers produce quality products to enhance a company’s competitiveness. Operational personnel, maintenance staff, or even supervision personnel can lack a clear understanding of an operation. They can make mistakes when operating the steam system, causing premature failures and safety issues in the plant.

SOPs are written to:

- provide individuals who perform operations with all the safety, health, environmental, and operational information required to perform a job properly
- protect the health and safety of employees, and to protect the environment
- protect the system and the plant
- ensure that operations are done consistently in order to maintain quality control of processes and products
- ensure that processes continue and are completed on a prescribed schedule
- ensure that no failures occur in manufacturing or related processes that would harm employees or anyone in the plant
- ensure that approved procedures are followed in compliance with company and government regulations
- serve as a training document for teaching users about a process
- serve as an historical record when processes are modified or SOPs revised
- provide an explanation that can be used in incident investigations that seek to improve safety practices and operating conditions
- prevent premature failure of components due to improper startups
- teach new employees

5.4 Steam Generation Best Practices

As indicated in Section 5.2.1, steam is generated by direct-fired firetube or watertube boilers, (the most common fuel being natural gas) or, in some cases, by utilizing waste heat or the heat energy of other chemical process streams. Therefore, steam generation best practices are intimately related to the heat generation, transfer, containment, waste recovery, and process controls best practices for process heating systems found in Chapter 4. The remainder of this section will list the best practices for chemical process steam generation; some best practices will simply be references back to Chapter 4, Process Heating Systems, while best practices not included in Chapter 4 will be explained in more detail.

5.4.1 Determine the Optimal Steam Pressure

Steam pressure should be as low as possible for performance specifications. Care should be taken in selecting the correct steam pressure because pressure that's too high can cause control problems, require additional safety equipment, and result in different materials of construction, etc. In addition, it takes more energy to produce higher temperatures and pressure steam.

If the majority of steam end-use devices are operating at a lower steam pressure than what is produced for the main header and other higher steam pressure requiring equipment, it may be advisable to lower the operating pressure of the boiler. In such cases, the higher pressure equipment may benefit from an adjustment, such as the installation of a stand-alone boiler. This evaluation must be done on a case-to-case basis. As a rule of thumb, a 10-psig drop in steam pressure can lead to a 1% reduction in energy costs.

Best Practices—Determine Optimal Steam Pressure

- The boiler plant should produce steam at the lowest possible pressure level to meet the plant requirements.
- Provide a separate heat source for parts of processes that require high pressure steam or process heating fluid, thus minimizing the need to operate the entire plant at elevated pressures or temperatures.

5.4.2 Reduce Boiler Flue Gas Losses

The explanation and best practices for reducing boiler flue gas losses are the same as those found in Chapter 4, Process Heating Systems, Section 4.4.1 Reduce Flue Gas Losses. In addition, the information in Sections 4.4.1.1 through 4.4.1.3 provides further explanation of the best practices found in Section 4.4.1.

Best Practices—Reducing Boiler Exhaust Gas Losses

- Monitor and maintain the proper level of O_2 concentration, 2-3% by operating at the correct air/fuel ratio for the burner.
- Use heat recovery of flue gas where possible to preheat incoming combustion air.
- Eliminate or reduce all sources of undesired air infiltration into the furnace.
- Perform proper maintenance on a regular schedule to reduce soot and other deposits on heat transfer surfaces, thus ensuring efficient transfer of heat to the process.

5.4.3 Performing Proper Boiler Maintenance

For greatest efficiency, boilers need proper maintenance at scheduled intervals. Scheduled maintenance ensures efficient, reliable operation. The key is not to “fix it when it breaks,” but keep it from breaking in the first place.

Best Practices—Performing Proper Boiler Maintenance

- Ensure that heat transfer surfaces on indirect heat generation furnaces are clean and free of deposits and soot.
- Ensure burner is operating properly and most efficiently within the limits set by controls and operators.
- Continuously inspect the furnace enclosure for deterioration or safety problems.

5.4.4 Use of Heat Recovery

The use of heat recovery devices to produce steam is normally an economically sound investment, but all situations should be evaluated on a case-to-case basis. Typical heat recovery devices include: waste heat recovery boilers (WHRB), heat recovery steam generators (HRSG), super heaters, and economizers. Further information on waste heat recovery best practices can be found in Section 4.6, Waste Heat Recovery Best Practices, specifically, Section 4.6.2, Waste Heat Boiler Steam Generation.

Best Practices—Use of Heat Recovery

- The addition of waste heat boilers to any process heating system is encouraged, especially if additional steam capacity is required or would be beneficial. The boiler can use the waste heat in hot gases and/or liquids from the flue gas of process furnaces or from hot process streams to produce steam. The additional steam capacity maybe sufficient enough to shut down or reduce the load on existing high energy consuming boilers.

- Check the steam demand schedule against the furnace operating schedule, as steam from a waste heat boiler can only be produced when a source of waste heat is present.

5.4.5 Reduce Blowdown Energy Losses

Solids, either suspended or dissolved, are always present in water. High levels of total dissolved solids (TDS), which eventually become sludge and settle in the bottom of a boiler, can both lower the boiler's heat transfer capabilities and cause significant damage to the unit. High levels of TDS also lead to foaming and carryover of liquid water into the steam supply. This reduces the efficiency of the system and can lead to water hammer, which may damage pipes, control valves, steam traps, and end-use equipment.

Solids are removed from the boiler by a process known as blowdown. There are two types of blowdown: bottom and surface. Bottom blowdown is a manual process to remove the dissolved solids that have accumulated on the bottom of the boiler. The procedure is performed at regular intervals according to the type of boiler as well as steam and water usage. Surface or top blowdown removes solids that are floating on or near the surface of the water in the boiler. Boilers have a metered opening just below the water's surface; high pressure inside the boiler forces or blows hot water (and the TDS) through this opening. There are three types of surface blowdown: intermittent, continuous, and automatic. A typical blowdown system can be seen in Figure 5.4.

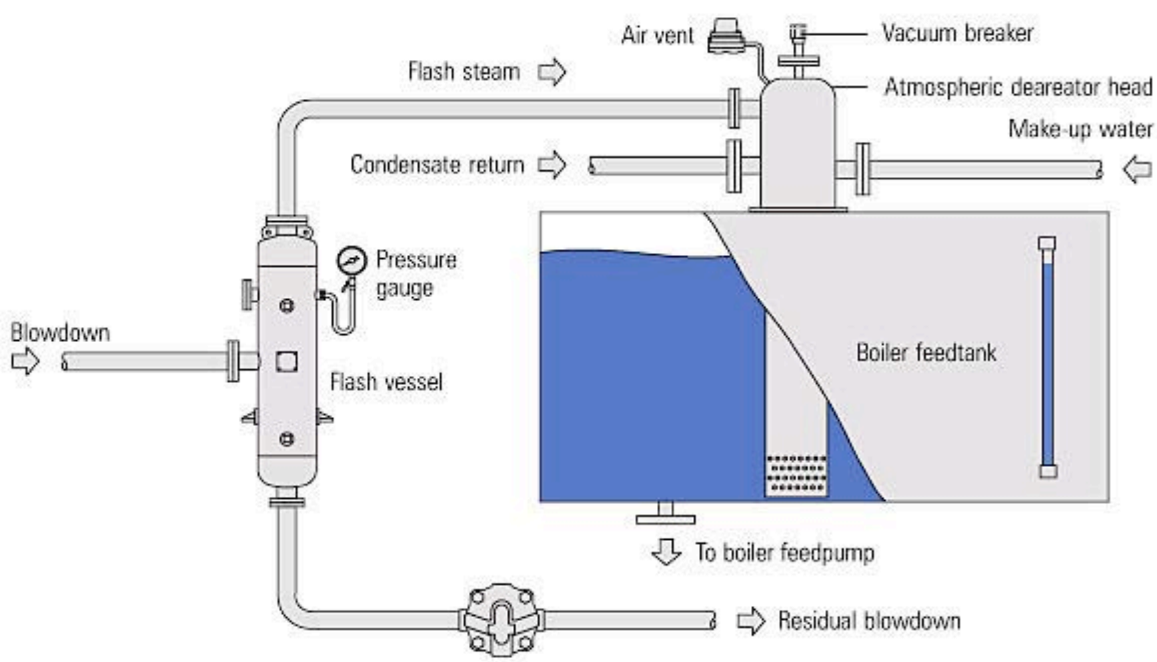

Figure 5.4 Schematic of Blowdown System[34]

[34] The Energy Solution Center website http://www.energysolutionscenter.org/BoilerBurner/Eff_Improve/Efficiency/Blowdown_Heat_Recovery.asp

All blowdown procedures remove hot water and, therefore, energy from the steam system. This causes a decrease in total energy efficiency. Removing more water than is necessary to control TDS wastes energy as well as money if water treatment chemicals are unnecessarily removed. In order to reduce these wastes and improve steam reliability, installation of an automated system that optimizes the interval and quantity of blowdowns should be considered. An automated system consists of controls, a valve, piping (if needed), and equipment that indicates TDS levels based on some measurement, such as the conductivity or relative density of the water.

Best Practices—Reduce Blowdown Energy Losses

- Whenever possible, improve water treatment mechanism to reduce the amount of total dissolved solids in the boiler feedwater, in turn reducing the frequency of blowdown.
- Install an automated blowdown system to optimize the interval and quantity of blowdowns, so the least amount of energy is wasted.
- Install a blowdown heat recovery device. This will generally include two methods of recovery, heat exchanger and flash steam generation.

5.4.6 Boiler Heat Containment

Containment of the heat produced within or transferred to a piece of process heating equipment is essential for efficient operation of a system. Many times, best practices that fall into the category of heat containment are easy and cost-effective to implement. Boiler heat containment best practices are much the same as the heat containment best practices for process heating systems; Section 4.5 should therefore be reviewed for more information on this topic.

Best Practices—Boiler Heat Containment

- Reduce containment vessel heat losses through the proper use of insulation and refractory.
- Reduce radiation losses from walls and openings.
- Eliminate unnecessary losses imposed on the system by unnecessary or inefficient cooling.

5.5 Steam Distribution Best Practices

While generating steam is a fuel-intensive process, transporting and using the steam require energy as well. The more efficiently all processes perform, the more efficiently the overall system will operate, requiring less fuel consumption for the same operation. This is called a systems approach to energy reduction thinking. The remainder of this section will provide best practices for improving the efficiency, reliability, and safety of the steam distribution system.

5.5.1 Eliminate Steam Leaks and Venting

Steam leaks and venting waste energy. Small leaks are often considered trivial and go unnoticed, never to be repaired. However, the cumulative loss from these leaks in the distribution and condensate recovery system can add up to tens of thousands of dollars. Figure 5.5 illustrates how even the smallest leak can result in large, unnecessary additional energy costs.

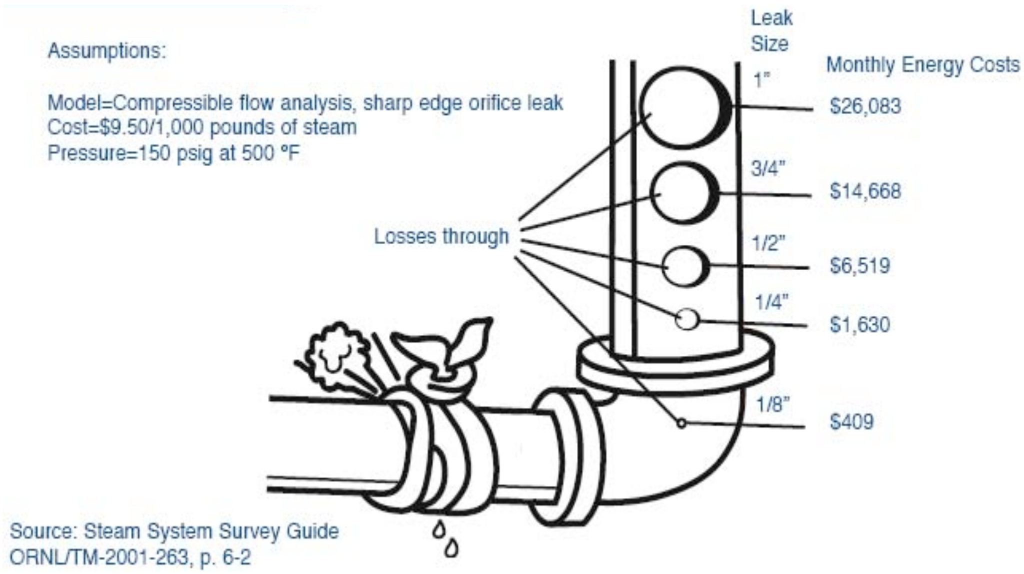

Figure 5.5 Impact of Steam Leakage on Monthly Energy Cost [Steam Opportunity DOE]

Best Practice—Eliminate Steam Leaks and Venting

- Minimize all avoidable steam losses from leaks and/or venting.
- Continually inspect steam distribution and condensate return lines for leaks and repair as necessary.

5.5.2 Proper Steam Line Materials and Installation

The B31.1 Power Piping Code and, specifically for the chemical industry, B31.3, prescribes minimum requirements for constructing power and auxiliary service piping. However, the code does not include regulations for determining optimum system function and effective plant operations. It does not define any other measures necessary to assure the useful life of piping systems. These concerns are the responsibility of the designer and after construction turn-over, the operating company personnel are responsible for plant activities.

Granted, all plants should abide by the guidelines set forth in codes B31.1 and B31.3. In addition, every plant should have in place a standard for materials to be use for different steam applications. Several examples are suggested below, however, each scenario should be treated on a case-by-case basis and the best decision should be based on information specific to the situation.

Steam Pipe

- carbon steel
- stainless steel
- alloys (depending on pressure and temperatures)

Steam Tube

- carbon steel
- stainless steel
- alloys (depending on pressure and temperature)

Condensate Line (Pipe material)

- stainless steel
- carbon steel (sch. 80)

Condensate Line (Tube material)

- stainless steel

Steam and condensate piping systems can be installed with any of the following, or a combination of any of the following:

- threaded pipe
- welded pipe joints
- flanges
- tube material
- tube connectors

Best Practices—Proper Steam Line Materials and Installation

- Materials used for steam and condensate systems should be specified and applied based on codes B31.1 and B31.1, as well as internal requirements for performance and reliability.
- All pipes or tubes should be welded, which minimizes leaks as the pipe expands and contracts during heating and cooling cycles. Welding also eliminates leaks from corrosive carbonic acid in the system, which is formed from carbon dioxide in the air and water.
- Screwed connections should be used to install equipment that requires frequent maintenance such as traps, valves, check valves and pipes smaller than two inches. Flanges are utilized in applications larger than two inches where maintenance or removal may be required.
- All steam supply and condensate return pipes should be properly supported, guided, and anchored, allowing for expansion of the pipes during temperature changes. A structure that is too tight can deform pipes and cause leaks.

5.5.3 Ensure Steam Quality

Steam quality is an important characteristic. In thermodynamic terms, quality is used to define how much vapor, by mass, is in a vapor/liquid mixture. The steam boiler or steam generator induces energy to the boiler water; phase change occurs (steam is generated) and the state of the water moves to the right from point A toward point B at constant temperature, see Figure 5.6. After the steam has reached point B, any increase in the steam energy is known as superheat. When energy is extracted from the steam at point B (phase change back to the liquid) the steam travels back toward point A on the curve below.

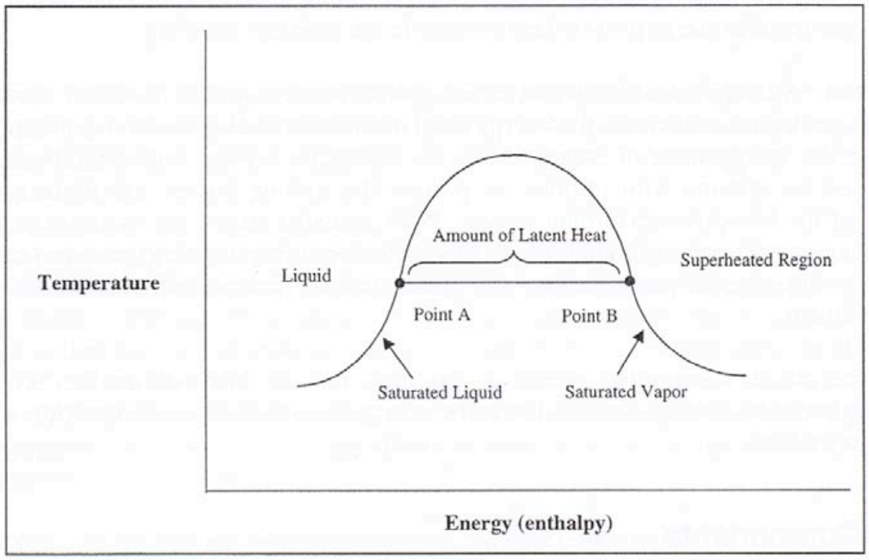

Figure 5.6 Temperature Energy Curve for Typical Process Steam System

Steam quality indicates where an operation would be positioned on the latent heat line (see Figure 5.6). Based on a review of chemical industry process steam systems, most processes require saturated steam in vapor form (Point B in Figure 5.6), also known as 100% steam quality or steam with no minute droplets of condensate in the vapor. The addition of any energy to superheat the steam can cause problems with heat transfer processes if the original design does not accommodate the superheated condition of the steam. Furthermore, in order to handle the pressure and temperature of the steam, superheated steam temperatures may require material changes. On the other hand, wet steam or steam that is less than 95% vapor (meaning 5% percent by mass is moisture or liquid) can lead to erosion, reduced heat transfer efficiency, premature steam component failure, and other problems.

Best Practices—Ensure Steam Quality

- Steam should be delivered to the end-use operation in the desired condition. Normally 100% saturate steam vapor is used.
- Always connect the branch line to the top of the main steam line. This will ensure dry, saturated steam to the process.
- Use proper drip-pocket steam traps, correct branch connections, and installation procedures where applicable.
- Install and maintain proper insulation on all steam and condensate return lines.
- Ensure proper pipe sizing is used to maintain correct velocities in steam line based on specifications of operation.
- Install and maintain coalescing mechanical separators where applicable.
- Implement the use of steam filters throughout the process steam system.

Use Proper Drip Pocket Steam Trapping

To ensure steam quality remains constant in the distribution system, all steam lines must be adequately trapped for condensate removal. This helps ensure continuous, efficient operation of the system at its design parameters. Condensate may produce pipe hammering and can damage equipment by producing rust. Air can also cause condensate to form.

A drip pocket vertical branch line is a properly sized vertical line that will remove "drips" of condensate formed by thermal losses in the steam line, even if the line is properly insulated. A schematic of a typical drip pocket steam trap is shown in Figure 5.7. The ideal diameter of the drip pocket depends on the diameter of the steam piping. The following parameters serve as guidelines for installing a drip-pocket steam trap.

- 2-inch steam line, 2-inch drip pocket
- 3-inch steam line, 3-inch drip pocket
- 4-inch steam line, 4-inch drip pocket
- 6-inch steam line, 6-inch drip pocket
- 8-inch steam line or above, one pipe diameter smaller than the steam line for the drip pocket

In addition, the vertical branch line should extend at least 18 inches in front of the drain line to the steam traps is tapped into the drip pocket branch connection with an additional pocket length of three or more inches off the bottom of the drain line connection. Finally, a blow-off valve should be installed at the bottom of the drip pocket.

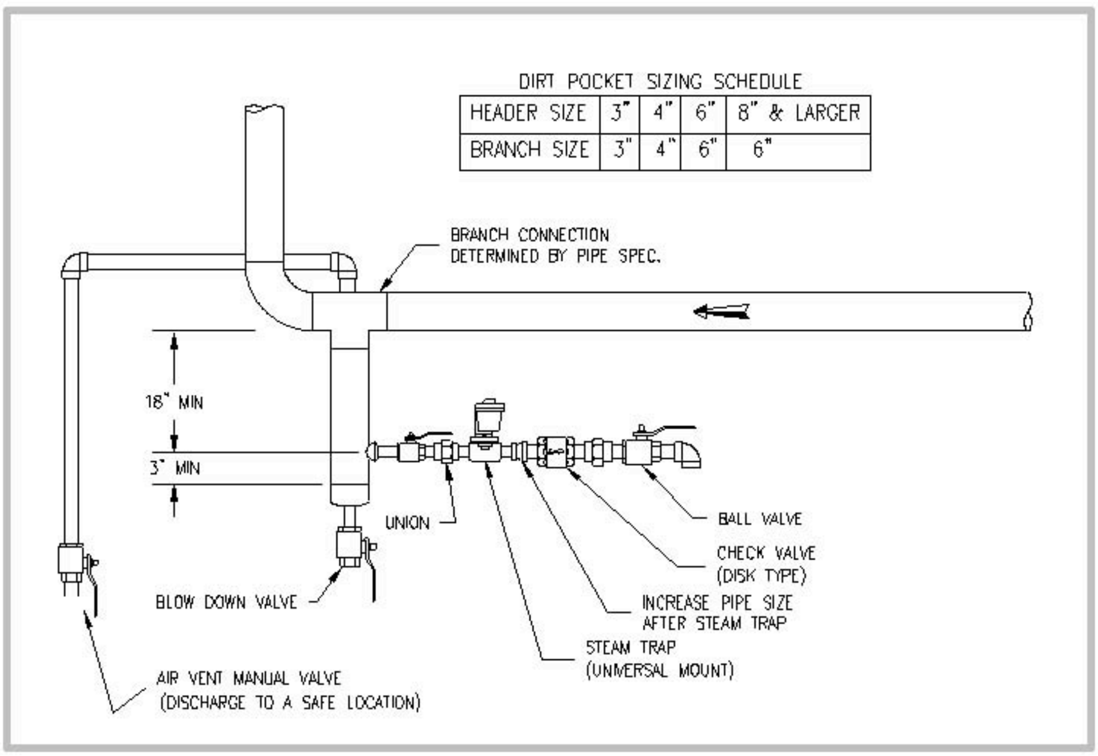

Figure 5.7 Schematic of a Typical Drip Pocket Steam Trap Installation

All low points in the piping where condensate could collect during periods of little or no steam usage require steam traps. Manual blow-down lines should be provided where large start-up condensate loads are expected.

Best Practices—Use Proper Drip Pocket Steam Trapping

- Steam traps should be installed at all low points in the process steam distribution system.
- Steam traps should be installed wherever there is a sudden change in direction.
- All valves, especially those that will be in the off position, should have steam traps installed behind them in the distribution system.
- Drip pockets should be used in conjunction with steam traps.
- When using drip pockets, follow suggested guidelines and parameters, making sure drip pockets are properly sized and installed.

Utilize Proper Insulation on all Steam Lines

As the temperature of the steam in the distribution system drops, energy is wasted. While some temperature drop is unavoidable, effectively insulating vessels, steam lines, valves, and even condensate return lines can help to reduce losses.

Best Practices—Utilize Proper Insulation on all Steam Lines

- Insulate as many steam lines, condensate return lines, and ancillary components as economically feasible.

Sizing Steam Lines

Selecting the correct size for steam lines is just as important as selecting and sizing the steam control valve or the heat transfer rate of a piece of end-use equipment. Undersized steam lines lead to steam pressure starvation at the end user, a condition that often is mistaken for a heat transfer problem or control valve issue. In addition, correctly sized steam piping ensures that steam quality is maintained at the design value. Over-sizing is never a problem except for its additional cost.

When designing steam headers, branch lines, and condensate lines, there are general rules regarding velocities in the piping. Steam velocity raises the issue of noise (DBA) and excessive pressure drops, which should be considered carefully on all new designs or retrofits. Following are some rules to keep in mind while sizing steam piping:

- Steam heating system velocities are typically in the range of 4,000 to 6,000 feet per minute.
- Process steam velocities are acceptable up to 10,000 feet per minute.
- Condensate piping velocities (steam) must be kept lower than 4,500 feet per minute
- Condensate piping velocities (fluid only) must be kept to 3 to 7 feet per second

Best Practices—Correct Pipe Sizing

- Follow the guidelines provided in Section 5.5.4.3 when sizing piping for a new design or retrofit.
- Steam line velocities should never exceed 10,000 feet per minute.

5.5.5 Additional Steam Line Needs

All steam lines must have either automatic or manual air vent devices to remove air during plant start-up (see Figure 5.7). If the system has no air venting capability, then all of the air in the steam line at start-up will flow into the process equipment. In addition, pressure gauges should be located throughout the system to provide pressure drop information. Pressure indication also provides information on the steam line sizing. If the line is too small for the steam load, the pressure drop will be high.

Best Practices—Additional Steam Line Needs

- Air vents and pressure gauges should be installed on all steam lines.
- Standard operating procedures for using air vents at startup should be instituted.
- Ball valves with a class four shutoff should be used in conjunction with air vents.

5.5.6 Proper Maintenance

Maintenance must be considered when designing and installing piping and associated devices. If these components are not accessible, there will be very little or no maintenance. Steam and condensate piping systems must be maintained. They are as important as the equipment they tie together. The first thing required is a chemical treatment program. The proper chemicals will allow the system to run at a neutral pH and provide a protective coating on the inside of the piping to suppress corrosion.

Best Practices—Proper Maintenance

- Steam and condensate piping should be checked periodically and repaired, if needed.
- Steam piping should be checked periodically for thickness using an ultrasonic thickness meter. Physical inspection during downtimes is also a good practice.
- Consider corrosion coupons for the piping of condensate systems. This will help determine chemical treatment effectiveness and gauge the condition of the piping.

5.6 Steam End Use Best Practices

As stated previously, optimizing the efficiency of steam-supplied operational end-uses generally requires a case-by-case assessment. This section will provide best practices that cover generalities of steam heat transfer and operational end-use equipment in the chemical industry.

Installation Guidelines:

Improper installation will cause:

- Premature failure of all components including:
    - Heat exchanger equipment
    - Steam traps
    - Control valves
    - Piping
- Poor control
- Waterhammer

Proper installation guidelines:

- Install a condensate drip pocket with a steam trap ahead of the steam control valve.
- Use ball valves with locking handles for pipes with diameters less than two inches. This provides the best safety procedure for lock out–tag out. Be sure to check with the appropriate persons to ensure compliance with any company, local, state, or federal regulations concerning lock out–tag out procedures.
- Install a strainer ahead of the control valve.
- Control valves selection is influenced by required turndown capabilities. A turndown capability is the valve's ability to control at a low point of operation. A valve that has a 40:1 turndown with a maximum flow of 1000 lbs. per hour, the turndown ratio is the highest output divided by the lowest. For example, a valve that requires 1000 lbs. per hour flow rate (max.) and a minimum flow rate of 25 lbs. per hour has a turndown ratio of 40.
    - Cage control = 40:1 turndown with the highest degree of controllability
    - Globe control valve = 30:1 turndown
    - Regulating valve = 20:1 turndown
- Install pressure gauges before and after the control valve.
- Control valve outlet piping must be increased to be equal to or larger than the inlet connection to the heat transfer unit. The control valve should be located at least 10 pipe diameters away from the heat transfer unit with the expanded pipe.
- Install a vacuum breaker and an air vent on the heat transfer unit or the steam supply inlet.
- Condensate drainage pipes should have a vertical drop away from the heat transfer unit of at least 18 inches or greater.
- The horizontal distance from the vertical drop leg (condensate outlet of heat exchanger) to the steam trap should never be more than eight inches to avoid steam locking.
- For capacities of 8,000 lbs. per hour or less, use a steam trap.
- For capacities of 8,000 lbs per hour or greater, use a control valve trap with a level controller instead of a steam trap.
- Install a test valve or a visual sight glass after the steam trap for visual indication of performance.
- Never take a RISE (rise in the vertical height elevation) in the condensate line after the condensate drain device if there is a modulating control valve (A control valve is responding to a PID controller –the valve can be at 0 or 100% or any place in between to meet the requirement of the system) off the inlet of the heat transfer unit. Condensate discharge piping rising (elevation) after a drain device is one of the most significant causes of premature failure of heat transfer equipment primarily due to the condensate not being readily removed from the process and causing water hammer.
- If gravity drainage is not achievable then a pumping steam trap or liquid mover must be installed to accommodate the lifting of condensate.

5.6.1 Get Necessary Heat Transfer Information

A few of the key issues with steam heat transfer

Several issues surfaced as we reviewed the operation of different chemical plants, prepared this document and analyzed numerous industrial heat-transfer applications. The more prevalent, which can be prevented with properly selected heat transfer components include:

- incorrect steam pressures
- code violations
- waterhammer
- poor temperature control
- premature failures
- dirt build-up
- improper trap selections
- condensate back pressure problems (including overhead condensate returns)

One of the most common comments from chemical manufacturers regarding the selection of the correct heat transfer unit is lack of specific requirements for the application. For example, when selecting the correct steam pressure, the end user does not normally know the steam supply pressure at the exact point the heat transfer equipment is going to be installed. Often an end user is unaware of the parameters that are required to determine the proper heat transfer. When a heat exchanger has failed, the end user will often simply purchase a replacement without doing root-cause analysis.

Very little consideration is given to design, selection, longevity, performance or failure (e.g., the maximum and minimum flows and normal operating conditions of the heat transfer.) This must be done with all components that are going to be selected in process applications. The end user needs to give the control valve manufacturer the correct minimum, maximum, and normal flow requirements for the process application. This is also true for the manufacturers of steam traps and other related steam equipment. Therefore, in every heat transfer process application, certain criteria must be provided to the manufacturer to ensure the correct heat exchange equipment is sized and selected. The following information should be determined for proper sizing and selection of heat transfer equipment and associated components for a chemical plant.

Process conditions:
- Process fluid or vapor
- Maximum flow
- Minimum flow
- Normal
- Process pressure
- Design pressure
- Maximum allowable pressure drop
- Inlet temperature
- Outlet temperature

- Specific heat
- Specific gravity
- Weight per pound
- Foul factor

Steam conditions:

- Steam pressure, temperature (upstream of control valve)
- Steam pressure, temperature (downstream of control valve)
- Design pressure
- Maximum pressure
- Minimum pressure
- Operating pressure
- Steam flow
- Design flow
- Maximum flow
- Minimum flow
- Operating flow
- Condensate return flow

5.6.2 Economics of Heat Exchanger Selection

Economic Considerations in Heat Exchanger Selection —There are economic considerations associated with the different types of heat transfer units. For example, low-steam pressure has several different heat transfer options. A plate-and-frame heat exchanger will have a lower initial cost compared to a shell-and-tube design, although both designs will meet performance specifications. But when steam pressure is increased to 100 psig, the selection of heat transfer equipment becomes limited to a shell-and-tube unit whose design is able to withstand higher steam pressure and temperature. A plate-and-frame unit will have a lower temperature and pressure rating due to the rating of its gasket materials.

Higher steam pressure can decrease the required heat transfer surface area, a result of the higher temperature differential between the steam and process. Pressure drops permitted by the system affect heat exchanger size. The highest allowable pressure drop results in savings if the heat exchanger surface area. As important as the pressure drop limitations are on the process side, it is as crucial to understand pressure drops on the steam side, when selecting the external components of the heat transfer unit.
Space restrictions sometimes affect heat exchanger costs. If a shell-and-tube heat transfer unit design must change to conform to a length or height restriction of an installation area, it will typically be more expensive to make the unit.

A shell-and-tube heat exchanger is more cost-effective to manufacture when designed with a long, small diameter shell, but the tube bundle typically must be removed for repair. Therefore, to accommodate removal of the bundle, the overall space for installation requirements is double the length of the shell. A shell-and-tube unit can also be shortened with multiple passes or bends but this design type is difficult to clean.

The end user must take into consideration all variables of the heat transfer design for installation.

5.6.3 Air in a Steam System

Air or non-condensable entrainment

The existence of air in a steam system has several detrimental effects on heat transfer. The following is a discussion of where the air comes from and how it affects heat transfer efficiency.

When steam is turned off, the vacuum formed by the condensing steam draws air into the system. When the system is re-energized with steam, the spaces fill with a steam/air mixture. The air will eventually be removed through steam traps and properly located air vents in the system. However, systems without proper venting will experience problems from the continued existence of air mixed with steam. Air is also introduced into the system when it's in operation. All steam systems require some amount of make-up water. This water contains mineral impurities that release air (gases) when the water is boiled to produce steam. These gases mix with the steam and exit the boiler into the piping system and heat exchangers. Air in the system can form thin films on heat transfer surfaces. Air is a very efficient insulator (thermal conductivity 0.2). A film of air of only 1/1000-inch thick has the same effect as a thickness of 13 inches of copper or 3 inches of cast iron. This dramatically reduces the heat flux of the heat transfer surface.

In addition to its insulating qualities, air also reduces transfer rate by lowering the temperature of the steam. The saturation temperature of steam is reduced when mixed with air in accordance with the law of partial pressures. Air contributes to the pressure of the mixture but does not contribute to the heat content. In a mixture of 80% steam and 20% air at a pressure of 100 psig, the saturation temperature is that of 80 psig steam and not of 100 psig. Just a small amount of air in the steam will reduce the saturated temperature several degrees. This reduction in temperature reduces the heat transfer rate by lowering the temperature differential.

Air or non-condensable removal

Steam equipment is fitted with vacuum breakers to prevent vacuums in the line from forming when steam is shut off. When steam collapses, it creates a vacuum that then draws condensate back into the heat transfer equipment. If allowed to cool, condensate can lead to carbonic acid corrosion. All heat transfers components, whether shell-and-tube, plate-and-frame, or other configuration, require vacuum breakers. When the vacuum breaker opens air is drawn into the system. Therefore, in addition to a vacuum breaker, it is again recommended that all heat transfer devices have an air vent. Both air vents and vacuum breakers are installed at points designated by the heat transfer manufacturer. The normal locations are close to the steam inlet or on the top portion of the heat transfer unit. This is the area where the steam condenses very rapidly. Air vents on heat transfer equipment and lines is an automatic device for venting air; it could be a modified steam trap to do this job.

Best Practices—Remove Air from the Steam System

- All heat transfer units require air-venting mechanisms.
- All heat transfer units require vacuum breakers. (Check valves that have been installed backwards do not suffice as vacuum breakers.)

5.6.4 Steam Valve Selection

Valves are classified for leak rates. In steam applications, Class 4 shut off or higher is the standard. This leak rate classification is from the American National Standard Institute (ANSI).

Types of valves:

- Check valve (prevents back flow)
- Gate (on/off services)
- Globe (modulating steam)
- Ball (on/off)
- Butterfly (on/off, limited by temperature and pressure)
- Test valves
  - Test valves are installed for a variety of reasons. They are typically installed to check flow, manually measure flow, identify performance, and for line sampling.
- Warm-Up valve
  - When installing an isolation or shut-off valve on the steam supply system (3 inches or larger) it is necessary to install a small valve around the isolation valve. At start-up, the smaller valve is opened first to allow the system to warm gradually, thus preventing any water hammer or thermal shock.

Turndown requirements

- 20 to 1—Regulator
- 30 to 1—Globe valve
- 40 to 1—Cage control valve