STEAM: A HEAT TRANSFER FLUID

Steam provides a means of transporting controllable amounts of energy from a central boiler room, where it can be efficiently and economically generated, to the point of use. For many reasons, steam is one of the most widely used commodities for conveying heat energy. Its use is popular throughout industry for a broad range of tasks from mechanical power production to space heating and process applications. This is why some consider steam to be the energy fluid [1].

The ability of steam to retain a large amount of energy on a per weight basis (1000–1200 Btu/lb) makes it ideal for use as an energy transport medium. Since most of the heat energy contained in steam is in the form of latent heat, large quantities of energy can be transferred efficiently at constant temperature, which is useful in many process heating applications.

The use of steam has come a long way from its traditional associations with nineteenth-century locomotives and the Industrial Revolution. Steam today is an integral and essential part of modern technology. Without the use of steam, our food, beverage, textile, chemical, medical, power, heating, and transportation industries would be crippled.

WHAT IS STEAM?

Water can exist in the form of a solid (ice), a liquid (water), or a gas (steam). In this book, our attention will concentrate on the liquid and gas phases and the equipment required to facilitate the change from one phase to the other. If heat energy is added to water, its temperature rises until a value is reached at which the water can no longer exist as a liquid. We call this the “saturation” point. Further addition of energy will cause some of the water to boil as steam. This evaporation requires relatively
large amounts of energy, and while it is being added, the water and the steam are both at the same temperature. As the steam is formed in a closed vessel, it develops pressure, allowing it to flow anywhere to a lower pressure, that is, through piping and distant equipment. Likewise, if we allow the steam to cool, it will release the energy that was added to evaporate it. These boiling, transfer, and condensing events provide a simple mechanism to transfer energy from one place to another, hence the basis of a steam system. Interestingly, steam is colorless, the white color often seen when steam discharges to the atmosphere is from the condensed water vapor in the steam.

Steam is Safe and Flexible

Water is plentiful and inexpensive. It is nonhazardous to health and environmentally sound. In its gaseous form, it is a safe and efficient energy carrier. Steam can hold five to six times as much energy as an equivalent mass of water. It can be generated at high pressures to give high steam temperatures. The higher the pressure, the higher the temperature, so it’s potential to do work is greater. Modern boilers are compact and efficient in their design, using multiple passes and efficient burner technology to transfer a very high proportion of the energy contained in the fuel to the water, with minimum emissions. The boiler fuel may be chosen from a variety of options, including natural gas, LP gas, oil, solid fuels, alternative fuels, and electricity, which makes the steam boiler an economical and environmentally sound option among the choices available for providing heat energy. Highly effective heat recovery systems can significantly reduce exhaust gas and water discharge energy losses, creating an overall efficiency of the steam system approaching 85%. Boiler plants can be centralized or installed at the point of use. Sizes range from a few pounds of steam to thousands of pounds of steam per hour. Steam is one of the most widely used media to convey heat over distances. Because steam flows in response to the pressure drop along the pipeline, expensive circulating pumps are not needed. Not only is steam an excellent carrier of heat; it is also sterile and thus popular for process use in the food, pharmaceutical, and health industries. Other industries within which steam is used range from huge petrochemical and biofuel plants to small local laundries. Further uses include the production of paper, plastics, textiles, beverages, food, metal, and rubber. Steam is also used extensively for power generation, humidification, and space heating.

Steam is also intrinsically safe—it cannot cause sparks and presents no fire risk. Many chemical plants and refineries utilize steam fire-extinguishing systems. It is ideal for use as a heat transfer media in hazardous areas or explosive atmospheres.

Steam is Easy to Control

Because of the direct relationship between the pressure and temperature of saturated steam, by simply controlling the steam pressure, one can control the temperature of the steam and the process material being heated. Furthermore, the total amount of energy input to a process stream is directly related to the steam mass flow heating that process. Modern steam controls like pressure-reducing valves and flow control valves are designed to respond very rapidly to process inputs. Therefore, today, steam
pressure and flow can be precisely regulated to add heat energy to a process. Industrial processes that have tight heating tolerances are well suited for process steam use.

The **heat transfer properties of steam are high**, and the required heat transfer area is relatively small. This enables the use of compact heat transfer equipment, which reduces installation costs and takes up less space in the plant. Most steam controls are able to interface with modern networked instrumentation and control systems to allow centralized control, as the case of a building/energy management system or process computers. With proper maintenance, a steam plant will last for many years, and many aspects of the system are easy to monitor on an automatic basis.

In contrast, hot water and hot oils have a lower potential to carry heat energy per pound. Consequently, large amounts of water or oil must be pumped around the system to satisfy process or space heating requirements. However, hot water is popular for general space heating applications and for low temperature processes (up to 200°F) where some temperature variations can be tolerated. Furthermore, thermal fluids, such as mineral oils, may be used where high temperatures (up to 700°F) are required but where high steam pressure is undesirable. An example would include using hot oil as the heating source in certain chemical process reactors. Figure 1.1 shows that saturated and superheated steam can provide a heating range from 200 to more than 1000°F.

**STEAM SYSTEM TYPES**

Generally, steam systems can be classified into one of the three categories:

1. Steam heating systems
2. Power generation steam systems
3. Process steam systems

**Steam heating** systems are generally closed loop low-pressure systems found in government and school buildings. The degree of control and efficiency is usually much less than what is found in process or power generation applications. Similar

![Figure 1.1](image-url)  
**FIGURE 1.1** Heat transfer fluids useful temperature ranges.
comparison can be made with respect to steam quality. Steam heating systems tend to be large and less sophisticated than process or power generation steam systems. Many of these low-pressure steam heating systems are being replaced with higher efficient hot water heating systems (Fig. 1.2).

**Power generation steam systems** can vary in size. Some are large high-pressure steam systems that use steam to drive a turbine generator. Nuclear power plants, coal- and biomass-fired power plants and other combined cycle cogeneration systems fall into this category. This type of steam system will generally require clean dry steam for extended turbine life and high-purity condensate. Controls can be quite sophisticated (nuclear reactor) or can be quite simple (newer cogeneration steam). Cogeneration may use heat recovery steam generators or HRSGs to capture waste heat and convert the energy to usable steam. Steam quality and high system efficiency requirements influence the design of these steam systems (Fig. 1.3) [2].

**Process steam** is the type of steam system that is the most applicable for the guidance in this book. These systems can range in size from small (<100 lb/h) to very large (>100,000 lb/h). Steam quantity and quality requirements influence the system design. Process steam systems tend to have very automated controls with tight tolerances. System reliability is essential, and preventative maintenance on these steam systems is critical. The steam system in a process application is usually considered an ancillary system. Steam is required for the process, but is not the saleable product. Consequently, steam systems may not receive attention until there is a problem. A good example of this application is brewing. Without steam flow, the output of the brewery comes to a halt. A good process steam system operation requires constant visibility with the plant management team (Fig. 1.4).
STEAM SYSTEM TYPES

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FIGURE 1.3 Steam power generation system.

THE PROCESS STEAM SYSTEM

The steam generated in the boiler must be conveyed through pipework to the equipment where its heat energy is used in some process-related application. Once the steam condenses and surrenders its energy, the condensate must be removed, collected, and prepared for reuse in the boiler. This cycle of steam generation, steam delivery, condensing, collecting, and pumping back to the boiler is the basic concept of a process steam system.

Generally, we can consider the basic steam system to be comprised of five subsystems: the fuel delivery and combustion system, the steam generator system, the steam delivery system and the condensate/feed water system are the four subsystems that account for the production of steam. The remaining subsystem, the water treatment subsystem, does not play a direct role in steam production; however, it plays an extremely important role in maintaining good steam quality and long life of the entire steam system equipment. The five subsystems are shown in Figure 1.5.

FIGURE 1.5 The five subsystems of a process steam system.
The fuel handling and combustion system is the part of the system that controls input to the steam generator. The fuel handling system may be a set of gas valves and regulators or oil valves and regulators for gaseous and liquid fuels. It may also be an auger and conveyor system for solid fuels like wood chips, coal, or refuge. For electric boilers, the fuel handling system would be the power feed or element contactors to the steam generator. In all cases, this part of the system controls the input energy and consequently controls the steam output.

The combustion system takes that fuel input and converts it to thermal energy. The efficiency of the combustion system plays a major role in the overall efficiency of the steam generator. This system mixes the right amount of air with the fuel to ensure it combests completely. Modern combustion systems have feedback controls that tie the steam generator exhaust chemistry to the generator combustion system to ensure high efficiency. In the case of electric boilers, the combustion system is essentially the electric elements or electrodes. The efficiency of the electric elements or electrodes is related to their cleanliness. The fuel handling and combustion control system details are presented in Chapter 7 on section “Fuel Delivery and Combustion Systems.”

The steam generator or boiler is the heart of the steam system. This is the machine that transfers the fuel energy from the combustion system to water in a pressure vessel to make steam. Steam generators come in a variety of sizes and configurations. This part of the system includes the insulated pressure vessel, pressure and water level controls, steam flow, and combustion flue gas removal. A detailed look at the available types and uses of the many steam generators is covered in Chapter 6.

The steam delivery system is the part of the steam system that conditions the steam to the right quality and pressure and conveys it to the steam using equipment. This part of the system includes steam piping, pressure-reducing and temperature control valves, steam separator and filters, steam accumulators, and steam flow meters. Each steam delivery system is uniquely designed for each process application. More detail is offered in Chapter 8.

The condensate and feed water system is the part of the steam system that separates the steam from the condensed water, collects it, and transfers it back to the steam generator. This part of the system includes the steam traps, condensate piping, condensate collection tanks, feed water tank or deaerator, pumps, and controls. The function of this part of the system is to provide a means to collect and feed hot, high-quality water to the steam generator for reuse to make more steam. Chapters 9 and 10 on the condensate and feed water systems provide a comprehensive review of the design and operational requirements of this part of the steam system.

The last part of the steam system is the water treatment system. This part of the steam system is not directly involved with the steam cycle but is considered essential to maintain the reliability and durability of the system components. The water treatment system includes the water conditioning equipment and controls needed to render the makeup water, feed water, and boiler water harmless relative to corrosiveness, scaling, and sludge buildup potential. The steam system contains metal components in contact with water, and without proper water conditioning, these metal components would not maintain system integrity very long. Specific methods used to treat steam system water and the consequences of improper treatment are described in Chapter 11.