Producing Hot Water by Direct Steam Injection

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Inline direct steam injection is more energy efficient than indirectly heating water in a tank. Use this overview of DSI equipment to select the appropriate system for your application.

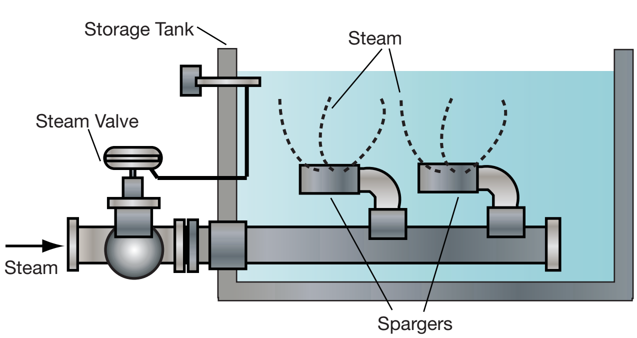
Direct steam injection (DSI) is a viable alternative to indirect heating for many applications that use process steam, require large volumes of hot water, or need accurate temperature control. As the name implies, DSI systems inject steam directly into cold water, unlike indirect heating, which transfers heat by conduction through a metal wall or tube.

With its high energy efficiency, compact footprint, accurate temperature control, and ability to provide a continuous supply of hot water, DSI overcomes some of the shortcomings inherent in the indirect approach (see sidebar). This article looks at these advantages and compares different types of DSI systems.

DSI advantages

Energy efficiency. Using virtually all of the energy in the steam to heat the water, DSI systems are up to 28% more energy efficient than indirect systems. Steam coils or heat exchangers are, at best, about 75% efficient, because only about three-quarters of the energy in the steam is actually used to heat the water.

For example, saturated steam at 100 psig contains 1,189 Btu/lb. As steam condenses in a heat exchanger, only the latent heat (about 880 Btu) is released to heat the water. The condensate, which still contains at least 309 Btu, is at 338°F. This condensate is either returned to the boiler or discharged from the system (and its heat content wasted).



▲ **Figure 1.** A steam sparger has a perforated pipe through which steam is bubbled directly into the water in a vented storage tank.R

As the condensate returns to the boiler, energy may be lost through faulty steam traps and ancillary equipment. Leaking steam traps, which are a major cause of energy waste, incur high maintenance costs. Additional heat is lost by radiation from condensate return lines. At the receiver tank, more energy is lost when the condensate flashes as it is reduced to atmospheric pressure. Overall efficiency falls, too, as mineral deposits accumulate on the wetted side of the metal conductor and create an insulating barrier.

With direct steam injection, 100% of the steam condenses as it heats the water. There is no need for condensate return lines with their attendant energy losses and steam trap maintenance problems.

Compactness. Even the most sophisticated DSI water heating systems are so compact that they can be suspended from a wall or ceiling or mounted on a compact skid on the floor. This type of system is preferred where space does not allow for a storage tank. When a large storage tank must be replaced, a steam injection system is easier to install in an existing building than a new large storage tank.

Temperature control. The more-sophisticated DSI systems provide very close temperature control at both constant and variable flowrates and in applications that involve frequent stopping and starting. This control is possible because heat transfers immediately from the steam to the liquid when heating starts. When demand and steam flow stop, heating ceases at once, unlike in a heat exchanger, which continues to release residual energy.

Continuous hot water supply. Direct steam injection heats the water instantly on a continuous straight-through basis as it is used. A DSI system that is properly sized for the available steam supply, cold water supply, and hot water demand can continuously deliver hot water as required. The user does not run out of hot water, and does not need to store large quantities of hot water.

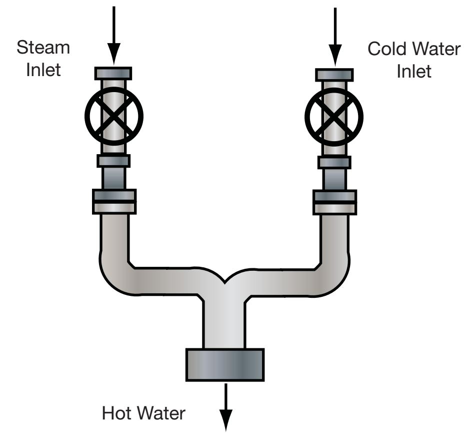
Types of steam injection systems

Several methods can be used to inject steam into cold water. These methods differ primarily in their ability to adjust to variations in steam pressure, incoming water pressure, and hot water demand. The most-sophisticated injection systems adjust automatically for these variations; others have more limited capabilities, but are adequate for some situations. The following discussion explains how these systems work and where they can be used effectively (Table 1).

Sparger. The simplest DSI system is the steam sparger, which is a perforated pipe or other fixture through which steam is bubbled directly into the water in a vented storage tank (Figure 1). Spargers are often installed in storage tanks and boiler feedwater tanks. They are also commonly used to heat cryogenic fluids.

Sparging systems are simple and relatively inexpensive to install, but their limitations can outweigh their benefits in many applications. It is difficult for spargers to achieve and hold a set water temperature, and heating large volumes of water can take a long time. Because there is no way to balance the pressure of the steam in excess of the surrounding water pressure, sparging often causes severe water hammer and vibration that damages storage tanks. Finally, sparging is the least efficient method of heating water because as steam is injected into the bottom of a tank, some of it rises to the surface and flashes to the atmosphere, wasting energy. Sparging is usually less than 50% energy efficient.

Mixing tees. As the name implies, a mixing tee (Figure 2) is a T-shaped device that blends steam with cold water. Mixing tees may have manual, semi-automatic, or automatic temperature control. With a manual mixing tee, the operator first turns on the cold water, then opens the steam valve to admit enough steam to heat the cold water; this type of system can achieve only approximate temperature control. Semi-automatic mixing tees require manual adjustment of steam and water, but they have an automatic steam shutoff that is activated if the water supply is interrupted. With auto-



▲ **Figure 2.** Mixing tees blend steam with cold water. They may have manual (shown), semi-automatic, or automatic temperature controls.

Table 1. Many common CPI applications can be handled by more than one DSI method.

Application	Sparger	Mixing Tee	Venturi	Dual Modulating
General Plant Cleanup		✓		✓
Tank Car Washing		✓	✓	✓
Tank Car Heating	✓		✓	✓
Brackish Water Heating			✓	✓
Filter Washing	✓		✓	✓
Line Tracing	✓		✓	✓
Cleaning and Sanitizing (Clean in Place)	✓		✓	✓
Adding Water to a Batch Process	✓	✓	✓	✓
Heating Jacketed Reactors, Blenders, and Other Vessels			✓	✓

The Limitations of Indirect Heating

Just like direct steam injection systems, indirect heating has advantages and disadvantages.

Indirect storage-tank heating systems require extended start-up time at the beginning of the work day. Most are not insulated, so they radiate and waste enormous amounts of energy. Close temperature control is not possible under the intermittent start/stop and variable-flow conditions that are typical of indirect heating, even with tankless (instantaneous) water heaters.

Since most indirect storage-tank heating systems cannot heat water instantaneously, they are used to heat stored water. As hot water is drawn off to meet demand, cold water enters the storage tank. The incoming cold water lowers the average temperature of the stored water, thus complicating efforts to maintain and control temperature.

When hot water demand exceeds the maximum capability of the storage-tank heating system to generate an adequate amount of heated water, the supply of hot water could be depleted. In most industrial processes, when the hot water supply is used up, the operation must be shut down until more water is heated.

Indirect systems are relatively inefficient because they use only about 75% of the available energy in the steam.

matic mixing tees, the temperature setpoint is programmed into a controller and then the steam and water supplies are turned on.

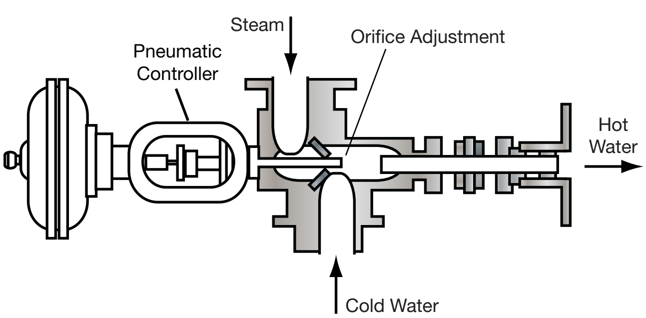
Manual and semi-automatic mixing tees cannot adjust for variations in steam pressure, water pressure, or hot water demand. Therefore, they are not recommended for use in plant sanitizing situations that require water heated to 180°F. They are, however, adequate for general plant washdown, and are often used in wash stations. Unless correctly operated and properly maintained, manual and semi-automatic systems can be hazardous because live steam may be ejected if the cold water supply is abruptly stopped.

When specifying DSI for multiple wash stations, it may be worthwhile to compare the cost of several individual mixing tees with the cost of a central variable-flow steam injection system, especially if the temperature requirement is the same at all the wash stations. In general, if three or more wash stations are called for, the installed cost of a central system may be lower. In addition, a central system prevents workers from misadjusting individual wash-station mixing tees.

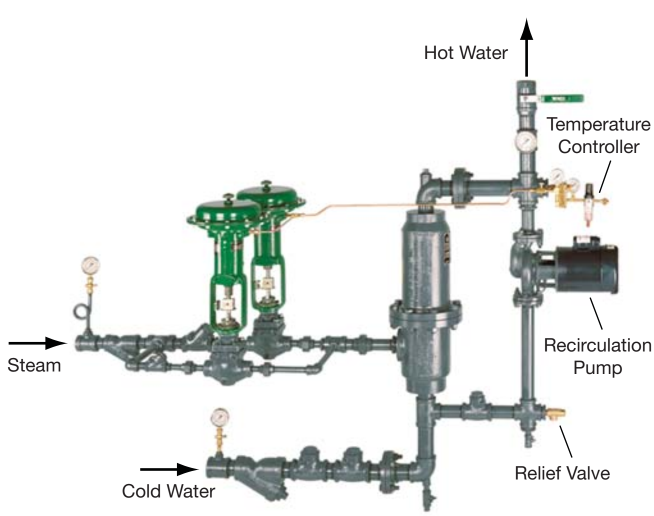
Venturi injection systems. In the venturi (or eductor) method, steam is drawn into the cold water through a venturi or constriction in the water line (Figure 3). By passing through the venturi, steam enters the water at a high (sonic) velocity. This creates a pressure differential and generates turbulence that promotes rapid mixing of the steam and cold water.

Venturi systems may have either a fixed orifice or a variable orifice. As their name implies, fixed-orifice venturi systems cannot be adjusted for variations in steam pressure, water pressure, or hot water demand. They are satisfactory only in applications where these conditions remain constant.

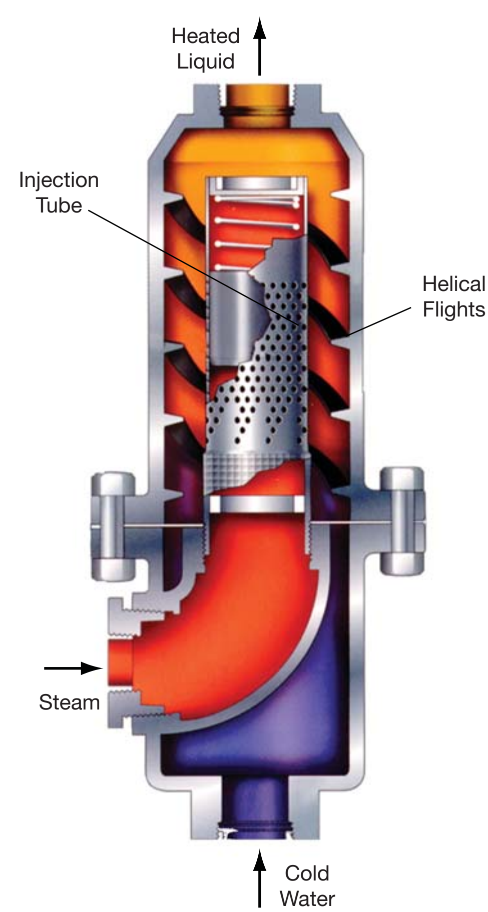
In a variable-orifice venturi system, the steam flow or water flow can be adjusted to deliver water at different temperatures. The adjustment may be manual or pneumatically regulated. Where steam pressure, incoming water pressure, and hot water demand remain fairly constant, variable-



▲ **Figure 3.** Venturi steam injectors draw steam into the water via a constriction in the water line.



▲ **Figure 4.** A dual-modulating system adjusts the steam flow at an external modulating control valve and at the point of injection.



▲ **Figure 5.** In a modulating steam valve system, steam enters through orifices in the injection tube. A spring-loaded piston in the injection tube rises or falls as more or less steam is required. Helical flights in the chamber promote thorough mixing prior to discharge.

orifice venturi systems are adequate. They can, however, experience water hammer if the steam pressure and cold water pressure are near equilibrium. Because they have very limited turndown capabilities, they cannot accommodate variable flows, low-flow conditions, wide variations in steam or water pressure, or fluctuating hot water demand without a storage tank. The liquid pressure drop through this type of system may exceed 30 psi, whereas the pressure drop through a dual-modulating system seldom exceeds 2 psi. In addition, venturi systems are noisier than other DSI designs because of the steam's sonic velocities.

Dual-modulating steam-injection system. The most effective DSI system is the dual-modulating steam-injection system (Figure 4). This device adjusts the steam flow at two locations — an external modulating control valve and the point of injection.

In practice, the steam pressure, water pressure, and hot water demand are seldom, if ever, constant. Although steam pressure may remain relatively constant, the pressure and temperature of the incoming cold water may change, and the demand for hot water may vary from maximum flow to no flow. Where a flow of hot water at a precise temperature is required and these conditions are likely to vary, a dual-modulating DSI system is recommended.

The steam control valve is activated by a temperature controller located at the hot water outlet. This controller may be manually set to any desired outlet water temperature, or it may be regulated remotely by a pneumatic or electronic temperature controller. The controller automatically signals the modulating steam control valve to admit more or less steam, depending on what is required to maintain the outflow temperature.

A single modulating control valve provides approximately a 10:1 steam flow turndown capability. Additional turndown capability, approaching 100:1, can be obtained with dual control valves.

In addition to regulating the incoming steam flow with a modulating valve, this system also controls the steam injection pressure at the point where the steam enters the cold water. At the point of injection, steam enters the cold water through hundreds of very small orifices in an injection tube. By breaking the steam up into many small streams and maintaining a positive pressure differential, all the steam is instantly injected into the water.

As the modulating steam valve varies the steam flow to maintain the outflow water temperature, the steam pressure works against a spring-loaded piston in the injection assembly (Figure 5). As the steam flow varies, it forces the piston to rise or fall, exposing more or fewer orifices.

By applying pressure against the incoming steam, the spring-loaded piston constantly maintains the steam pressure above the incoming water pressure. This eliminates the water hammer that typically occurs when steam and water pressures are at or near equilibrium, such as what occurs with sparging.

These design features enable the dual-modulating system to deliver hot water quietly within precise temperature tolerances over a wide range of flow conditions. The close temperature control prevents overheating and saves energy — for instance, overheating 100 gal/min of water by just 10°F wastes approximately 500,000 Btu/h.

In addition to variable-flow applications, dual-modulating systems are widely used in processes that require hot water to be delivered in a sequence of different temperatures because the temperature of the hot water can be changed almost instantly.

Table 2. Consider the items on this checklist when selecting a DSI method for a particular hot water application.

The nature of the application
Process conditions
Water flowrate, minimum and maximum (gal/min or L/min)
Cold water inlet temperature (°F or °C)
Hot water outlet temperature (°F or °C)
Steam pressure (psig or barg)
Water pressure (psig or barg)
Materials of construction for piping, valves, and other components
Temperature control required
Pneumatic (local)
Electronic (remote)
Programmable logic controller
Distributed control system
Electrical area classification and power required
Space considerations for locating equipment

Final thoughts

Whether for applications that use process steam, require large volumes of hot water, or need accurate temperature control, direct steam injection heating is often preferable to indirect heating. Table 2 summarizes the factors to consider when selecting and specifying a DSI system for a particular application. CEP

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