DIRECT STEAM INJECTION HOT WATER SYSTEMS FOR JACKETED HEATING

By Philip Sutter
Pick Heaters, Inc.

INTRODUCTION

Many process plants currently use steam or hot water to heat jacketed devices such as tanks, kettles, dryers, reactors, glass lined vessels, or similar adaptations such as coiled tubing placed inside or outside tanks or vessels.

In this article, we will take an in-depth look at the advantages and disadvantages of steam and hot water for jacketed heating, and compare indirect and direct steam injection systems for making hot water.

In heating applications where processes require operating temperature up to 350°F (177°C) steam is often the first heating medium considered because it is readily available. However, hot water should be given equal consideration.

.ADVANTAGES AND DISADVANTAGES OF STEAM

Figure 1 illustrates a typical jacketed heating system using steam. Because it is readily available and easy to apply, steam is often used for jacketed vessel heating. Steam provides quick heat-up and it is predictable e.g. 100 PSIG (7 BARG) saturated steam is always 338°F (170°C) with 1,189 BTU/lb total heat content.

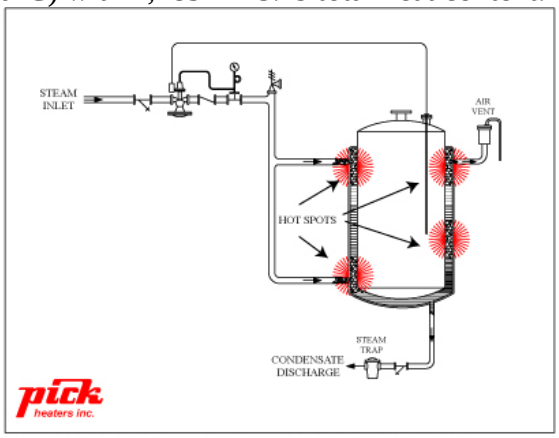


FIGURE 1. TYPICAL STEAM HEATED JACKETED VESSEL.

Despite its advantages, steam has several shortcomings. It does not offer precise temperature control, and energy transfer is not uniform. Due to uneven distribution, higher temperature steam typically collects in the upper portion of the jacket, with cooler condensate collecting near the bottom.

Internal hot spots also develop around hot steam inlet nozzles, adding to the problem of uneven product heating. This increases the likelihood for product burn-on and local overheating.

Furthermore, a steam trap is a necessary component of a steam-heated jacketed vessel. It allows condensed steam to exit the jacket, making room for more steam. If improperly sized or poorly maintained, energy will be wasted and temperature control will be compromised, which frequently results in damaged product or lower product yields.

Reactions requiring both heating and cooling are cumbersome for the steam-heated system because of the dramatic temperature difference between the
steam and the cooling water. At the conculsion of the heating cycle all steam and condensate must first be driven out of the jacket prior to introducing cooling water. This is a time-consuming process that is often not done completely. The problem is most severe with glass-lined reactors, which may be damaged by thermal shock and steam hammer if cooling water contacts residual steam in the jacket.

Currently, an increasing number of process engineers are switching from steam to hot water for jacketed heating. There are several basic reasons for this trend:

- The temperature in the jacket can be controlled much more accurately with hot water than with steam. This higher degree

of control protects against damage to or loss of product through overheating.

- Hot water distributes heat more evenly than steam. This eliminates hot spots which often cause product to bake onto the walls of the vessel, and at worst, ruin the entire batch.
- Hot water ensures a better quality end product. This is particularly important in processes requiring very precise product temperature control.
- In critical processes utilizing glass-lined reactors, steam can shock and damage the lining. Hot water allows smooth transitions from heating to cooling with no thermal shock.

In addition, many are switching to **direct steam injection (DSI)** systems to create the hot water for several basic reasons:

- With an advanced-design steam injection heating system, the temperature of the process can be adjusted at any predetermined rate on any desired time cycle.
- A steam injection hot water system can be programmed to heat then cool a process by stopping the heating cycle and introducing cooling or tempered water into the jacket at any desired rate and temperature.
- In this system the condensate (from the steam that was injected) leaves the circulating loop through a back pressure relief valve at the lowest temperature after all the possible heat has been extracted. In a steam system, on the other hand, condensate at a much higher temperature must be returned to the boiler in a condensate return line with its inherent heat losses.

ADVANTAGES AND DISADVANTAGES OF HOT WATER

The use of hot water to heat reactor vessels solves many of the problems associated with steam. The jacket temperature can be controlled more accurately with hot water because hot water distributes heat more evenly over the wetted surface of the vessel. This eliminates hot spots, which can cause the product to burn onto the walls of the vessel and potentially ruin the entire batch. By eliminating burn-on, product quality is protected and product filtering and costly clean up time are minimized.

Hot water offers a wide range of operating temperatures because when pressurized, water will remain in the liquid state and not flash into steam. For example 72 PSIG (5 BARG) water can be heated in a pressurized circulating loop to 310°F (154°C) without boiling. The process can be gradually ramped up or down to desired temperatures, eliminating the potential of thermal shock.

For processes requiring both heating and cooling, hot water can be adjusted at a predetermined rate on a desired time cycle through the use of cascade or heat/cool temperature control loops, or an in-plant PLC or DCS. A hot water system can be programmed to heat, hold, then cool a process by introducing cooling or tempered water into the jacket at a controlled rate and temperature without having to stop the process as when using steam.

In addition to offering precise temperature control, water is readily available, easy to handle, non-flammable, safe to the environment, and inexpensive as compared to heat transfer fluids.

What is the downside of using hot water in jacketed vessels? The product heat-up time using hot water will not be as rapid as it is with steam. However, once up to temperature the steam heated system may be difficult to keep from overheating.

Another limitation is that the jacket water temperature cannot equal or exceed the saturated temperature of the steam supplied to the system. For example, when operating the system with 150 PSI (10.3 BARG) steam, the jacket water temperature cannot exceed 352°F (177°C) at 130 PSIG (9 BARG), because of the 20 PISG (1.4 BARG) pressure differential requirement for DSI, and above that temperature the water will flash back into steam.

MAKING HOT WATER WITH INDIRECT HEAT EXCHANGERS

Where steam is available, indirect heat exchangers are commonly used to heat water for jacketed vessels (see Figure 2). In these systems, steam does not come in direct contact with the water which is being heated. Heat energy is transferred across a membrane such as a tube bundle or series of plates. As energy is transferred, steam condenses and is discharged through a steam trap and routed back to the boiler.

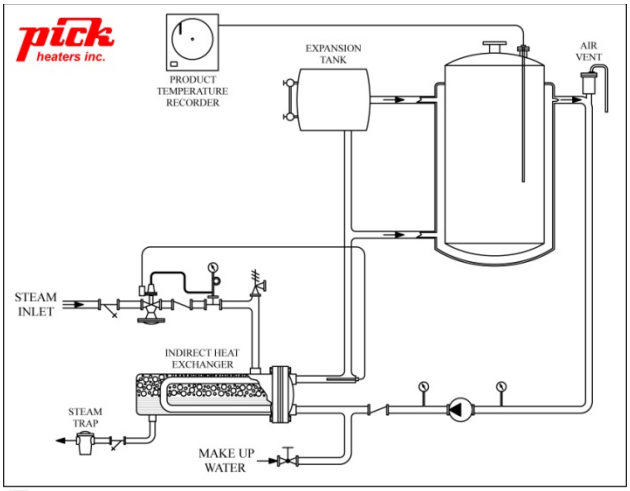


FIGURE 2. TYPICAL HOT WATER JACKETED HEATING SYSTEM WITH INDIRECT HEAT EXCHANGER.

Indirect heat exchangers are designed to use only the latent heat from the steam or approximately 83% of the total heat energy, while the sensible heat (or approximately 17% of the total BTU's) is discharged from the exchanger in the form of condensate. Much of the remaining BTU's are lost en route back to the boiler making the indirect heat exchanger an inefficient method of heating a reactor vessel.

Another problem inherent in indirect exchangers is poor temperature control (typically ±10-15°F accuracy) due to the lag time between the adjustment of control equipment and the time it takes to transfer heat energy from the steam through the tube bundle or plate surface. System start up times will be longer as all the metal mass in the heat exchanger must be heated up, and additional components such as an expansion tank is required to balance the system pressure .

Finally, a steam trap is still required in an indirect system with all of its inherent costs, maintenance, energy loss, and reduced productivity problems.

ENERGY COMPARISON - DIRECT vs. INDIRECT HEATING OF WATER

Direct steam injection (DSI) heaters inject steam directly into the circulating water loop. For processes which return the jacket water below 212°F (100°C), they achieve **100% heat transfer** by using both the sensible and the latent heat of the steam. Above this temperature there is a minimal drop in efficiency.

Let us compare the efficiency of an indirect (shell and tube type) heat exchanger to a DSI heater. The application chosen demonstrates the annual energy consumption for heating a jacketed blender which mixes powders with liquids and then dries the mixture. Assume the process operating conditions are as follows:

Product volume:	10,000 lb of a water-like product
Blender operating heat load:	4,816,340 BTU/hr
Jacket water temperature:	250°F
ΔT across jacket:	*55°F (250° - 195°F)
* This is the required ΔT to be made up by the heater.	
Water circulating flow rate:	175 GPM
Water loop pressure:	50 PSIG
Steam pressure:	150 PSIG Saturated
Hours of operation:	16 hr/day; 4000 hr/year
Boiler fuel type and cost:	Nat. Gas at 0.85 /Therm
Boiler efficiency:	82%

Based on these conditions, the steam requirement for heating with an indirect heat exchanger would be 5,620 lb/hr, while the steam requirement using a DSI heater would be 4,662 lb/hr. Factoring in the energy required by the boiler to preheat the feed water and to generate steam at 82% boiler efficiency, the indirect heat exchanger will require 7,182,634 BTU/hr while the DSI heater will require only 6,612,080

BTU/hr **or 7.9% less energy than the heat exchanger!** This energy savings of 570,554 BTU/hr will result in an hourly fuel savings of 5.71 therms of natural gas (a fuel heating value of 100,000 BTU/therm). At 85¢/therm this translates into a fuel cost savings of $4.85/hr, or an annual fuel savings of over $19,000. Results may vary depending upon fuel costs and operating conditions.

This example demonstrates the dramatic energy savings to be realized by the DSI heater and is based upon the very conservative assumptions that:

1. The heat exchanger steam trap does not leak steam.
2. There is no volumetric loss due to condensate flashing at the receiver tank.
3. 195°F water discharged from the system using the DSI heater is not returned to the boiler. Instead, 65°F boiler make-up water is used.

Please Note:

The 195°F water discharged from the closed loop as a result of DSI may be returned as boiler make-up water which would increase the fuel savings even further, **up to 17% more efficient than the heat exchanger.**

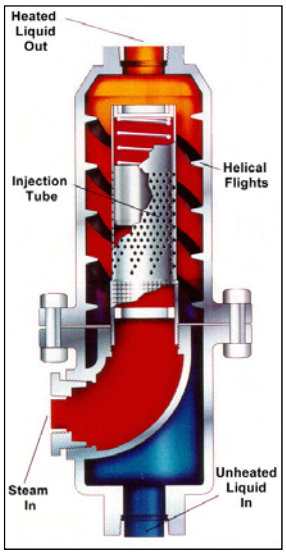
There are several objections to the use of DSI which need to be addressed when considering this approach. Most of these relate to the fact that the steam must be thoroughly absorbed into the water at the point of contact or it may result in "steam hammer". If the steam is not thoroughly absorbed, it will expand and then collapse downstream in the piping or the jacket. This creates an implosion due to the dramatic change in volume between steam and water which results in noise and vibration known as steam hammer. This is especially a problem with simple steam-to-water static mixers, spargers, and venturi/eductor type heaters. In order to assure thorough absorption of steam into water, the steam pressure should be at least 10-20 PSI greater than the water pressure at the point of injection.

Furthermore, cold make-up water must be heated at the boiler, because condensate might not be returned to the boiler. This could result in additional costs for chemical treatment. However, the energy savings from DSI will more than offset these costs.

MAKING HOT WATER WITH A DIRECT STEAM INJECTION (DSI) SYSTEM

When using an advanced design Pick™ DSI System, steam flow is modulated at two points: the steam control valve, and also at the point of injection within the heater. This dual modulation results in superior temperature control over a wide range of hot water demands or when a sequence of varying temperatures or pressures are needed to meet process requirements.

In a Pick™ DSI Heater, steam enters the cold water at low to moderate velocities through hundreds of small orifices in an injection tube (see Figure 3). By breaking up the steam into multiple small streams and also maintaining a positive pressure differential, all the steam is quietly injected and instantly mixed into the flow of water within the heater body.



■ FIGURE 3. MULTIPLE ORIFICE DSI HEATER

During operation, steam pressure works against a spring-loaded piston inside the injection tube assembly. As the steam flow

varies, it forces the piston to rise or fall exposing more or fewer orifices (see Figure 4).

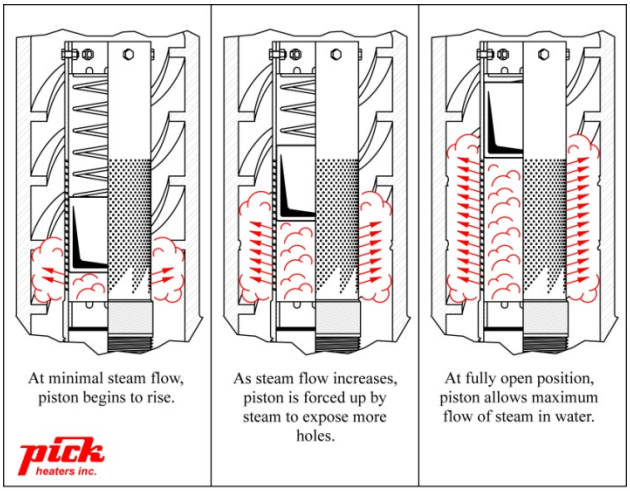


FIGURE 4. VARIABLE ORIFICE STEAM INJECTION TUBE

By applying water pressure and spring force against the incoming steam, the spring-loaded piston constantly maintains steam pressure in excess of incoming water pressure. This prevents steam hammer which occurs when steam and water pressures are at or near equilibrium.

Another important design feature of the Pick ™ DSI Heater is the helical flights within the mixing chamber. These create controlled turbulence to assure thorough and immediate mixing of the steam and liquid within the heater rather than in downstream piping. As a result, these heaters are much quieter to operate than (high velocity) venturi or static mixer type heaters.

The heater creates very little internal restriction to liquid flow. Velocities are not excessive and very little pressure drop (less than 2 PSI) is generated across the heater, minimizing friction losses and pump horsepower requirements. The hot water discharge temperature can be sensed immediately downstream of the mixing chamber and requires very minimal piping (less than 5 pipe diameters) before entering the jacket.

The external steam control valve is actuated by a temperature controller, which is responding to water discharge temperature. This may be manually set to any desired outlet water temperature as Figure 5 illustrates. Water temperature setting may also be regulated remotely by a pneumatic or electronic temperature controller (PLC, DCS), and by sensing the product temperature (commonly referred to as cascade temperature control). With this arrangement, system operation is fully automatic. The operator simply inputs the desired product set point temperature. At the beginning of the cycle water temperature is driven to a predetermined maximum level. Then, as the product approaches set point, water temperature is gradually decreased to prevent overshoot.

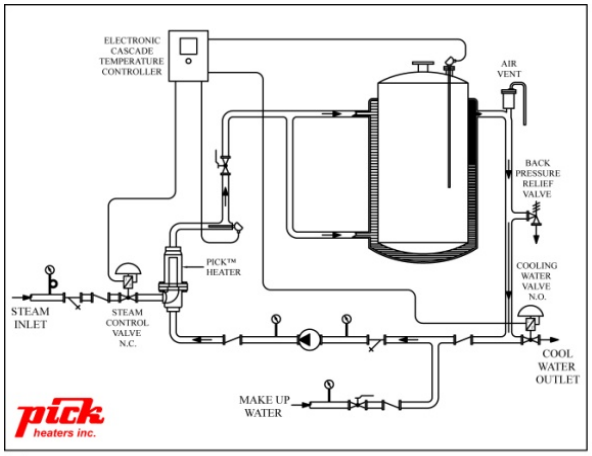


FIGURE 5. TYPICAL JACKETED HEATING SYSTEM WITH PICK™ DSI HEATER.

Control is automatic – regardless of outflow demand. System loop pressure is maintained by an adjustable back pressure relief valve (BPRV) which eliminates the need for an expansion tank. As steam enters the system, an equal volume of condensate is pushed out of the BPRV. System pressurization at this valve permits water loop temperatures above 212°F (100°C).

A single steam control valve provides better than a 10:1 turndown capability. Turndown capabilities up to 100:1 can be obtained with the use of dual steam control valves. This capability is particularly important in heating jacketed vessels because the hot water demand at reactor start-up is significantly greater than it is as the product approaches set point.

In conclusion:

Water is superior to steam for heating jacketed reactors because it:

- eliminates hot spots and uneven heating – unlike steam, where temperature control is difficult to maintain and easily overheats.
- allows smooth transitions from heating to cooling with no thermal shock – unlike steam which requires complete purging of steam prior to the addition of cooling water.
- is environmentally safe and non-flammable – unlike heat transfer fluids which require special handling and constant monitoring.

Direct steam injection (DSI) is superior to indirect exchangers for heating water because of:

- rapid response to changing process conditions – ensures precise temperature control within a fraction of a degree.
- demonstrated costs savings – 100% energy efficiency saves as much as 17% in fuel costs.
- compact design and ease of maintenance – saves space and system down time.

In particular, Pick DSI heaters with dual modulating steam injection control provide:

- thorough mixing of steam and water within the heater body – eliminates the need for excessive downstream piping.
- the ability to handle the widest range of steam flow turndown of any DSI heater.
- lowest water pressure drop and lowest noise level of any DSI heater.

Philip Sutter is a Vice President with Pick Heaters, Inc., West Bend, WI (262-338-1191; Fax 262-338-8489). He has over 30 years of experience designing, engineering, and selling liquid process heating systems for the food, chemical and pharmaceutical industries.