THE ADVANTAGES OF HOT WATER VS. STEAM FOR JACKETED HEATING

As presented by Philip J. Sutter at the Chemical Engineering Expo, June 4, 1998 in Houston, TX

INTRODUCTION

In jacketed heating applications where processes require operating temperatures up to 350°F, steam and hot water serve as typical forms of heat transfer.

Currently, an increasing number of process engineers are switching from steam to hot water for heating jacketed reactors or vessels. 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 ensures a better quality end product. This is particularly important in processes requiring very precise product temperature control.
- 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.
- 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 hot water set, 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, then introducing cooling or tempered water into the jacket at any desired rate and temperature.
- In this system the condensate leaves the 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 is returned to the boiler in a condensate return line with its inherent heat losses.

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. Then, we will review several specific applications now utilizing direct steam injection systems for jacketed heating.

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 – 100 PSIG saturated steam is always 338°F with 1,189 BTU/lb total heat content.

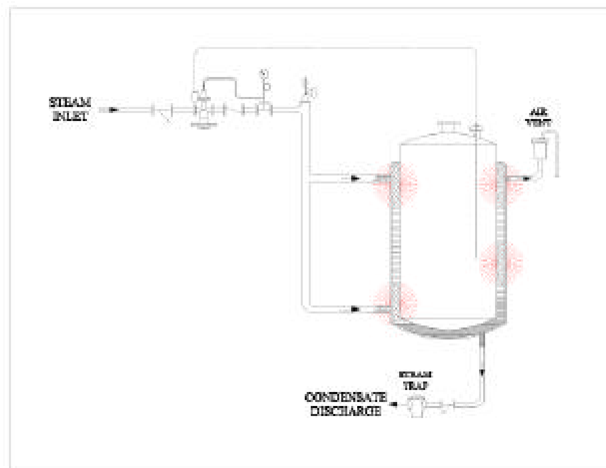


FIGURE 1. TYPICAL STEAM HEATED JACKETED VESSEL.

Despite its advantages, steam has several shortcomings. It does not offer precise temperature control, and energy transfer is not uniform. Due to uneven distribution, superheated 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 poor, 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. 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.

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 70 PSIG water can be heated in a pressurized circulating loop to 310°F without boiling. The reactor 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 distributed control system (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.

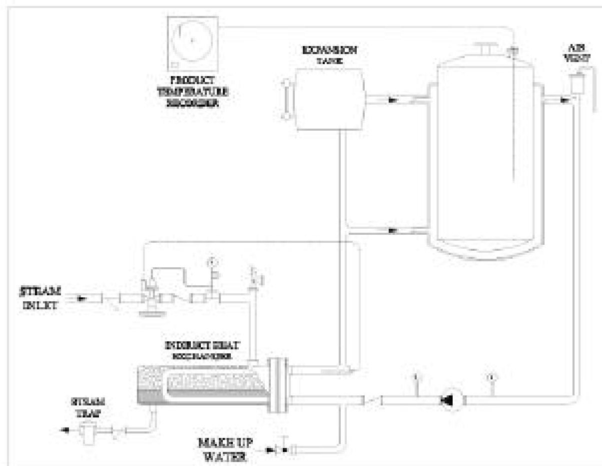
In addition to offering precise temperature control, water is readily available, easy to handle, non-flammable, safe to the environment, and relatively inexpensive.

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 steam, the jacket water temperature cannot exceed 352°F at 130 PSIG, because 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 ±6-8°F) 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.

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, 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 0.52 /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 52¢ /therm this translates into a fuel cost savings of $2.97/hr, or an annual fuel savings of nearly $12,000. 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 mixing tees, spargers, and venturi 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

Before reviewing specific applications, it is important to understand the unique design characteristics of the DSI system which each of these applications employed.

In all cases, a Pick™ Heater with its variable orifice injection tube and external modulating steam control valve was used as the key component to ensure smooth and quiet injection of steam into the liquid.

With this 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 small bubbles 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.

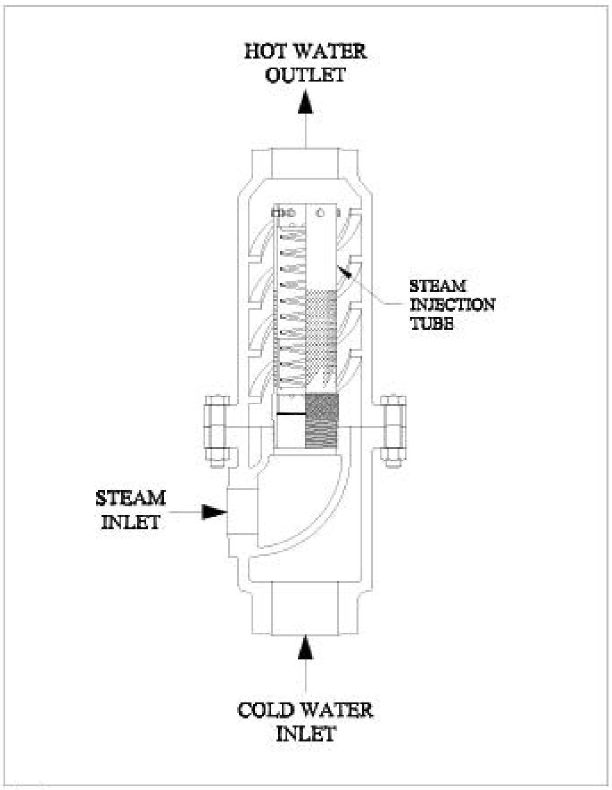


FIGURE 3. CUT-AWAY OF A PICK™ DSI HEATER

The heater creates very little internal restriction to liquid flow. Velocities are not excessive and very little pressure drop (less than 2PSI) is generated across the heater, minimizing 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 steam control valve is actuated by a controller, which is responding to water discharge temperature. This may be manually set to any desired outlet water temperature as Figure 4 illustrates. Water temperature setting may also be regulated remotely by a pneumatic or electronic controller sensing the product temperature (commonly referred to as cascade temperature control). With this arrangement, system operation is fully automatic. The operator simply inputs the product set point. At the beginning of the cycle water temperature is driven to a predetermined maximum level. Then, as the product approaches its set point, water temperature is gradually decreased to prevent overshoot.

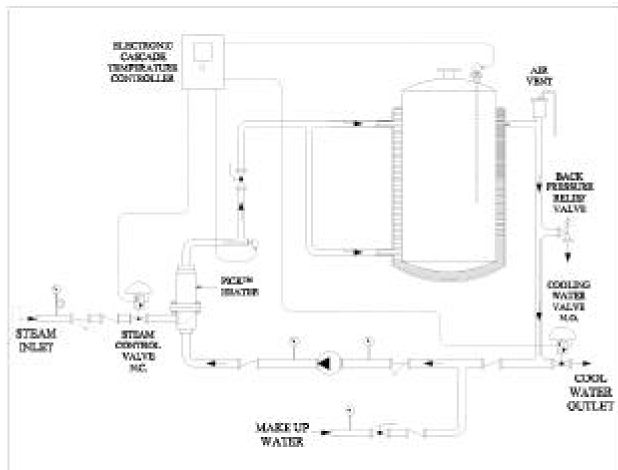
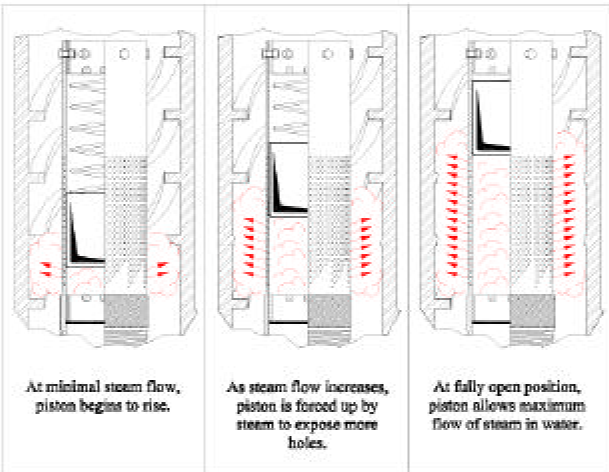


FIGURE 4. TYPICAL JACKETED HEATING SYSTEM WITH PICK™ DSI HEATER.

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.

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 product approaches set point.

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 5).



■ FIGURE 5. VARIABLE ORIFICE STEAM INJECTION TUBE.

By applying pressure 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 venturi type heaters.

APPLICATION PROFILES

Konica Graphic Imaging International (KGI), Glen Cove, NY, is a Division of Konica Corporation, Tokyo, Japan. KGI manufactures coated films, papers, and chemicals. Chemicals are made in batch processes. Each batch is very expensive.

During the manufacturing process, heating as well as cooling steps are involved. This is achieved by circulating heating/cooling fluid through the jacket. Over the years KGI has tried several process methods:

1. Steam in the jacket
2. Two separate sources:
   a. hot water for fast heating
   b. warm water for maintaining temperature
3. A Pick ™ system for fast heating, maintaining temperature, and cooling.

Chandra Shah, Project Manager at KGI states, "The steam system works nice. It meets our requirements of fast heat up and temperature control within ±0.5°F. However, the steam has its price. Since most of the batches require both heating and cooling operations, control systems are very complex requiring PLC control. The complex maze of valves makes it more difficult to maintain. Of course, there may be some hot spots, but it had minimal effects on products, which were manufactured at the time. However, with development of new products, which were more sensitive to such hot spots, KGI started looking for alternate means."

To avoid hot spots, an indirect steam heat exchanger system was tried. The primary reason for this approach was that only one system was required to be installed and could serve several jackets at a time. Each batch had its own temperature control valve. Due to the closed loop and expansion tank, it has a much larger inventory of water. This adversely affected the system response. "This system had operating problems right from the beginning," says Shah. "There were several reasons for this. Primary among them was switching from heating to cooling and vice-versa. This created a pressure imbalance resulting in system failure."

"Also, most of our production is done in safe light conditions. However, installation of valves and equipment in safe light makes it difficult to service. A system with heating and cooling components installed in a small package like Pick's makes it possible to place it nearby but outside, in white light."

"The above experience and considerations made us look into one system that gives hot/warm/cold water, as well as a low water inventory so that changing from hot water to warm water and warm water to hot water is fast and it is small enough to install nearby, but outside the batch area." A Pre-Packaged Heating/Cooling System manufactured by Pick Heaters, Inc. was installed.

"Compared to the steam heated system, batch heating time went up as expected, but to a value we can live with," Shah concludes. "Most important, with the Pick ™ system, we were able to manufacture quality products, which was not possible with the steam heated system. The confidence with the Pick™ system is so high that in certain parts of the plant, it will entirely replace the steam heated system."

Graver Technologies, Newark, DE, uses hot water, rather than steam, to heat their 10,000 lb capacity jacketed blender. The system must mix powders and small quantities of liquids, then dry the mixture, in a very short time. Hot water was chosen over live steam because of safety, ease of control, and uniformity of jacket temperature resulting in a product of consistent, high quality.

Frank Matunas, Director of Engineering at Graver Chemical states, "Our product is very heat sensitive, so precise temperature control is desired."

"Steam is erratic," said Tom Baer, Graver's Maintenance Supervisor. "Hot water makes our results very predictable. We set the temperature and that's what we get." Baer adds, "On top of that, except for boiler maintenance, the hot water system is very easy to take care of."

A pre-packaged heating/cooling system manufactured by Pick Heaters is used in conjunction with an electronic cascade recording temperature controller. The Pick ™ system features 316 stainless steel piping, circulation pump, automatic steam and water cooling valves, all pre-piped, skid mounted, and coupled to the blender.

The system was designed to run in a closed loop configuration with condensate piped back to the boiler feed tank.

"The entire process scheme is simpler with hot water," said Matunas. "There are no problematic steam traps required with the hot water recirculation loop. Cool down is controlled, precise, and simple without an awkward transition between the heating and cooling operation."

"Energy efficiency," said Baer, "is an added benefit of the Pick™ hot water system. And believe me, energy efficiency will be important again very soon."

Equistar Chemical (formerly Quantum Chemical Company), Cincinnati, OH, is the largest U.S. supplier of polyethylene to the plastics industry. The company's Process Research Center (PRC) was examining the process conditions under which catalysts enhance ethylene and propylene polymerization.

Researchers at the PRC used small scale autoclaves in a laboratory environment to develop catalysts and to set conditions for the company's larger pilot and commercial reactors. "When doing this work," Dr. Albert Masino*****, project scientist, stated, "We wanted tight temperature control".

Masino said his main objective was "to have control systems that maintained precise temperatures, and that were rapidly responsive."

"Water is an excellent medium for accurate temperature because it is responsive over a wide temperature range," Masino explained.

"Finding a heating system able to fulfill our project design requirements was difficult," admits Masino. The water heating systems would have to fit into autoclave reactor enclosures only twice the size of a phone booth. Also, the necessary flow rates in gallons per minute had to be small.

Pick Heaters was able to develop two custom designed systems to meet Quantum's requirements. The systems were mounted on galvanized steel frames designed for easy installation in the reactor enclosures. Each of the pre-packaged systems used a Pick™ 6X7-3LF heater. Also included in the systems were recirculation pumps, cooling water valves, and interconnecting piping.

Masino said, "The PRC's design objectives had been realized. We routinely raised temperatures in the reactors rapidly from 21°C to 95°C with no overshoot. Being experimental, we wanted a temperature control system that allowed us to manipulate and control variables very accurately."

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, 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 OSHA noise level of any DSI heater.

Philip J. Sutter, is a Vice President with Pick Heaters, Inc., West Bend, WI (262-338-1191; Fax 262-338-8489). He has over 17 years of experience designing, engineering, and selling liquid process heating systems for the chemical and pharmaceutical industries. He is a graduate of Moraine Park Technical College, Fond du Lac, WI.

***** Currently with Chevron Chemical Co, Kingswood TX`