Sustainability for Utility or Process Heating Using Direct Steam Injection

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ABSTRACT

For any manufacturing plant, balancing safety, product quality, plant footprint and energy consumption is an ever changing challenge. Profit and maintenance seem diametrically opposed. Replacing an inefficient process or utility liquid heating system with direct steam injection in-line heating saves space, maintenance and is up to 30% more energy efficient than traditional forms of heating. This paper examines several case studies, (including a continuous annealing line and a meat processing plant), of diverse manufacturing plants where direct steam replaced other forms of process and utility heating. Energy savings of 700mBTU per day and 14MMBTU/hr are documented in these case studies. The paper quantifies space, maintenance, and energy comparisons and outlines how this form of heating may be a solution to consider for companies with a sustainability and energy saving initiatives.

Introduction

Sustainability in industry is a hot topic but few folks define it in a way that is understandable and practical. In fact, even if a company has a 'sustainability program' guided by an Energy Czar and company initiatives focusing on sustainable practices, often times projects for improvement are pushed aside to deal with day to day manufacturing issues.

Sustainability is not just about changing out light bulbs or turning lights off when you leave a room; it's about saving major amounts of energy in processes, about low-maintenance operations, about space savings, and about establishing a manufacturing process that fits your product, exactly.

This paper examines sustainability through fluid heating and looks particularly at one method of fluid heating – Direct Steam Injection (DSI) – an alternative to replace the status quo of heat exchangers or sparge systems to custom fit a system for a sustainable process.

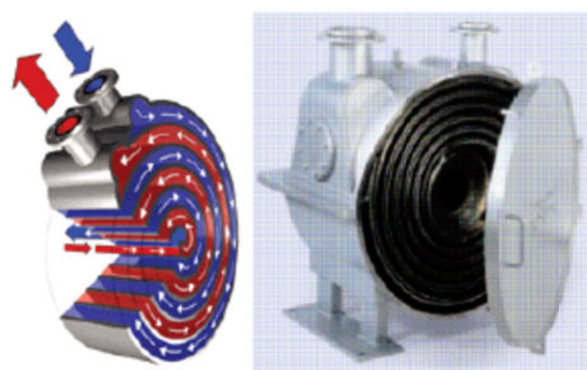
Direct steam injection is not appropriate for every fluid heating application and it cannot be used if the liquid or slurry is not water miscible. When this is true, however, DSI is an alternative that may save a manufacturer money, energy, space, maintenance time, and chemical use.

Figure 1: Sustainability Triangle

Heat Transfer Methods

Of the several methods of heat transfer in use, all but Direct Steam Injection (DSI) and sparging require an intermediate metal surface to transfer the energy.

Conventional surface-contact heat exchangers, such as shell and tube (Figure 2), plate and frame, tube in tube and spiral heat transfer designs, use an intermediate surface to transfer heat energy between the hot media (normally steam or water) and the material being heated. To make this process more effective, the metal plate surface area is increased providing a greater hot surface area over which the slurry flows. Heat exchangers tend to clog when using dense slurries and, even when they do not have process-created difficulties, they require labor-intensive maintenance.

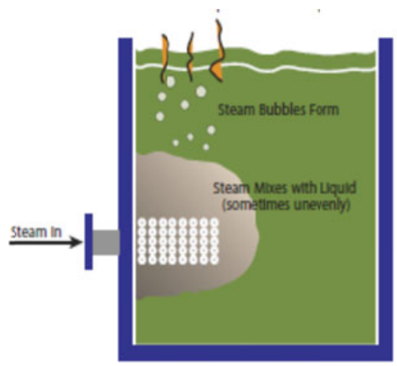


Traditional Sparging

Though simple and relatively low cost, sparging depends on quiescent material velocities in large tanks and vats. Sparging systems force steam into the material through a series of holes in a simple pipe, raising the material temperature gradually, and using thermal brute force. Hot water displaces cooler liquids as the volume of steam increases in the material [see Figure 3]. This displacement can cause gas bubbles to form in the material often coalescing into larger, equipment breaking bubbles as they burst on the tank wall or in the process piping. [See figure 4]

While this process heats the material, it tends to be uneven because no slurry is ever uniformly dense as it settles in a quiescent state.

It is impossible to control temperature or condensation rate with any degree of precision with steam sparging. Further, sparging often has gas condensation issues causing equipment-damaging hammer.



Features of Direct Steam Injection

Unlike indirect methods of heating, direct steam injection (DSI) does not have a 'heat transfer barrier' such as the wall separating the steam and the fluid in the heat exchanger. While necessary in some applications, heat transfer barriers have a specific rate of heat conduction that can lengthen the device's response time to process changes. Direct steam injection heaters do not have a barrier and can respond instantly to a signal from the temperature controller. In effect, because there is no barrier, there is little lag time with a direct steam injection heater. The fluid temperature will change immediately with changes in the regulated steam flow. Direct steam injection heaters can be regulated as fast and as precisely as the control loop is capable of measuring and responding to changes in temperature.

This instant transfer of heat provides two main advantages of direct steam injection: precise temperature control and energy efficiency. More that 20 percent of steam's energy can be present as sensible heat. Because it utilizes both the latent and sensible heat of the steam, a direct steam injection heater requires less steam flow for a given process than indirect heating methods. Condensate return is not needed because all the steam's energy is transferred to the process. In effect, 100 percent of the condensate energy is recovered.

Different direct steam injection control valves make use of various physical principals for their operation. The various control schemes each provide different levels of temperature control accuracy as well as different maintenance requirements.

DSI heaters are often the best option for hard-to-heat fluids, such as slurries or highly viscous materials that tend to clog and for fluids that require nearly instantaneous heating such as some foods and sludge that would bake onto heat exchanger surfaces.

Comparing Direct Steam to Other Heat Transfer Methods

Direct contact steam heating is suitable for many applications, but cannot be used when the process fluid cannot tolerate the addition of steam. Where the introduction of steam is acceptable, DSI offers significant energy savings and process efficiencies. Other advantages and limitations of direct-contact steam heating depend on the method and type of heater used.

Several types of direct contact steam injection heaters include tank spargers, in-line spargers, mixing tees, and internally modulated steam injection heaters. Direct contact steam heaters can be classified as either externally modulated or internally modulated; this refers to how the steam injected into the process fluid is controlled.

External Steam Control (Modulation)

An externally modulated steam heater utilizes a steam pressure control valve to regulate the amount of steam injected into the process. The valve is located in the supply steam piping. At times, steam velocity and the steam/fluid mixing vary widely over the operating range. Vibration, poor temperature control and inefficiency result at some operating conditions. Tank spargers often experience steam hammer and vibration damage to tanks (figure 4). Energy inefficiencies also occur with this heating method because steam does not completely mix and escapes from the tank.

Mixing Tees are also externally modulated devices. They are available in manual, semi-automatic, and automated systems to mix steam and cold water each with varying degrees of accuracy. Both semi-automatic and manual mixing tees experience difficulty in compensating for changes in steam pressure, water pressure or hot water demand. Proper operational guidelines and maintenance procedures must be closely followed to avoid unstable operation and poor temperature control.

More sophisticated externally-modulated devices control steam flow by utilizing multiple orifices in the heater. When properly instrumented, this type of device provides improved temperature control and good turndown capabilities. As with other externally modulated devices, steam pressure at the point of injection can vary widely, resulting in poor steam/fluid mixing. These heaters often require regular monitoring and maintenance with routine disassembly for cleaning plugged orifices. Hard water tends to scale and foul these heaters because steam is at less than sonic velocity.

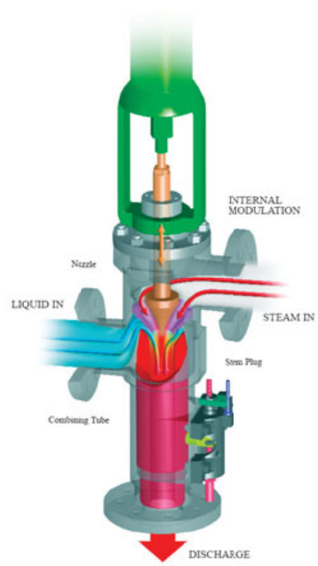
Figure 4: Damaged and Patched Sparge Tank

Internal Steam Control (Modulation)

A more advanced and controllable technology is the internally modulated Direct Steam Injection (DSI) heater. Steam flow is controlled through a stem-plug assembly inside the heater. Changing the steam discharge area of the nozzle varies the amount of steam passing through the nozzle, and maintains good mixing characteristics (see figure 5). Internal modulation eliminates the need for an external steam control valve.

Internally modulated direct contact steam heaters inject metered amounts of steam into the process fluid through a variable-area steam nozzle. The nozzle design ensures constant steam pressure and velocity at the point where steam contacts the liquid or slurry, eliminating the potential for pressure upsets and ensuring smooth heater operation. Internally modulated direct contact steam heaters are cleaned by their own turbulent mixing action (usually sonic velocity steam), so they do not encounter fouling or scale buildup. Because of this cleaning and mixing action, they also have the flexibility to heat slurries containing a high concentration of solids or non-Newtonian liquids.

A consideration of internally modulated Direct Steam Injection systems is that the differential between the steam pressure and process pressure at the discharge of the heater must be maintained to ensure proper operation. The units are typically controlled automatically through a loop controller based on discharge temperature.



Energy Savings – A Major Advantage of DSI

Today, manufacturers and processors are encouraged to ‘think green’. However maintaining product quality by heating liquids and process fluids reliably and to precise temperature is still the main goal of these manufacturers. For example, a baby food manufacturer must maintain the taste, nutritional value and safety of their product while saving time, maintenance, energy and costs.

In many applications, direct contact steam injection heaters show energy savings over indirect heat exchangers and spargers that help meet this objective while also improving the bottom-line and product quality.

More than 20% of steam's energy can be present in sensible energy. By using both the latent and sensible energy of the steam, a direct steam heater will require less steam flow for a given process when compared to indirect heating methods. Condensate return is not needed, as all of the steam's energy has been transferred to the process. In effect, 100% of the condensate energy is recovered. Estimating the energy savings of replacing a heat exchanger can be calculated using basic fluid heating assumptions. An example for water heating is shown in Table 1. At these process conditions, energy savings of just under $300,000 per year is realized.
Knowing process conditions (such as flow rate, incoming temperature, required output temperature, and steam pressure), the energy usage can be calculated. The needed energy using a heat exchanger can be compared to using a DSI heater, giving an estimated energy savings. Direct steam consistently shows a reduction in energy usage. In some cases the estimated savings are dramatic with a payback period of months.

Table 1: Energy Calculations Comparing Heat Exchanger to DSI for Water Heating

Process Flowrate	150 gal/min
Temperature of Incoming Water	60ºF
Required Output Temperature	180ºF
Header Steam Pressure	110 psig
Heat Exchanger Capacity Required	80%
Boiler Efficiency	78%
Condensate Recovered and Returned to Boiler	0%
Condensate Heat Lost During Return	100%
Condensate Return Line Pressure	0 psig
Boiler Makeup Water Temperature	60ºF
Boiler Fuel Cost	10.00 $/MBtu
Water Treatment Cost	0.30 $/1,000 lb
Average Onstream Time	24 h

	Heat Exchanger	DSI
Required Energy Load	150,210 Btu/min	150,210 Btu/min
Steam Flow Required	164.9 lb/min	129.1 lb/min
Energy Required at Boiler	246,047 Btu/min	192,597 Btu/min
Water Treatment Cost	$2.97/h	$2.32/h
Operating Cost	$150.60/h	$117.88/h
	$3,614.30/d	$2,829.15/d
	$25,300.10/wk	$19,804.02/wk
	$1,315,605.32/yr	$1,029,809.22/yr

Beyond Energy Savings

Other advantages of DSI heating include reduced maintenance for heat exchanger cleaning. Sometimes, other pieces of equipment can be eliminated (i.e., mixers) because of the turbulent action and thorough mixing that occurs in the heater. The small size of DSI heaters can reduce floor space requirements. Precise temperature control saves *energy by heating fluids to* *precise temperatures without overshooting temperature set-point.* Space savings can also be realized in better use of plant layout.

Energy savings is the main focus of most industrial sustainability efforts, but smart companies maximize the entire sweet spot by examining the total impact of business decisions. The physics of direct steam injection lend it to contribute to all the corners of the sustainability triangle.

Energy efficiency. The direct contact of the media to be heated and the steam facilitate a rapid and exact attainment of set-point temperature with 100% thermal heat transfer and precise temperature control, allowing for major energy savings of up to 30% for fluid heating when compared to heat exchangers.

Low maintenance. Because of the very high velocity of the steam, direct steam valves do not foul, scale or burn on products. This increases uptime, decreases cycle times and lowers chemical or ingredient usage. This can often lead to less scraped product or increase process confidence.

Precise temperature control. Also saves energy by reaching and maintain the optimal process temperature process often use less chemicals and water.

Space savings. In-line direct steam injection heaters fit with process piping and require little clearance for installation and maintenance. (Figure 6)

Figure 2: Space Quantified

Heat Load - Btu/hr (5,000,000)	Tube-in-Tube (HX area)	Direct Steam Injection Unit
Floor space needed		
	316Lx304Lx321L	36x26x64
Weight of unit	1300 lb	700 lb

Product quality. The precise temperature feature assures better products such as whiter bleached pulp, happier anaerobic bugs, no burn on product, etc.

Figure 7: Direct Steam System

Case Studies

Steel Mill – Annealing Line

Early in 2008, a major steel mill in West Virginia replaced an aging water heating tank within the annealing phase. Three internally modulated DSI heaters were installed to heat water for the wash-down stage of the process. Energy usage before and after the changes was recorded and documented as part of an Energy Savings Assessment (ESA) program with the United States Department of Energy (DOE). Preliminary readings show a whopping decrease of 11,900 lbs/hr of steam flow to perform the same water heating. This translates to dollar savings of approximately $59,000 USD per month and a return on investment of only three months. The mill is looking at other areas of their process where DSI heaters could replace other heat exchangers or spargers. (See case Study: HeavyMetals_Arcelor_Mittal_EnergySavings)

Meat Processing Plant – Central Hot Water

Creekstone Farms processes premium Blank Angus Beef products. Critical to their operations is plant hot water. Their system was failing and had become a maintenance nightmare as it needed to be constantly fixed. They decided to replace the central hot water system with a direct steam injection system. The system measured 700mBTU savings per day upon startup. Creekstone Farms is also saving over $12,000 per year in parts for maintenance. The company was also able to eliminate seven (7) electrical motors from their old system. (See Food Manufacturing Magazine: Smart Sourcing Award: The Price Was Right (Oct. 2010))

Municipal Wastewater – Anaerobic Digestion

An Illinois wastewater facility installed a direct steam injection heater in line to heat sludge in their anaerobic digestion process. The unit heats sludge to the exact setpoint temperature alleviating concerns that steam would kill the anaerobic microbes. Struvite build-up does not exist and the system generates more energy than the plant uses for much of the year. Costs for water softener and other boiler pretreatment had dropped to about $500 USD per month from $2,000 USD. The unit operates as designed with no maintenance issues. (See Case Study: *Anaerobic Digesters Heated by Direct Steam Injection, Experience and Lessons Learned* – Jim Huchel, Wastewater Department Foreman, City of Crystal Lake, IL)

Pulp Mill Uses Direct Steam Injection in Bleaching Process

Bleaching medium consistence pulp stock requires exact and constant temperature attainment. In comprehensive tests for temperature control of pulp stock at a large Midwestern pulp mill using the internal modulated direct steam injection heater on medium consistency stock, probes were placed at the inlet, outlet and downstream of the process to test the heated stock's temperature and measure any variance. Flow rates varied from 1,100 to 1,820 GPM [249.8 to 408.8 m3/hr=] while the stock temperature was maintained well within optimal bleaching parameters. Time to set-point was also lowered resulting in a lower net use of energy in the process. This process experienced a 33% reduction in steam usage over the previous sparge method used to bleach pulp stock. (See Case Study: *Improving the Bleaching Process via Precise Temperature Control*)

Specifying Direct Steam Injection for Water Heating

Specifying direct steam injection heating and properly sizing the equipment for an application entails an examination of process requirements, general process information and fluid characteristic (table 1). If the liquid to be heated cannot be mixed with water or steam, direct steam injection is not appropriate and indirect methods of heating are the only options. When the fluid is water miscible, however, DSI can be explored. Properties such as specific heat, density and viscosity as well as solids content and whether any abrasive or corrosive materials are present need to be identified.

Application conditions such as flow rate (normal, minimum and maximum), inlet and discharge temperatures, process pressure and steam pressure and pipe sizes must be considered. Users should determine whether manual or automatic temperature control is desired and whether continuous, intermittent or variable operations will be the norm.

The specifying process engineer may also want to discuss the application requirements with a specialist familiar with direct steam injection technology.

The simplest of direct steam heater systems needs a minimum of components and should follow the basic principles of steam usage, piping and safety procedures. Conformance to all applicable local, state and federal laws, codes and standards should be followed strictly. Designing the system to meet the heaters' specified temperature, pressure and flow rating is important.

Often, manufacturing engineers order complete systems from the direct steam injection heater manufacturer to be sure the proper controls fittings, gauges, steam traps, pipe sizes and other components are in place (figure 7). These plug-and-play complete systems only need to be plumbed into the piping at the processing plant.

When to Consider Direct Contact Steam Injection

Direct steam injection can be used for many process and utility fluid heating applications. Hot water is used in the production of food, chemicals, pharmaceuticals, pulp and paper, metals refining, grain milling, fermentation, water treatments and many other processes for which the precise control of flow rate, output temperature and other factors is critical. For example, in the food industry, a few degrees difference in water temperature can mean the difference between adequate sterilization and a potential food safety problem.

The energy savings associated with replacing a heat exchanger wit direct steam injection heating can be estimated by using standard thermodynamic analysis and calculating the required energy from known process conditions (flow rate, incoming process fluid temperatures, required output temperature and steam pressure). The specifying engineer should compare the amount of energy needed for direct steam injection heating with that needed for a heat exchanger. (You can find a calculator that does this for you on line at http://www.hydro-thermal.com/calc/htesc.html)

Conclusions

While all direct contact steam injection cannot be used for every fluid heating process, it makes sense to examine it as an option where it is usable.

To utilize DSI heating, the fluid to be heated must be water miscible (that is, the fluid and water must mix). When this is true, DSI can be used for a variety of process and utility heating applications. From the simplest water heating application to more complicated processes such as heating medium consistency stock for paper production, corn mash for ethanol production, anaerobic digestion for sewage, tomato paste for food production, DSI is a versatile and effective heating method.

Properties of the process fluid must be considered when using DSI. These characteristics include the fluid's specific heat, density and viscosity. Specific heat determines the energy input needed to heat the substance.

Steam transfer categories include indirect and direct contact methods. Of the two, direct contact heat transfer is most energy efficient because it uses 100% of the sensible and latent heat energy in steam.

There are multiple advantages to using direct contact steam injection for process and utility heating. These benefits are realized by an internally modulated system which gives all of the following characteristics to a steam heating process.

Direct steam injection fits into several sustainable focuses for process heating:

- Energy efficient
- Precise temperature control
- Instant temperature rise
- Smaller footprint
- Less maintenance
- No condensate return system
- Eliminates need for external mixers
- Eliminates hammering and vibration
- Eliminates scaling and fouling
- Heats liquids and slurries

When specifying and sizing DSI heaters, the advice of an engineer specializing in Direct Steam Injection is advised as well as knowing several fluid and process properties to determine the proper heater for the process and for maximum performance.