



Successful Integration of Direct Steam Injection for Sludge Heating

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Direct Steam Injection (DSI) heating is an emerging technology in sludge heating applications for Municipal, Industrial, and Agricultural sludge processing with anaerobic digestion. DSI has a long track record in challenging slurry heating applications. Steam is readily available and can be inexpensive to produce. Scaling from small to large flows with steam is very effective and reliable. Steam can also assist with producing sterile conditions. When applied correctly, DSI provides significant process benefits and overcomes a number of limitations associated with conventional sludge heating methods. In this article we will attempt to de-mystify DSI and identify methods for successful integration in your process.

Sludge Heating in Anaerobic Digestion

Most WWT plants above 5 mgd utilize anaerobic digestion as it provides a rapid breakdown of solids. Microbes in the digester break down the organic material producing methane gas as a byproduct. This methane gas can be captured and used to power boilers and electrical generation sets. The operating temperature balance within an anaerobic digester is critical for maintaining the correct biological environment. The microbes for both the acid formers and methane formers optimize their processing capacity at the stable temperatures. Mesophilic digestion thrives at 95 °F and Thermophilic conditions require 131 °F for optimum digestion. Maintaining precise temperature control provides the ideal environment for processing the sludge. Sludge can be heated prior to delivery to the digester and then re-circulated through a heater to maintain processing temperatures.

Unlike Aerobic digestion which operates at ambient conditions, Anaerobic digestion operates at higher temperatures to stimulate the microorganism activity and accelerate the biological process. In order to achieve higher operating temperatures, heat must be added to the process, and the temperature of the digester must be maintained. One of the challenges present when heating municipal sludge, in the heat sensitive nature of sludge. The media used in a sludge heat exchanger generally is limited to 150 °F to avoid scorching and fouling of the tubes in the exchanger. This low media temperature significantly increases the size of the heat exchanger required to heat the sludge. Sludge also tends to have high viscosity which can cause high pressure drops leading to excessive demand on feed pumps. Higher viscosity sludge's also present heating issues relative to uniform heating, hot spots, etc.

Traditional Sludge Heating

Tube-in-Tube Heat Exchanger – These units employ nested tubes in which sludge flows down the center and the heating media flows through the channel between the tubes. The units are quite large with tube lengths of 18' and tube diameters of 4" or 6".

Spiral Heat Exchanger – This design consists of small spiral channels that move the sludge in a circular fashion. Smaller channels improve heat transfer efficiency; however, these smaller channels are prone to plugging and require higher operating pressure. Most units are designed with a "quick access" plate to allow for frequent cleaning of accumulated debris.

Internal Sludge Heat Exchangers – An inner water-jacketed draft tube located within the digester is used to maintain sludge temperature. These tubes are long (typically 15') and the tube must be cleaned by removing the cover of the draft tube. To thoroughly clean the entire tube, the digester must be drained to have access to the entire heat transfer surface.



Process Issues Associated with Heat Exchangers

- The media used in a heat exchanger generally is limited to 150 °F to avoid scorching and fouling of the tubes in the exchanger increases the size of the heat exchanger. This low media temperature significantly increases the size of the heat exchanger required to heat the sludge.
- High liquid velocities reduce fouling in the HX, but lead to high liquid pressure drops across the heat exchanger increasing pump load and energy consumption.
- Significant dedicated floor space for their installation and removal of tubes for cleaning.
- High building costs required to support the weight of the heat exchanger along with large floor space requirements for installation and tube removal
- Increased maintenance costs and production downtime due to frequent cleaning.
- When converting from Mesophilic to Thermophilic processing, multiple heat exchangers are required in series to avoid exceeding the maximum temperature differential between the sludge and heating medium leading to increased capital costs and pump energy consumption

Direct Steam Injection Heating

Early attempts of DSI heating in anaerobic digestion were commonly done with steam sparge type devices. These devices have a fixed steam exit area and use an external control valve to adjust steam flow. Problems experienced were hammer and vibration leading to unstable operation and poor temperature control.

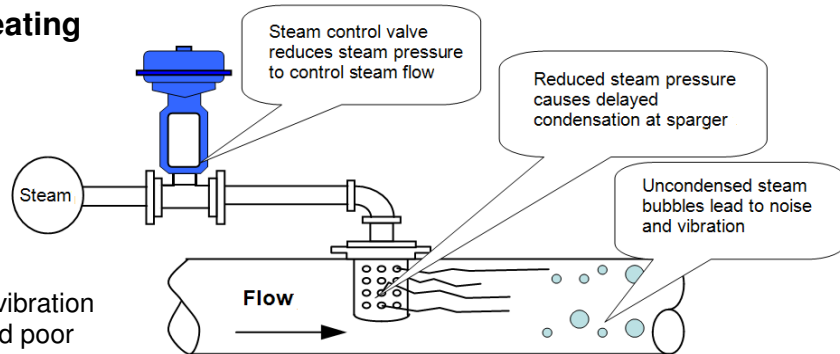


Figure 1 Steam sparger

Keys to Successful Direct Steam Injection – How it Works

One of the key factors to successful DSI is maintaining **high steam velocity** for effective mixing and condensation of the steam into the sludge or slurry. High velocity is maintained by altering the exit area of the steam rather than the steam pressure to adjust steam mass flow. This approach is known as internal modulation to achieve choked flow. **Choked flow** is the phenomenon of accelerating a vapor to sonic velocity by creating a pressure differential through an engineered nozzle. By establishing choked flow, the **steam mass flow can be metered** to precisely control the heating of the slurry. This produces predictable results based on position of the stem plug. Through a variable-area steam diffuser, steam flow is metered at the point where steam and liquid first contact and mix. This method eliminates the need for an external steam control valve or downstream mechanical mixing devices.

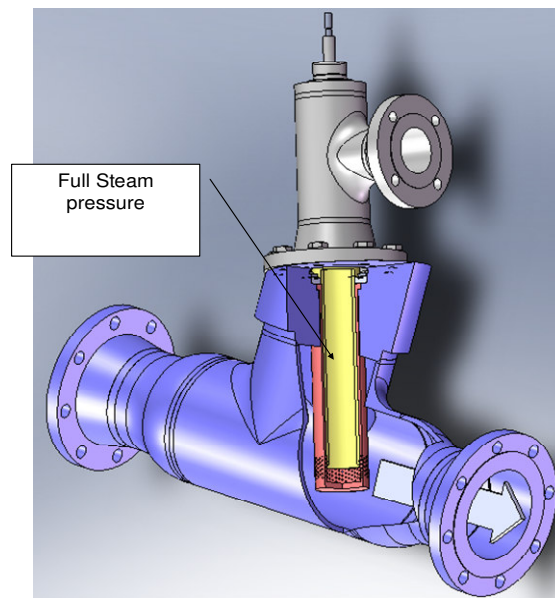


Figure 2 In-line DSI Sludge heater



Criteria for Selecting a Direct Steam Injection Sludge Heater

First ... and most important is the need for a differential between the steam pressure and the liquid pressure. Direct steam injection heater operation is optimized by maintaining high steam velocity to drive the condensation of the steam and transfer energy in a stable and rapid manner. This differential will determine the velocity of the steam. The ideal case is where the liquid pressure is less than 60% of the absolute steam pressure. Many direct steam heaters will not operate if that condition is not met, particularly those that utilize an external steam control valve to adjust the amount of steam injected. In externally controlled heaters, the steam pressure is substantially reduced through the steam control valve, so the available steam pressure is much lower than the design pressure.

Second, ... minimizing the differential between the steam pressure and the liquid pressure presents fewer process upsets, leading to more stable DSI heater operation (no hammer & vibration), better pump integration, and improved temperature control. All these can be optimized by maintaining high velocity steam injection to promote rapid and complete condensation of the steam. A multi port jet diffuser heater design utilizing an unique internal steam control design whereby the steam and liquid pressures can be much closer and still provide high velocity steam injection. The ability to operate with liquid pressures up to 80% of the absolute steam pressures will allow for stable operation and a low pressure drop across the heater thereby minimizing process upsets.

In general, the pressures should meet the following condition:

$$P_{Liquid} \leq [(P_{Steam} + 14.7) \times 0.8] - 14.7$$

Equation 1 (PSI)

There are a variety of ways to meet this condition in real world applications:

1. Choose a steam supply high enough to meet the requirements
2. Reduce the liquid pressure
 - a. Move the heater to a higher elevation
 - b. Trim pump impellers
 - c. Change pressure settings in control loops

Other factors to consider when selecting a Steam injection Sludge Heater:

- High velocity steam is essential (<1,000 fps ideal) for rapid condensation
- Steam velocity is a result of steam/liquid pressure differential
- Steam jet characteristics greatly influence steam condensation and avoid hot spots in slurry
- Proper sizing is important for smooth operation
- Mechanical mixers to blend steam and fluid are not practical because of bubble size

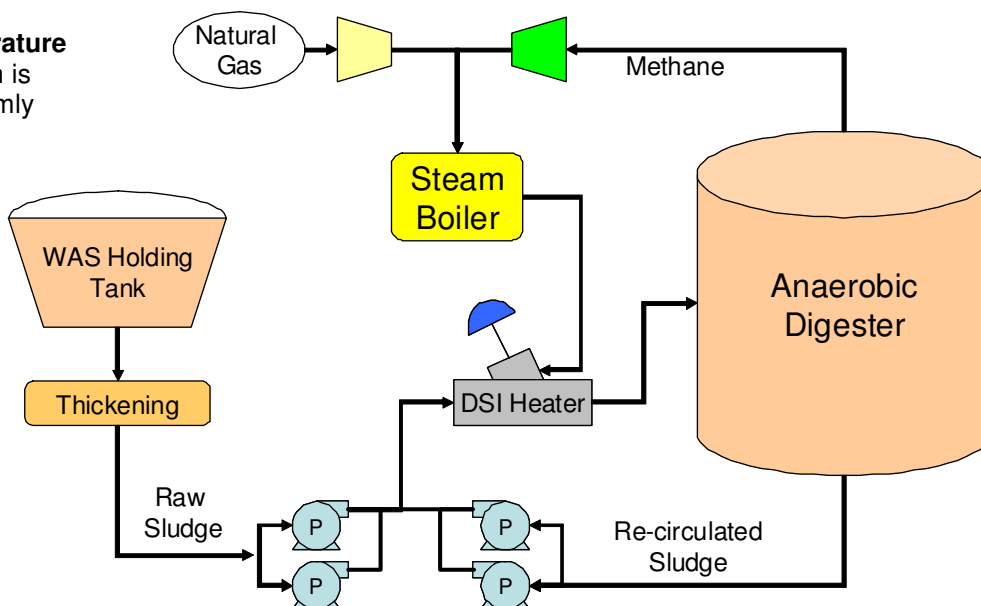
Benefits of DSI Heating for Wastewater Sludge

Direct steam Injection heating can overcome a numbers of limitations and process restrictions associated with conventional sludge heating methods such as heat exchangers. Installation can be done in the existing sludge feed or re-circulation lines.



Precise Temperature Control

– Steam is dispersed uniformly at high velocities into the sludge. This provides instantaneous heat transfer in a single pass with precise temperature control to ± 1 °F without the need for an external steam control valve.



No Plugging or Fouling

– DSI heaters have no hot surfaces to initiate scorch of the sludge. This eliminates plugging and fouling which is common in heat exchangers that utilize tubes or channels, thus reducing maintenance cycles and improving reliability.

Lower Capital Investment - The physical size reduction, going from a heat exchanger to DSI heater can be significant. A 20:1 reduction in space requirements is not uncommon. No space is required for the removal of tubes and the DSI heater can also be installed in the piping framework without the need for dedicated floor space or a foundation.

Energy Savings – The lower pressure drop (typically 1-2 psig) across a DSI heater compared to heat exchangers, translates into reduced demand on system pumps. **Error! Reference source not found.** shows typical costs for electrical motor use. DSI heaters may lower the horsepower requirements over 50% as compared to multiple HX in series. Direct Steam Injection heating also transfers 100% of the heat energy into the sludge.

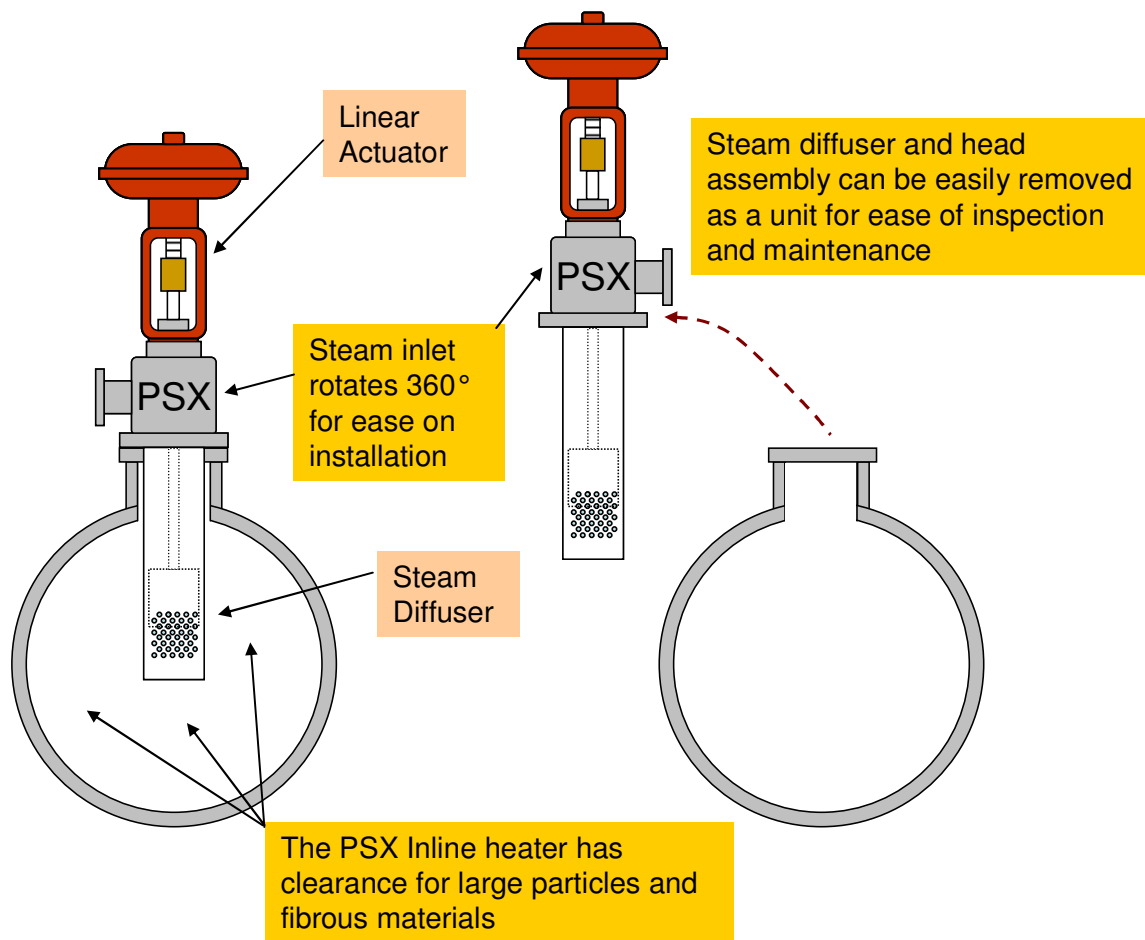
Efficiency	90%	0.08 \$/KW-h		0.1 \$/KW-h	
Duty	95%	\$/d	\$/y	\$/d	\$/y
Horsepower	KW				
1	0.8	1.51	552	1.89	690
2	1.6	3.02	1,103	3.78	1,379
3	2.4	4.53	1,655	5.67	2,069
4	3.1	6.05	2,206	7.56	2,758
5	3.9	7.56	2,758	9.45	3,448
7.5	5.9	11.33	4,137	14.17	5,171
10	7.9	15.11	5,516	18.89	6,895
15	11.8	22.67	8,274	28.34	10,343
20	15.7	30.23	11,032	37.78	13,790
25	19.7	37.78	13,790	47.23	17,238
50	39.4	75.56	27,581	94.46	34,476
75	59.0	113.35	41,371	141.68	51,714
100	78.7	151.13	55,162	188.91	68,952
200	157.4	302.26	110,324	377.82	137,905

Table 1 - Electrical Motor KW Costs

Minimizing Flow Disruption – An inline design DSI heater can maintain the proper flow velocities and provide minimal hang up points for fibrous rag type materials.



Ease of Maintenance – The unique design of the PSX Inline heater allows for simple removal of the Steam Diffuser assembly for inspection, cleaning, and maintenance.



Developing a successful sludge heating strategy is obtainable, and can be achieved by planning and utilization resources that are available. The integration of DSI heating into your anaerobic process can be done reliably and with predictable results.

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ProSonix specializes in solving difficult process heating problems through innovative products and engineering solutions. Mr. Cincotta has been in the process heating world for 20 years, working in the starch, paper, energy, and ethanol areas. He holds a MS-Engineering degree and specializes in process equipment design. He holds 6 patents for steam equipment and has presented technical papers to TAPPI, WEFTEC, FEW, and the Biomass Conference.

For additional information, please visit www.pro-sonix.com, or contact ProSonix by phone at 800-849-1130 or by e-mail at info@pro-sonix.com.