THE ECONOMICS OF DIRECT STEAM INJECTION IN WASTE WATER

ABSTRACT
Sludge heating, to maintain temperature in anaerobic digesters, is typically performed by utilizing indirect heat methods, specially heat exchangers that utilize hot water as a media source. Increasingly, direct steam heating is being explored as an alternative mean of maintaining digester temperature. The cost of installing, operating and maintaining the various heating designs is outlined. IN addition, the effect on the heaters relating to fouling and buildup were examined. It is shown that direct steam heating has advantages in the area of size, cleanliness and reduced maintenance requirements. Indirect heaters are the heating method of choice when a treatment plant does not have steam available, or deems the addition of a boiler beyond the needs of the plant.

KEYWORDS
Sludge heating, direct steam, heat exchanger, fouling

Introduction
Although a very common means of heating fluids in the industrial world, direct steam injection (DSI) is not a standard mean of heating sludge. Typically, the sludge is heated to the desired temperature utilizing one of the three following technologies: tube in tube, tube in bath or spiral heat exchanger.

Tube in Tube
A tube in tube is a heat exchanger consisting of a long, double-walled tube in which the sludge is heated with hot water through an annular opening. The heat exchanger normally operates in a counterflow manner as can be see below.

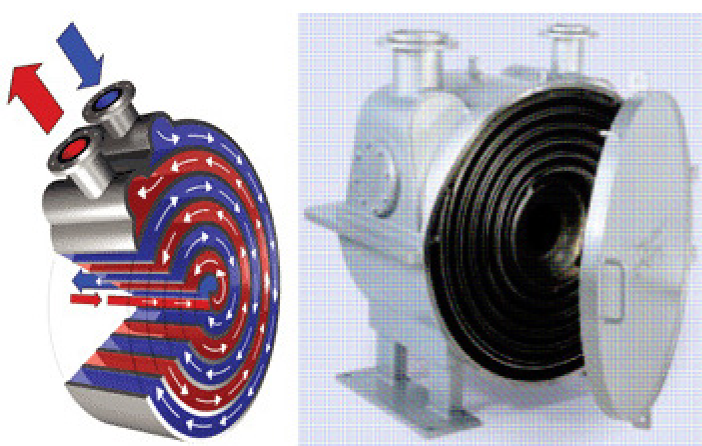

Figure 4 Spiral HX Courtesy of Alfa Laval Corporation

All water to sludge heat exchangers must be carefully designed and operated to maintain high sludge velocities in order to reduce the occurrences of fouling or buildup on the heat exchangers surfaces. Typically, water temperatures feeding the heat exchanger are kept fairly low (<150F) due to the tendency of the sludge to form deposits on the tube walls at higher temperatures. The low available temperature differential in the water path increases the need to have high water velocities and high water flow rates to achieve the desired heat transfer.

Direct Steam Injection

Direct Steam Injection is a direct method of heating that mixes precisely metered amounts of steam directly with a liquid or slurry – providing an instantaneous transfer of heat from steam to liquid. Direct steam injection heaters are extremely compact and efficient.

Figure 5: Direct Steam Injection Heater
Courtesy of Hydro-Thermal Corporation

COMPARISON OF INSTALLATION, PERFORMANCE AND MAINTENANCE COSTS OF HEAT EXCHANGERS AND DIRECT STEAM INJECTION HEATERS

Installation

Floor Space

Heat Load BTU/HR	Typical HX Area	Tube in Tube Footprint	Sprial Footprint	Tube in Bath Footprint	DSI Footprint
1,000,000	82	36 x 72 x 96	50 x 40 x 35	42 x 72 x 120	12 x 55 x 12
2,000,000	164	48 x 96 x 120	50 x 50 x 42	56 x 96 x 136	15 x 56 x 15
5,000,000	410	48 x 120 x 192	60 x 50 x 60	60 x 120 x 210	18 x 73 x 15
10,000,000	820	60 x 120 x 240	N/A	72 x 132 x 240	23 x 102 x 18

As demonstrated above, the required floor space for DSI heater is much less than any of the other heating methods utilized in sludge heating.

Weight Considerations

HX Area (ft^2)	**Tube in Tube Weight** Empty/Full	**Tube in Bath Weight** Empty/Full	**Spiral Weight** Emply/Full	**DSI Weight** Empty/Weight
82	3,332 / 4,226	2,593 / 13,042	4,000 / 8,000	217 / 297
164	6,167 / 8,954	4,449 / 25,503	6,700 / 8,100	447 / 480
410	13,121 / 21,322	8,876 / 52,416	9,000 / 11,000	704 / 760
820	23,398 / 43,008	14,347 / 80,030	14,000 / 18,000	1050 / 1150

Table 2: Weight in Pounds

When installing indirect heating equipment, it is very important to evaluate the support structures required for the heaters operating weight. Direct steam injection heaters do not require floor space in order to be used in the process. They can be mounted in-line or above the area where the heater will be used.

Access Considerations

Cleaning
All heat exchangers operating sludge heating will eventually bee dot be disassembled for cleaning of the tubes. Heat exchangers used in this application must contain a means for easy access to tube bundle. Generally, the access will be either a clear distance surrounding the heat exchanger for removal of the fouled tubes. Depending on the style selected, DSI heaters require little or no cleaning. If necessary, cleaning the units is generally a simple procedure due to the small unit size and few parts.

Crane and Lifting Equipment
On larger heat exchangers, the tubes are heavy enough that they must be removed with the air of a cream or other lifting equipment. Cranes are generally electrically powered and must be mounted to a support structure strong enough to handle the weight of both the crane and its rated load. In addition, access for installation, maintenance and removal of the crane must be planned.

In some cases, fork lifts or other temporary lift or roller equipment could be used in place of a crane. In these instances, adequate clearance for the forklift must be allowed. DSI heaters are much smaller and lighter than a comparable heat exchanger and do not have internal parts requiring regular maintenance. As such, permanent lifting equipment is generally not required although access for temporary life should be planned.

Replacement Part Access
The heat exchanger loop contains a number of parts that will be periodically replaced due to life considerations. These parts include:

- Burners and other heating elements
- Blowers and exhaust fans
- The tube bundle due to thinning of the tube walls
- Steam traps, condensate return pumps due to fouling and scaling

Appropriate access to parts must be planned to reduce the downtime associated with maintenance process. Because of their small size, DSI heaters generally require a removal distance equal to about half the length of the heater body for replacement part access.

Installation Cost

Structural Flooring and Floor Support

The floor under the heat exchanger must be strong enough to handle the weight of the heat exchanger and its contents. Given, the relatively large size and weight of the heat exchangers use in sludge heating, they typically are located near the ground level in order to reduce the structural requirements and associated costs of the installation in locations more convenient to the process rather than convenient to the structure. The substantially smaller size of DSI heaters allows them to be installed in locations more convenient to the process rather than convenient to the structure. Considerably less support structures are required which can be greatly lessen the installation cost. See Table 2 for weight comparisons.

Floor Space

The larger the footprint of the indirect heat exchanger consequently requires more floor space near the digester in order to reduce the pressure and heat losses in the piping network.

Both steam/water heat exchangers and DSI heaters, because of their small size, require little, if any floor space. Often, they are installed directly into the system piping and result in no net floor space requirements. However, it is important to remember that both styles of heater require steam. The inclusion of steam requires a boiler that will require significant floor space. However, there is generally not a strong requirement that the boiler be located very neat to the digester. As a result, the boiler is normally located at a location convenient for access to water, gas supply, etc.

For installations using a steam/water heat exchanger, there will also be a need for a condensate return system. This system requires a steam trap, collection well, condensate return pump and the associated piping to return the condensate to the boiler. This equipment is not required for a DSI heater. Thus making the installation cost and time requirements much less compared to other heating methods.

Piping

All heating systems require piping for sludge. Sludge is circulated from the digester, through a heating mechanism and back to the digester in a manner to promote mixing in the vessel. Depending on the style of the heating being used, the length of the sludge piping can vary significantly.

Style of Heater	Relative Length of Sludge Piping	Steam Pipe Diameter	Steam Pipe Length	Water Pipe Length
Tube in Water Bath	Long	N/A	N/A	N/A
Tube in Tube	Long	N/A	N/A	Moderate
Direct Steam – Low Pressure	Short	Large	Moderate	N/A
Direct Steam – High Pressure	Short	Small	Moderate	N/A

Table 3: Piping Length Conparison

In a direct fire heating system, no additional piping is required. However, the sludge piping in often longer than desirable due to the need to locate the sludging heating system near the base of the digester.

In hot water/sludge heating systems, there is a need for piping the water from the primary heating device to the sludge heater. This piping must be insulated to reduce heat losses and ideally is kept as short as possible to reduce piping losses. However, the length may be only be as short as practical given the constraints on the location of the primary water heater.

Steam piping is required in a DSI system. It is also required in hot water systems where the hot water is generated in a steam/water heat exchanger. The length of the piping is dependent on the location of the boiler relative to the digester. The pipe diameter is a function of the allowable pressure drop in the steam pipe and the pressure of the steam exiting the boiler. Generally, longer distances, or lower initial steam pressures will result in larger steam pipe diameters.

Gas piping for the methane and alternative fuel source will be required. Since the gas is typically at low pressures, the piping is generally relatively large in diameter.

Insulation

It is good energy practice to insulate any pipe that is substantially warmer than the surrounding air to minimize energy loss and prevent the environmental temperature swings from changing they system performance of the system.

Pipe to be insulated would include the hot water piping and steam pipe. A tube/water bath heat exchanger with integral heater would require insulating of the entire vessel, but no heating of the individual pipe. A tube/tube or tube/bath sludge heater with an external heating system would require installation on the hot water piping to the heater as well as on the steam piping if steam is used to heat the heat exchanger water. DSI heaters require installation on the steam pipe from the boiler to the DSI heater.

Energy Source

The primary heater in any sludge system will require electrical power to operate its controls, fans and other auxiliary equipment.

Steam Boiler

The most significant requirement of the boiler installations as compared to a direct fire water system is the requirement for a water treatment system. Boilers require a clean source of treated water in order to maintain the proper heat transfer rates and prolong the life of the boiler. The treatment mechanism consists of both physical (softening) and chemical treatment of the water. If the boiler is being used to supply water to the DSI heater, there will be no return condensate to the boiler and the amount of the water to be treated will be higher. This will drive up the size of the treatment system.

Maintenance

Fouling

Fouling if heat exchangers in sludge heating can occur wherever a fluid with dissolved or entrained solids contacts a surface warm enough to cause the solids to precipitate or melt on the hot surface. There are several instances where this can occur in sludge heating environment.

Solids in the sludge can burn onto the surface that is hotter that 150F. In a tube/bath or tube/tube heat exchanger, if the media temperature exceeds 150F, burn-on can occur. As a result, media temperatures must be kept below this level in most instances. This effectively eliminates the use of steam as an energy source in the heat exchanger. In addition, sludge velocities are generally kept quite high (>4ft/s) in order to reduce the potential for fouling to occur. The higher velocity increases the ear on the tube and also results in generally higher-pressure drops through the heat exchanger.

Most DSI heaters have no hot surfaces where burn-on can begin to occur. As a result, there is generally no maintenance required to keep them clean. E Injected steam drops to the discharge temperature of the sludge virtually instantaneously, eliminating hot spots that could cause precipitation to occur.

Cleaning

Tube style heat exchangers must periodically cleaned to remove scale and buildup on tube walls. The buildup may be fats or mineral deposits that are contained in the sludge steam. This style of cleaning may be planned or may only be performed on an as-needed basis when the performance of the heat exchanger has noticeably degraded. All heat exchangers used in the sludge heating world are designed to be cleaning periodically, and maintenance is generally ½ to 2 days in duration. Spiral heat exchangers are generally less prone to build up due to their inherently higher velocity. However, they are more likely to develop plugs if rags or other larger objects enter the vessel. When this occurs, the unit must be opened up and the foreign object removed manually.

Inspection

Inspection is generally done indirectly by monitoring the performance of the heat exchanger against known parameters. For example, in a spiral heat exchanger, the temperature rise across the heat exchanger may be monitored. If the temperature rise exceeds the normal value, it may be an indication of a plugged condition. Other indirect inspection techniques might include a flow meter to insure flow rates are maintained through the heat exchanger or pressure monitoring devices or alarms to warn of plugging or excessive fouling issues.

Steam Traps

In tube heating utilizing a steam/water heat exchanger, the system for returning the condensate to the boiler includes a device that allows hot water to exit the heat exchanger while preventing the steam from leaving. These are generically known as steam traps and are often prone to failures due to scaling and buildup on the working parts. When these units fail, the heat exchanger and condensate removal system work poorly, resulting in energy loss and potentially damage to the heat exchanger or piping network due to steam hammer.

To protect against such damage, the water to the boiler must be softened and treated with a small amount of chemicals that help reduce the buildup. The steam traps also need to be monitored regularly for proper operation. In DSI heating system, no steam traps are required.

Condensate Return Systems

The condensate from a steam water heat exchanger is returned to the boiler through special pumps that receive the condensed steam from the steam trap that return it under pressure to the boiler feed water supply. Because these pumps are handling very hot water, they are subject to corrosion and phase changes that can quickly wear out the pump. For this reason, they are subject to regular maintenance check and rebuilds. In DSI heating system, the steam is injected directly into the sludge. Therefore, no condensate return system is required.

Boiler Blowdown

Boiler blowdown is a regular process used to removed sediment and other solids that accumulate inside the boiler during regular operation. The sediment is a combination of the solids introduced in the feed water and those solids that enter the deed water in the condensate return system. Boiler blowdown is generally an automatic, timed process whereby a portion of the boiler water, where solids are likely to be present, is discharged to a drain. Generally, 5-10% of a continuous boilers output is discharged in this manner. Much of the cost associated with the blowdown procedure is due to the loss of hot treated water in the process.

For an example of the potential saving see the DOE tip sheet 19 at:
http://www.oit.doe.gov/bestpractices/pdfs/minimize_blowdown.pdf

In DSI systems, blowdown is reduced since there is no condensate return system where solids can be introduced into the feed water steam. This can be represent a savings of 2-5% of the energy and treatment costs present in an indirect heating system.

Water Treatment

All types of heating systems will require some treatment of the water to be used in the heating process. The complexity and maintenance of these systems will vary considerable with the type and style used.

For a water bath system with integral heating, the maintenance of the system will be minimal. The water is generally strained fro solids and may have some other chemical treatment to prevent buildup of bacteria or other growth in the piping. The strainers must be periodically cleaned and water chemistry monitored for proper levels.

When steam is used as part of the sludge heating process (DSI or steam/water heat exchanger) there is periodic maintenance of the water treatment required. Water softener salt and boiler feed water chemicals must be replenished as needed. The main constituents of the treatment plant should be periodically check and maintained. Water quality from the boiler should be checked periodically to unsure that the boiler chemistry and level of hardness are within recommended limits set by the boiler manufacturer.

Replacement

Tube type or DSI heating equipment generally have useful lives of at least 10 years before replacement is generally necessary.

Performance

Process Control

Due to tight constraint on allowable media temperature (<150F) due to fouling concerns, the heating surface for a tube/tube or tube/bath heat exchanger must be considerably larger than would be desirable for a heat exchanger without such considerations.

Media Inlet Temperature	Media Discharge Temperature	Sludge Inlet Temperature	Sludge Discharge Temperature	Relative Area Required
200	190	95	102	1.0
175	165	95	102	1.3
150	140	95	102	2.1
140	130	95	102	2.6

Table 4: Temperature Requirement and Size Evaluation

The above table shows the effect of media water temperature on the size of the heat exchanger required as the water temperature drops closer to the operating temperature of the digester. As can be seen, a heat exchanger operating with an inlet temperature of 140F requires 2.6 times the area that a heat exchanger would need if the water temperature could be raised to 200F. The upper limit on the media temperature for sludge heating, coupled with the large mass of the heat exchanger, results in limited ability to vary the media temperature or flow rate to quickly and accurately manipulate the discharge temperature in response to process changes. As a result, there is an inherent dead band in the temperature control loop that results in temperature swings during operation.

The temperature swings can cause the tube wall to periodically exceed the desired maximum temperature resulting in incipient fouling, setting up a process by which fouling can continue to the point of the heat exchanger becoming unacceptable for the intended use.

With DSI heaters, there is no heat transfer barrier and thus no lag or dead band in operation. As a result, the temperature control is generally quite good and the system can respond quickly and accurately to process changes.

A significant advantage of DSI heaters is the large operating range of the equipment, particularly with regard to steam flow. A steam injection heater may offer steam turndown ratios of as much as 50:1. This allows the unit to be designed with capacity in excess of the normal operating requirements. As a result, the heater may be able to handle a more significant swing in inflow temperatures without a significant impact on the digester temperature. In addition, there would be additional capacity for the system to “catch-up” form an upset or startup condition.

Energy
Energy in the wastewater treatment plant falls into two general categories: generated and purchased. Methane produced in the digestion process is generated energy. All other energy sources such as electrical, oil or natural gas are purchased.

As a generated source, methane is effectively free and is used to provide primary sludge heating energy. Most installations supplement the primary heaters with an alternative energy source for periods when the digest is not generating sufficient methane to heat the sludge to the desired temperature. During these periods, there is a net cost associated with purchasing the energy. Electrical energy to power the plant is usually purchased, although some larger installations also use their methane to generate electricity. They may also supplement their electricity with power purchased from electrical utilities. In the sludge heater, the most energy efficient means of heating the sludge is generally the direct fire or SDA approach. In direct fire, there are limited losses in the conversion process, but there is also a limit to the amount of energy that can be captured from the methane since the only use of the methane is the sludge heating. Any excess methane is generally burned for no benefit.

If the methane is burned in a boiler to generate steam, there is the potential reduction of plant energy use since the steam can be used for multiple uses besides the heating of sludge. Example would include building heating – hydronic heating, line tracing or general plant hot water creation. If the steam is used to generate hot water to be used in a sludge heater, there are additional energy losses due to the two energy transfers in the process. Losses form the process include blowdown losses, flash losses and heat lost in the condensate return lines.

In DSI heating, the advantages of the bouler are still present, without the subsequent disadvantages from the steam/water heat exchanger. There is no condensate return line so all the energy in the steam is injected into the sludge line. Thus DSI heating is an extremely efficient means of utilizing the methane byproduct and heating the sludge line.

Given the large size of the typical heat exchanger and the need to maintain high internal velocities inside the heat exchanger, the sludge pump often has to overcome higher pressure drops through the heat exchanger. The additional pressure drop requires additional pump horsepower to drive the pump. As can be seen from the following chart, increasing one or two horsepower sizes can have a substantial impact on motor operating costs.

Chart 1:
Energy Cost Evaluation

		.06 $/KW.h	
Horsepower	**KW**	**$/day**	**$/year**
1	0.663	.95	343.62
2	1.99	1.91	687.27
3	1.99	2.86	1,030.86
4	2.65	3.82	1,374.47
5	3.31	4.77	1,718.09
7.5	4.97	7.16	2,577.14
10	6.63	9.54	3,436.19
15	9.94	14.32	5,154.28
20	13.26	19.09	6,872.37
25	16.57	23.86	8,590.46
50	33.14	47.72	17,180.93
75	49.71	71.59	25,771.39
100	66.28	95.45	34,261.86
200	132.57	190.90	68,723.71

Motor Duty: 80%
Efficiency: 90%

Other Operating Costs

Other operating costs associated with the sludge heating process include the cost of operating an air compressor, recirculation pumps for water and sludge and compression of the methane prior to burning in a boiler of direct firewater heater.

Many communities require that all continuous boilers operating at pressures higher than 15 psig (1 bar) need a trainer boiler operator onsite at all times. Boilers that operate at pressures lower than 15 psig generally do not require a boiler operator.

Degradation Over Time

A tube sludge heater will change in performance over time as the tubes foul or plug. Often, fats and other solids will attach themselves to the tube wall. The additional mass results in significant reduction in the heat transfer coefficient for the heat exchanger. This increases the required media flow rate or temperature to maintain the desired temperature rise.

In order to increase the heat transfer tate through the heat exchanger, tube style heat exchangers have relatively thin walls between the media and sludge. Corrosion wear due to grit or other solids and the high internal velocities can cause leaks to occur in the heat exchanger. Water may then enter the sludge stream though the leaks wasting a considerable amount of energy.

CONCLUSION

Sludge heating represents a number of challenges in the wastewater world. A treatment plant must weigh installed cost versus operating and maintenance costs over the installed life of the equipment. The major factors to be considered in sludge heating include fouling, control and performance issues, and accuracy of temperature control and energy efficiency.

In most instances, direct steam offers significant advantages over the life of the heating system. Direct steam heating requires less floor space and weighs much less than other technologies currently utilized in the wastewater world. Due to its reduced weight constraints, direct steam heating equipment can be mounted in- line or above the treatment process leaving precious floor space for other process equipment. Direct steam heaters are also much easier to clean and require minimal access due to their compact design. Minimal maintenance is required due to the injection process. Overall, direct steam heating performs better and leads to reduced cost of ownership when evaluating the technology to current practices.

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