Keeping Things Hot:

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Anaerobic Digester Heat Exchanger Operation, Design Considerations and Lessons Learned
General Design Method

• Given: Sludge/Water flows, inlet temperature, and fouling factor
• Find: Required pipe length to transfer required amount of heat
• Optimize: Geometry for space constraints, pressure drop requirements, and cost
Boiler Sizing

• Heat capacity of boiler must be greater than maximum heat transfer (i.e. no fouling factor) to avoid overloading the boiler
  – Overloaded boilers “sweat”, which means internal temperature drops below condensation temperature, which causes exhaust vapors to condense and form water on the outside of the boiler
    • Causes the inside of the boiler to corrode
  – Most boilers assumed to be 80% efficient
Anaerobic Digestion Temperatures

- Bugs in digestion need specific temperatures to work correctly
  - Psychrophilic: 15°C (59 °F)
  - Mesophilic (Body Temperature): 35°C (95 °F)
  - Thermophilic: 50°C (122 °F)
Anaerobic Digestion Temperatures

- Mesophilic and Thermophilic Gas Production

**Figure 2.** Effect of temperature on the relative specific production of biogas.

**Figura 2.** Influencia de la temperatura en la producción específica relativa de biogas.
Digestion Tank Heating Requirements

- Heat loss from tank
  - Heat lost from walls above and below ground
  - Heat lost through tank floor
  - Heat lost through tank roof
  - Heat lost through piping
Types of Heat Exchangers
Fouling Factor
Fouling Factor

• Sometimes specified, sometimes not
• The purpose of the fouling factor is to make the heat exchanger design conservative and reduce maintenance for the plant operators
• 0.001 hr*ft^2*°F/BTU (0.000176 m^2*°C/W) is a standard
Ways to Reduce Fouling

– Higher sludge velocities prevent solids from settling and baking (similar to constantly stirring a pan while cooking)

  • Our minimum is 2 ft/sec for sludge velocity, but one Engineer recommended 5-6 ft/sec...probably works great, but has higher pressure drop in piping
Ways to Reduce Fouling

– Lower hot water inlet temperature
  • Some manufacturers recommend nothing above 130°F, but our recommendation is 150°F. We have done 160°F before.
Ways to Reduce Fouling

• Ways to reduce fouling
  – Glass lining (must be done at beginning of project)

• Surface roughness
  – Carbon or Stainless Steel: 0.00015 ft
  – Ductile Iron: 0.0008 ft
  – Glass: 0.000005 ft
  – PVC: 0.000005 ft
General Heat Transfer Observations

- Higher velocities create more turbulent flow
- Higher viscosities create more laminar flow and lower heat transfer
Sludge Head Loss and Heat Transfer

- Sludge is **NOT** a Newtonian Fluid (because viscosity is **NOT** constant)
- Bingham Plastic
Fluid Properties Change with Temperature

• Density ($\rho$)
• Thermal Conductivity ($k_f$)
• Specific Heat ($C_p$)
• Viscosity ($\mu$ or $\nu$)
Sludge Head Loss and Heat Transfer

- Viscosity, if available, is best to use because it’s more accurate and affects heat transfer
  - Test the sludge!
- Otherwise, head loss factors based on solids concentration can model head loss effects for sludge, but not heat transfer
ASME Section VIII Requirements

• Pressure Test based on Maximum Allowable Working Pressure (MAWP)
  – Head loss in system < Operating Pressure < Relief Pressure < MAWP

MAWP of Vessel

Maximum Allowable Working Pressure (MAWP) of a vessel per ASME Section VIII is;
• The maximum pressure, at the top of vessel, at which the weakest part of the vessel can handle.
ASME Requirements

• Hydrostatic Test
  – 1.3MAWP for short or long radius bends
    • Victaulic couplings do not meet ASME requirements!
  – 2.0MAWP for castings (because of the ductile cast iron)
ASME Requirements

• ASME Testing
  – Authorized ASME Inspector (AI) required to approve results of ASME tests
  – Do not paint prior to hydrostatic/proof test
Design
Design Lessons Learned

- Equipment needs to fit within allowable footprint area, or fit within entryways (doors or windows), and pipes normally 20’ or less in length
Operations
Heat Exchanger Troubleshooting

• Monitor pressure drop across heat exchanger
  – clogged pipe
• Monitor hot water temperature change
  – fouling within heat exchanger
Heat Exchanger Troubleshooting

• Monitor the sludge and water inlet temperatures
  – Closer = less heat transfer
• A change in sludge viscosity will affect the sludge head loss and temperature change
Cleaning Your Heat Exchanger

• Mechanical or Chemical
  – Should be compatible with the exchanger materials and not affect the digestion process
  – Contact local chemical suppliers
The Worst Lesson Learned
Boilers

• The most dangerous product we have
Boilers

- But there are plenty of safety features to make sure they are designed correctly.
Boiler Water Supply Line

• Normal Operating Pressure of boiler ranges from 12 to 20 psi
• Controlled by pressure reducing valve on water supply line
Boiler Water Supply Line

- Backflow preventer located after pressure reducer
Expansion/Compression Tank

- As water heats up the liquid volume after the backflow preventer expands.
Expansion/Compression Tank

- Expansion/compression tank used to compensate for volume expansion and avoid over pressurizing the system
- Tank size based on liquid volume, temperature change, and pressure ratios from starting to pressure relief setting
Pressure Relief Valve

• Most hot water boilers we work with have a design/relief pressure of 30 psi
• Valve size based on heat capacity of boiler
Hot Water Temperature

• Normally exits boiler at 180°F, but can be adjusted
  – Too low temperature likely to cause boiler to “sweat”
Hot Water Temperature

- 3-Way Mixing Valve used to combine lower temperature from exchanger outlet with boiler outlet water to get the “right” temperature at the exchanger inlet
Hot Water Temperature

• What’s “right”? Opinions vary. It ranges from 130°F to 170°F, but 150°F is my recommendation

• High temperatures make baking sludge more likely, so higher velocities recommended at higher water temperatures
Hot Water Temperature

- Most boilers have a maximum $\Delta T$ of boiler outlet to boiler inlet of 40°F to prevent cracking of the fire tubes.
Hot Water Temperature

• If heat exchanger outlet creates a $\Delta T$ higher than allowed a preheat blend pump may be needed to combine boiler outlet and exchanger outlet water prior to water entering the boiler
Hot Water Temperature

• Amount of flow needed to get the “right” temperature based on mass and energy balance
  – $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$ Mass Balance
  – $\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$ Energy Balance
  – $\dot{m}$: Mass flow rate (lb/min or kg/min)
  – $h$: Enthalpy of fluid at given temperature (BTU/lbm or kJ/kg)
Water Pump Sizing

• Based on heat transfer requirements, and the head loss in the heat exchanger and recirculating piping
Water Pump Sizing

• Pump needs to pump “away” from the expansion/compression tank
  – Otherwise the tank will absorb the pressure from the pump
Air Removal

• Air trapped within water must be removed from the system
• Air separator is used at the high point of the water circulation piping, normally after the boiler
Fuel Burner

- Burner attached to the boiler to create heat
Fuel Burner

• Uses a mixture of fuel and combustion air
• Amount of fuel needed is based on Lower Heating Value (LHV) of fuel
  – LHV caused by moisture in the gas/air
Fuel Burner

- Amount of air is based on stochiometric amount required for complete combustion
  - Excess air (110% to 120% of stochiometric amount) is provided to ensure complete combustion and reduce pollutants, but it also lowers flame temperature
Fuel Burner

• Most burners we use are “forced draft”, which means that the burner forces air through the system and has better control of the amount of air
  – Alternate methods are “induced draft”, where it is located at the exhaust outlet
  – Alternate methods are “natural draft”, where flow of air is based on temperature difference between exhaust and ambient temperature
Boiler Heat Transfer

• Flames/exhaust pass through flame tubes and transfer heat to water
Boiler Heat Transfer

• Wetback boilers are cheaper and have lower maintenance costs because they don’t include refractory lining on the end opposite the burner.

• The most heat is transferred after each bend when the exhaust flow is most turbulent.
  – Some boilers include corrugated tubing to create turbulence.
Exhaust Flow

• Exhaust stack allows the spent gas and pollutants to leave the boiler building and enter the atmosphere
  – Most exhaust gas is assumed to be 450°F as it exits the boiler
  – 250°F is lowest possible temperature with natural gas and still prevent condensation
Exhaust Flow

• Exhaust gas needs to leave the stack before it cools down and causes condensation, which will ruin the boiler
  – Thicker insulation reduces heat loss and prevents other nearby combustible materials from catching on fire
  – Shorter, straighter stacks have less head loss which prevents the exhaust flow from stalling and cooling
Burner Gas Pressure

- Burners require a minimum gas pressure to work correctly
- A pressure regulator modifies the gas inlet pressure to overcome head loss in the gas train and have sufficient pressure once it reaches the burner
Burner Gas Pressure

• The pressure required seems to vary by manufacturer, and changes based on the orifice size in the burner or gas train size, so this must be confirmed *before* the bid

• Natural Gas pressure almost always sufficient for the burner

• Digester Gas may be lower than required for burner

WesTech
Gas Booster

• Required if digester gas pressure < minimum pressure required for boiler
Gas Booster

• Confirm that gas pressure regulator can handle the maximum pressure provided by the booster

• Low pressure switch before the booster is required to ensure a vacuum is not created within the digester
Boiler Safety Equipment

- Low Water Cutoff
  - Makes sure enough water is in the boiler to prevent overheating the fire tubes, cracking them, and causing an explosion
  - Turns off boiler if water level is low
Boiler Safety Equipment

• High Temperature Switch
  – Makes sure that boiler is not overheated, which may over pressurize the boiler and cause an explosion
  – Burner is turned off if boiler is too high
  – Normally a manual reset is required to continue operation
Boiler Safety Equipment

• Pressure Relief Valve
  – Allows hot water within the boiler to escape if pressure becomes too high
  – Most valves are set to relieve at 30 psi
  – Relief outlet needs to be piped to floor drains to avoid spraying hot water and hurting others
Boiler Safety Equipment

• Flame Detector
  – Confirms that the pilot light is on before allowing gas through main gas trains
  – If pilot is off but gas is flowing an excess amount of gas may be present and cause an explosion
Boiler Safety Equipment

• Gas Pressure Regulator
  – Adjusts the flow of gas by adjusting the downstream pressure
  – Prevents an excess amount of gas which may cause an explosion
Boiler Safety Equipment

• High or Low Pressure Switches
  – Makes sure the fuel pressure is in the correct range for the burner
  – Located after the gas pressure regulator
  – Shuts motorized safety valves if pressure is outside of allowable range
Boiler Safety Equipment

• Motorized Safety Valves
  – Usually come in pairs, one as a redundant
  – Operated by control panel
  – Will only open if the other sensors confirm the situation is safe
Boiler Safety Equipment

• Check Valve
  – Used when multiple gas trains combine before the burner
  – Normally placed on the non-digester gas train to prevent corrosion
Boiler Safety Equipment

- Flame Arrester
  - Prevents propagation of flame in gas line
  - Similar in design to digester cover flame arresters
Boiler Safety Equipment

• Purge Cycle
  – Prior to allowing gas fuel to flow to the burner the forced draft burner sends air through to make sure no gas has accumulated after the last operation which could cause an explosion
  – Cycle lasts 15 to 30 seconds