The F.W. Webb Company

Steam Fundamentals and Best Practices

Thursday, October 31, 2019
Steam Generation

Why Do We Use Steam?

- Steam is a safe and very efficient heat transfer medium
- Easy to control due to pressure / temperature relationship
- Gives up heat at a constant temperature
- Easily distributed based on pressure drop – i.e. no circulation pumps needed
Steam & Condensate

Steam is the gas phase of water. It is produced when water is heated to its boiling point and enough heat energy is absorbed to change phase from a liquid to gas.

Condensate is the hot water near boiling point that is formed as steam releases its heat energy. This can be as a result of minimal heat losses as steam is being delivered, or “purposely” condensing steam at point of heating, producing large amounts of condensate.

Regardless, a steam system is a balance of the gas (steam) and hot liquid (condensate) form of water.

Steam Terminology

- **PSIG** – Basic unit of measurement for pressure – *pounds (force) per square inch.*
- **Lb/hr** – Basic unit of measurement of steam flow rate – *pounds (mass) per hour.*
- **BTU** – Basic unit of measurement for all types of heat energy.  
  
  Heat energy required to raise 
  one pound of water one degree Fahrenheit

- **Sensible Heat** – Heat energy that raises the temperature of water between its freezing and boiling points.

- **Latent Heat** – Heat energy that changes water from liquid to gas (steam) and is used for heat transfer. This energy is typically 3 – 5x greater than the Sensible Heat energy available in water.

  Latent Heat is released during heating, and steam condenses back into hot water (condensate).
The basic unit of measurement for all types of heat energy is the British Thermal Unit or BTU. Specifically, it is the amount of heat energy necessary to raise one pound of water one degree Fahrenheit.
Phase Change: Water to Steam

1 lb. of Water = 15.3 oz (70°F @ 0 PSIG)

Volume of Water = 0.016 ft³

Volume of Steam = 26.8 ft³

Steam occupies 1,675 times the amount of space than water.

Steam Generation

<table>
<thead>
<tr>
<th>GAUGE PRESSURE PSIG</th>
<th>TEMP °F</th>
<th>HEAT IN BTU/LB</th>
<th>SPECIFIC VOLUME CU. FT/LB</th>
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<tr>
<td></td>
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<td>SENSIBLE</td>
<td>LATENT</td>
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Saturated Steam Table

Table 3: Properties of Saturated Steam

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<tr>
<th>Gauge Pressure (PSIG)</th>
<th>Temperature (°F)</th>
<th>Heat in Btu/lb</th>
<th>Specific Volume (cu. ft. per lb)</th>
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</table>

Heat Energy Available in 1 Pound of Condensate
946 Latent BTUs
218 Sensible BTUs

Heat Energy Available in 1 Pound of Steam
1,164 BTUs/lb

Amount of Space Occupied by 1 Pound of Steam
218 Sensible BTUs
• **Flow** occurs due to pressure drop – always from a higher pressure source to a lower pressure source.

  *In general, more pressure drop allows more flow.*

• **Heat transfer** occurs from a higher heat source to a lower one
Overview of Industrial Steam Loop

Typical Steam System Components

**Steam Traps**
Remove condensate and air, hold back ("trap") steam

**Regulators & Control Valves**
Valves used for temperature control or to reduce the steam pressure

**Condensate Return Pumps**
Electric or Mechanical, used to pump condensate back to the boiler when it does not have sufficient pressure
Steam Distribution
Steam Supply Piping

How Fast Does Steam Travel?

- Steam can travel in pipes at velocities exceeding 90 mph
- Speed allows heat energy to be delivered quickly, especially compared to water or oil heating systems
- Pressure and pipe size determine how fast steam will travel
Steam Header Sizing

- Greater Cost
- Greater Heat Loss
- Greater Volume of Condensate Formed
- Lower Pressure to Steam Users
- Not Enough Volume of Steam
- Water Hammer and Erosion

Steam Velocity

Velocity of Steam Flow is determined by the Size of the Outlet Nozzle Size on a Boiler.

Proper Steam Header Sizing…
1. Maximum Steam Load Required.
2. Boiler Design Pressure
3. Velocity
   - Process Heating
   - Superheated Steam
   - Sterilization
Pipe Sloping
Properly Pitched Steam Main – General Guide is 1/8” per 10 ft.

Better Condensate Drainage w/ Lower Velocities
Properly Sizing Drip Legs & Steam Traps

Drip Leg Diameter Correctly Sized

1. Pipe Size
   Same Size – Up to 6”
   ½ the Size – Above 6” (But, never less than 6”)

Drip Leg Diameter Too Small

Installing Steam Traps

PROPER DRIP LEG LOCATION & SIZING

2. Length of Drip Leg
   1 ½ times the Diameter of the Distribution Line
   Never less than 18”
Properly Spacing Drip Legs & Steam Traps

Drip Traps on Steam Mains Located Every 150 – 300 ft. of Straight Run of Piping

Properly Locating Drip Legs & Steam Traps
What is water hammer?

- Water hammer is a pressure or wave resulting when a fluid in motion is forced to stop or change direction suddenly (momentum change).

- https://www.youtube.com/watch?v=7MxsKkAnLC0
The Danger Of Water Hammer
PERSONNEL SAFETY!

WHAT ABOUT SYSTEM COMPONENTS?

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Water Hammer Damage

Example of piping damaged by water hammer

What do we want at the Point-of-Use?
Air & Non-Condensable Gases

1. Temperature Reduction - Air is an insulator!
   - It cannot hold the temperature or latent heat of steam.
   - 25 times more resistant to heat transfer than water.

2. Carbonic Acid
   - Air is absorbed into the condensate reducing the pH.
   - Builds on the inside of the pipe reducing the Inner Diameter.

Air is an Insulator

- Air does not hold the temperature or latent heat of steam.
- 25 times more resistant to heat transfer than water.
Steam Conditioning Station

- **Steam Supply**:
  - 771 Btu/lb
  - 83% Dryness Fraction

- **Particulate Removal**: Remove dirt/rust.

- **Steam Discharge**: 891 Btu/lb
- 96% Dryness Fraction

- **Entrained Moisture Removal**: Reduce wear & tear on downstream equipment.

**Double Warranty**
- On Downstream Controls

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Steam Conditioning Station

- **Remove Air/NCs**: Reduces Heat Transfer Flow Rate

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**Double Warranty**
- On Downstream Controls
Condensate Recovery

Now That We’ve Made Steam

What Do We Do With It?
Since Steam is used to Transfer Heat Energy From One Location to Another . . .

It only makes sense that we take the heat energy back out and use it to do work.
When are we done with the steam?

And, what do we do?

Remember:

The Latent Heat added at the boiler is what we have available to do work in our equipment

BUT . . .

When we remove Latent Heat we create Condensate
# What is a Steam Trap?

An automatic valve…

1. Stops the flow of steam allowing for complete heat transfer.
2. Discharge Condensate & Air as required.

## 3 Types of Steam Traps

1. Mechanical or Density
2. Thermostatic or Temperature Controlled
3. Thermodynamic or Velocity Controlled

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# What makes up a Steam Trap

- A Steam Trap has an orifice
- An orifice alone is not a steam trap
  - If flow changes, orifice is not correct
  - If pressure drop changes, orifice is not correct
  - The orifice must change size as conditions change
What makes up a Steam Trap

- A Steam Trap should have a valve
  - A valve may be fully opened and fully closed or modulated to vary the size of the orifice as conditions change

What makes up a Steam Trap

- A Steam Trap should have an Operator
  - An operator senses when to move the valve and supplies the power to move the valve
  - Traps are different in the types of valve and the types of operator they use
STEAM TRAP FUNCTION

- PREVENTION OF STEAM LOSS
- CONDENSATE REMOVAL
- AIR AND NON CONDENSIBLE GAS REMOVAL
- REACT TO CHANGES IN LOAD

Most Common Steam Traps

1. Float & Thermostatic Traps
   - Excellent for main headers.
   - Ideal for process/batch process.
   - Best air removal option.

2. Inverted Bucket Traps
   - Good for continuous systems.
   - Poor air removal.
   - Prime required.

3. Thermodynamic Traps
   - Ideal for Medium & High Pressure Drip Legs
Float & Thermostatic Steam Traps

**Benefits**
- Simple Construction
- Continuous Discharge
- Fast Response To Changing Loads
- Hot Discharge
- Function Under High Back Pressure
- Energy Efficient
- Excellent Air Venting

**Considerations**
- Relatively Large & Heavy
- Floats Can Be Damaged By Severe Water Hammer
- Poor With Superheat
- Not Self-Draining – Can Freeze
- Fails Closed When Over Pressurized
- Can Fail Open Or Closed

Inverted Bucket Steam Traps

**Benefits**
- Simple Construction
- Rugged
- Fast Response To Changing Loads
- Hot Discharge
- Function Under High Back Pressure
- Operation Is Generally Cyclic
- Generally Fails Open

**Considerations**
- Poor Air Venting
- Poor With Superheat
- Not Self-draining – Can Freeze
- Fail Open With Prime Loss
- Fails Closed When Over-Pressurized
Thermostatic Steam Traps
BENEFITS & CONSIDERATIONS

Benefits
- Simple Construction
- Small & Light
- Mount In Any Position
- Self Draining (Freeze Proof)
- Operates Over A Wide Pressure Range
- Energy Efficient
- More Subcool Limits Flash Steam Created

Considerations
- Condensate Subcooling may require additional pipe run
- Bellows can be damaged by Severe Waterhammer
- Bellows offers Limited Superheat Capability
- Bimetal slower reacting

Thermodynamic Steam Traps
BENEFITS & CONSIDERATIONS

Benefits
- Simple Construction
- Small & Light
- Mounting In Any Position
- Operation Easily Checked (Audible)
- Not Damaged By Freezing Or Water Hammer
- Operates Over A Wide Pressure Range
- Gradual Failure – Open Position

Considerations
- Marginal Air Venting
- Sensitive To Excess Back Pressure
- Blast Discharge
- Noisy Discharge
- Marginal Dirt Handling
Time For A Break

Applications & Hook Up Drawings
• **Flow** occurs due to pressure drop – always from a higher pressure source to a lower pressure source.

*In general, more pressure drop allows more flow.*

**System Pressure: Modulating vs. Constant**
Main Line Drip or End of Main Hook Up

Warm-Up Load Calculations

Table 4: Warm-Up Load in Pounds of Steam per 100 Ft of Steam Main

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</table>
Running Load Calculations

(Feet) X (5A Run Load X 5C Efficiency)
150 X (1.36 X .07) = 17.43 pphr running Load
Trap Load = 17.43 x 3:1SF = 52.29 pphr

Unit Heater Hook Up
System Pressure: Modulating vs. Constant

Shell & Tube Exchanger Hook Up
Air Heating Coil Hook Up

Normal Operation

Heat Exchanger

Product Temperature Input

$P_1 > P_2 = \text{Heat Exchanger Dry}$
**Downstream Lift = System Back Pressure**

- **Rule of Thumb:** 1 psig ≈ 2 ft lift
- 1 psig = 2.3 ft
- 10 psig = 23 ft

**Stall Condition – No Steam Supply**

- **Product Temperature Input**
- **Heat Exchanger**
  - \( P_1 < P_2 = \text{Heat Exchanger Flooded} \)
Stall Chart

What does a stall chart not take into consideration?

Reasons for System Stall

- Overly conservative fouling factors during HEX design – adds additional surface area
- Back pressure at equipment discharge – elevation or static pressure
- Modulating Control – Steam pressure
- Vacuum
- Process demands- Flow or temp changes
- Oversized equipment – excess surface area
Effects of System Stall

- Inadequate condensate drainage
- Water hammer (Thermal Shock)
- Frozen coils, damaged tube bundles
- Poor temperature control
- Control valve hunting – control stability
- Reduction in heat transfer capacity

System Stall Solutions

Installation of a vacuum breaker:

Objective:
To relieve a vacuum within equipment allowing for condensate drainage.

Shortcoming:
This practice will only help if the condensate is gravity drain to atmosphere,
Allows undesirable air into the system.
Vacuum breakers often fail due to a poorly chosen location
Loss of valuable flash steam
Flash Steam Generation

Phase Change: Water to Steam

1 lb. of Water = 15.3 oz
(70F @ 0 PSIG)

Volume of Water = 0.016 ft³

Volume of Steam = 26.8 ft³

Steam occupies 1,675 times
the amount of space than water.
What is Flash Steam?

<table>
<thead>
<tr>
<th>Gauge Pressure (psig)</th>
<th>Temperature (°F)</th>
<th>Heat In Btus</th>
<th>Specific Volume Cu. ft. per lb.</th>
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<tbody>
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Percent flash for various initial steam pressures and flash tank pressures.

Table 12: Percent Flash

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Quantify Flash Steam

Flash Steam
- Mass = 100 lb
- Spec. Vol. = 26.80 ft³
- 99.4% of Total Volume

Condensate
- Mass = 900 lb
- Spec. Vol. = .016 ft³
- 0.6 % of Total Volume

Steam Trap Energy Losses

- Failed Open or Blowing Traps, average 10 – 11% of your trap population. Traps that have failed in the open position do not allow steam to condense in the exchanging surface. This results in the need for more steam to do the needed work. This results in added fuel oil expenses. These losses are measurable and can be quantified.

- Failed Closed or Cold Plugged Traps, average around 10% of your trap population. Traps that have failed closed, do not allow condensate to be removed from the exchanging surface. This results in poor system efficiencies, corrosion and water hammer. Although we can not measure their effect of fuel oil costs, there is a hidden loss in maintenance and trouble and complaint calls.
Steam Trap Energy Losses

Modified Napier Formula, can be used to estimate steam loss through a trap blowing to atmosphere. The following is the equation used in calculating the approximate loss:

**Modified Napier Formula**

Steam loss in lbs./hr = \((24.24) \times (Pa) \times (D^2)\)

Where:

\(Pa\) = Pressure in Absolute ex. Gauge Pressure + 14.7

\(D\) = Orifice Diameter in Trap in Inches.

Example: Inverted Bucket Trap on main steam drip station on 125-psi steam service 0.75" pipe connection, rated at 125-psi differential. From manufacturers’ literature, this trap has a 0.125" orifice. Using the Modified Napier Calculation, the calculated steam blow through this orifice is as follows:

Steam Loss in lbs./hr = \((24.24) \times (Pa) \times (D^2)\) or the following:

Steam Loss in lbs./hr = \((24.24) \times (139.7) \times (0.125 \times 0.125)\) or 52.91 lbs./hr loss

### Steam Flow Through Orifices Discharging to Atmosphere

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77

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Steam Flow Through Orifices Discharging to Atmosphere

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78
Trap Testing Methods

• Visual
• Audio / Ultrasonic
• Temperature
• Mechanical
RECAP OF KEY POINTS

- Steam – Latent Heat
  - Proper Piping
- Select the Right Steam Trap Technology
- Steam Quality and Non Condensable Gases
- Reduce Back Pressure after Trap


Slides Courtesy of:
Armstrong International
SpiraxSarco
Watson McDaniel
### How Did We Do?

1. Give the definition of steam.
   A. *Water that has enough heat energy to change state from Liquid to Gas*

2. What is a BTU (British Thermal Unit)?
   A. *Amount of energy required to raise 1 lb water 1 degree F*

3. In the properties of saturated steam, list the following for 24.7 psi absolute:
   - Temperature = 239
   - Latent Heat = 953
   - Specific Volume = 16.5

4. List the 3 categories most trap designs fall into.
   A. *Mechanical, Temperature, Velocity*

5. The following trap designs fall into which category:
   - Bellows (radiator trap) = Thermostatic
   - Inverted Bucket = Mechanical
   - Disc Trap = Thermodynamic
   - Float and Thermostatic = Mechanical

### How Did We Do?

   A. Visual, Audio, Temperature, Mechanical

7. 30 feet of lift after a trap will create approximately _______ pounds of backpressure.
   A. 15 psig

8. List the four basic functions all steam traps must be able to perform in your system.
   A. *Hold back steam, Remove condensate, Vent air, react to changes*

9. When Condensate at a higher pressure is reduced to a lower pressure _____is formed and why
   A. Flash Steam
   A. *Condensate at the lower pressure cannot exist at it’s original pressure*

10. When testing a steam trap with temperature, the reading received is the actual steam temperature related to the pressure inside the pipe. True or False?
    A. False