Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Steam Systems
Virtual INPLT Training & Assessment

Session 8

Tuesday – May 25, 2021

10 am – 12:30 pm

Agenda – Session EIGHT

- Safety and Housekeeping

- Today's Content:
  - Review of Session 7
  - Specific Topics & Applications
  - Presentations from VINPLT attendees

- Q&A

Better Buildings is an initiative of the U.S. Department of Energy

Safety and Housekeeping

- Safety Moment
  - Look out for your colleagues – speak up if you see something that is not right and if you believe someone can get hurt in a situation
- Break points after each sub-section where you can ask questions
- When you are not asking a question, please MUTE your mic and this will provide the best sound quality for all participants

- We will be recording all these webinars and by staying on-line and attending the meeting you are giving your consent to be recorded
  - A link to the recorded webinars will be provided, afterwards

Steam Virtual INPLT Agenda

- **Week 1 (April 6) – Industrial Steam Systems Fundamentals and Introduction to SSST**
- **Week 2 (April 13) – Focus on Steam System Generation and Introduction to DOE's MEASUR Tool**
- **Week 3 (April 20) – Steam System Generation & Cogeneration (CHP)**
- **Week 4 (April 27) – Steam System Distribution, End-Use & Condensate Recovery**
- **Week 5 (May 4) – Energy Efficiency Opportunities in the Generation Area**
- **Week 6 (May 11) – Energy Efficiency Opportunities in Generation & Cogeneration (CHP) Areas**
- **Week 7 (May 18) – Energy Efficiency Opportunities in Distribution, End-use and Condensate Recovery**
- **Week 8 (May 25) – Industrial Steam System VINPLT Wrap-up Presentations**

Session 7 – Review

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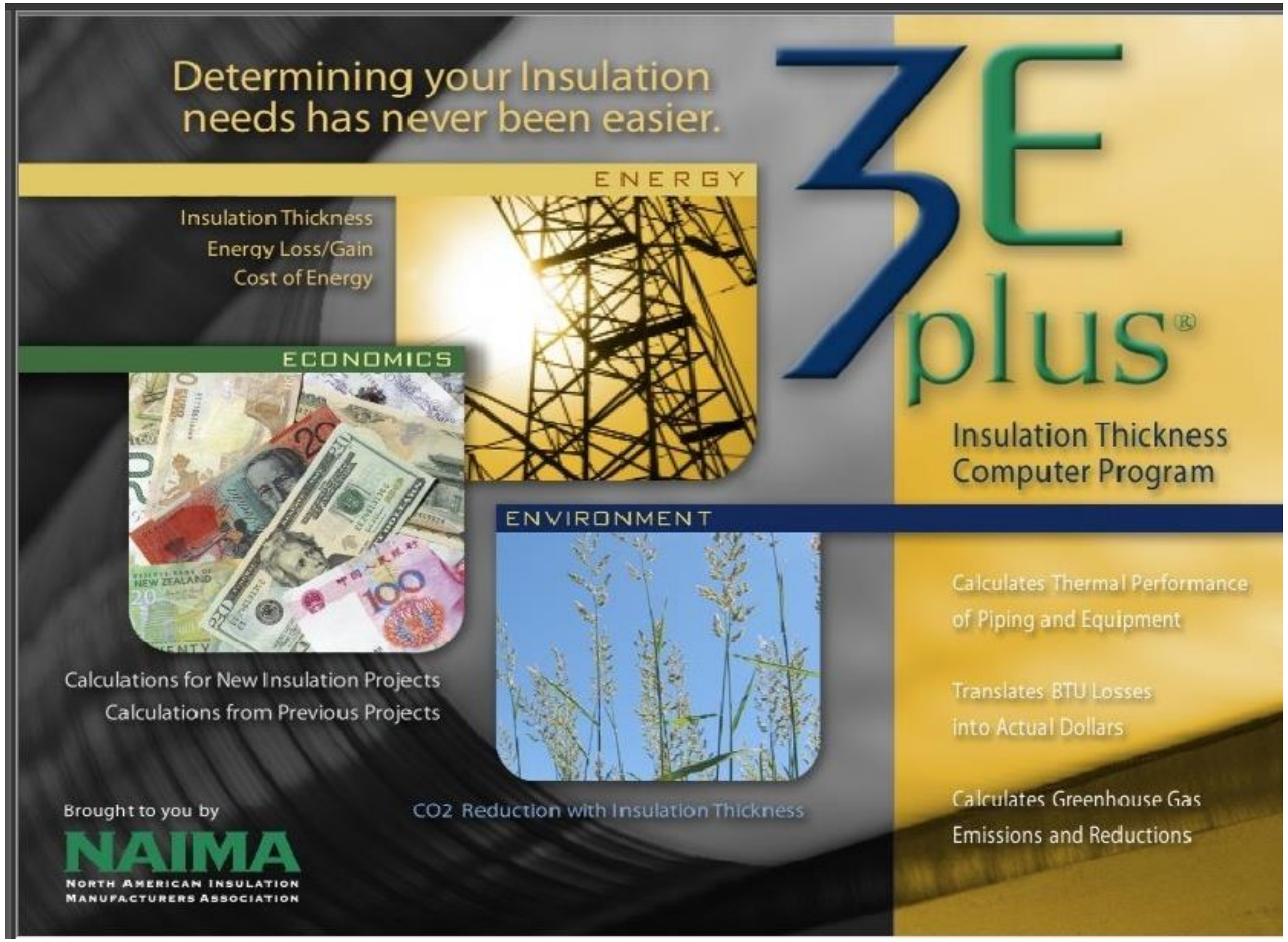
Pipe Failures

- Steam leaks occur in all plants and a continuous improvement type steam leak management program should be implemented in industrial plants
- An “order of magnitude” steam loss estimate can provide enough information to determine if the repair must be made immediately, during a future shutdown, or online
- Pipe failures (steam leaks) often present a “safety issue” that demands immediate attention

Insulation Evaluation Software

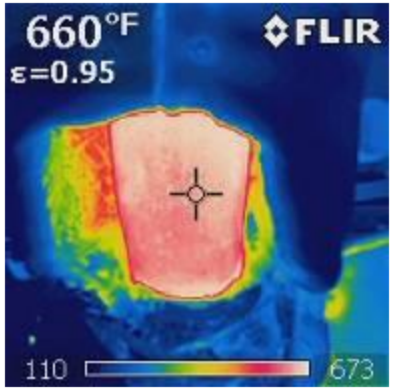


- [Pipe Insulation | Calculate Thickness | 3E Plus Software (insulationinstitute.org)]

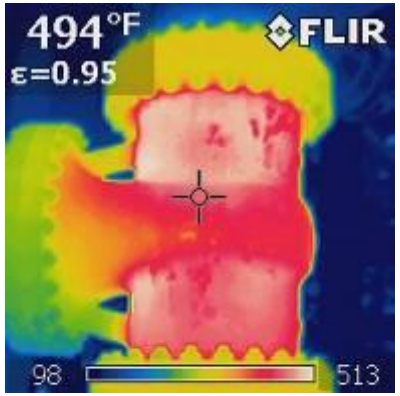
- Software outputs include:
  - Surface heat transfer loss
  - Insulation surface temperature
  - Simple payback, Life Cycle Cost of an insulating project

Steam System Insulation

- Why is insulation necessary on steam systems?
  - Personnel safety – high temperatures
  - Minimize energy losses
  - Protection from ambient conditions
  - Preserve system integrity



- Typical areas of insulation improvement opportunities
  - Distribution headers
  - Inspection man-ways
  - Valves
  - Condensate return lines
  - End-use equipment
  - Storage tanks, vessels, etc.



Steam Demand

- Steam demands take on many different forms
- Reducing steam consumption can often result in the most significant energy reduction opportunities
  - Eliminate inappropriate steam use
  - Reduce appropriate steam use
- Nevertheless, it is extremely difficult to cover end-uses that are specific to industrial processes in a general class
  - Hence, general methods will be described and tools provided to capture and quantify steam demand savings

Common BestPractices – End-Use

- Reduce steam usage by a process
  - Improving the efficiency of the process
  - Shifting steam demand to a waste heat source
- Reduce the steam pressure needed by process, especially in cogeneration systems
- Upgrade low pressure (or waste) steam to supply process demands
- Process integration leading to overall energy optimization of the plant

Effective Steam Trap Management Program

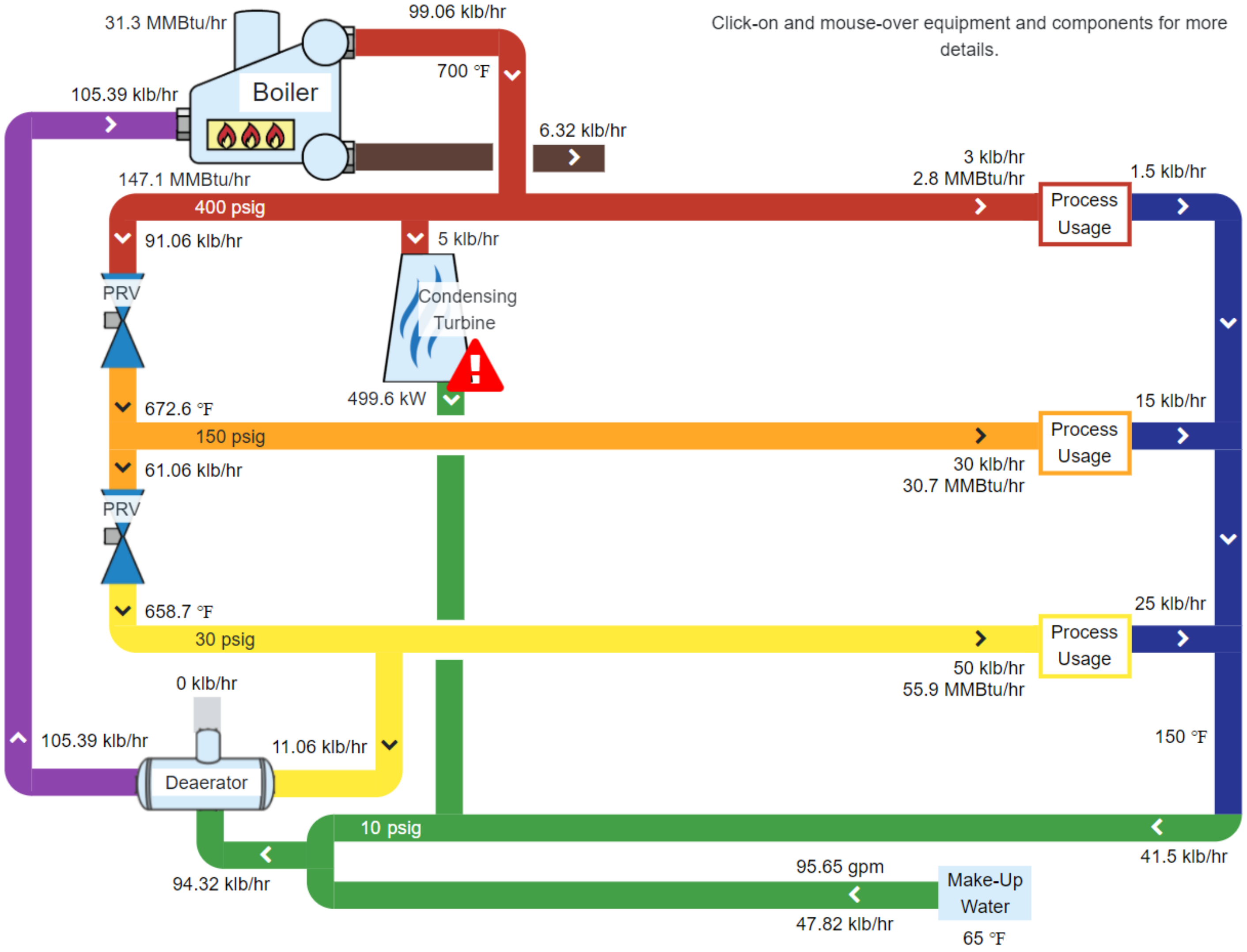
- Maintain a steam trap database
  - Type of trap, model number, size, etc
  - Application
  - Energy loss if failed open
  - Problems if failed closed
  - When was the last recorded failure, repair
- Prioritize repairs based on loss estimates and criticality of steam system and production operations
- Daily monitor receiver vents
- Inspect all traps at least once a year
- Trap maintenance training is essential

Condensate Recovery

- Condensate typically has worth
  - Energy
  - Make-up water reduction
    - This generally improves feedwater quality
      - Resulting in a reduction in boiler blowdown
  - Chemicals

- Condensate recovery costs generally center on the recovery system piping
  - Recovery equipment
  - Return piping

MEASUR – Pulp & Paper Mill Model



MEASUR – Pulp & Paper Mill Model

COST SUMMARY

Power Balance	
Generation	499.6 kW
Demand	5,499.6 kW
Import	5,000 kW
Unit Cost	$0.05 /kWh
Total $/yr	$2,190,000

Fuel Balance	
Boiler	147.05 MMBtu/hr
Unit Cost	$5.00 /MMBtu
Total $/yr	$6,440,979

Make-Up Water	
Flow	95.65 gpm 50,272,661.49 gal
Unit Cost	$0.01 /gal
Total $/yr	$502,727

Total Operating Cost
$9,133,705

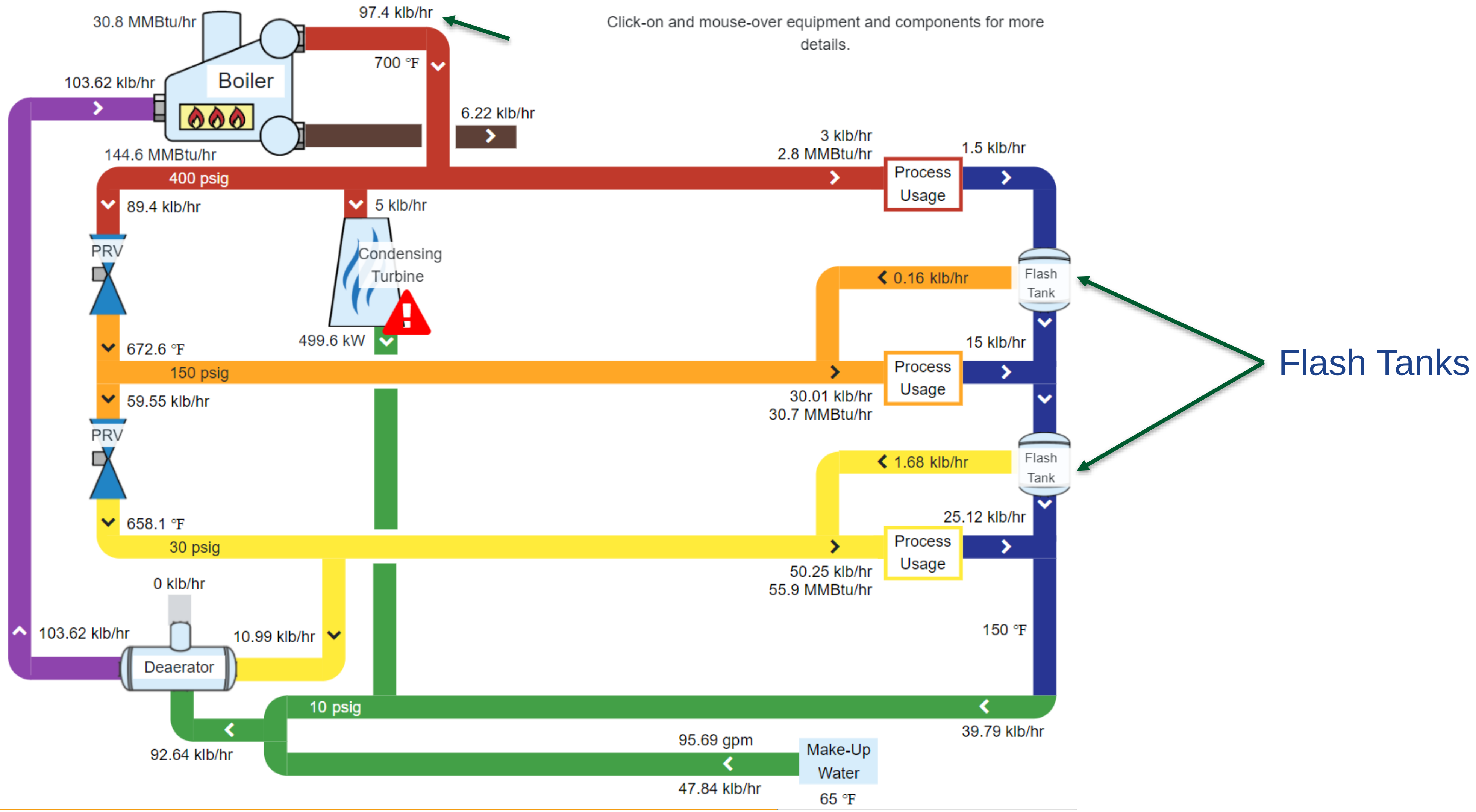
MARGINAL STEAM COST

High Pressure	$9.04 /klb
Medium Pressure	$9.04 /klb
Low Pressure	$9.04 /klb

Energy Efficiency Opportunities (Heat Recovery)

- Condensate Flash Steam Recovery

MEASUR – Pulp & Paper Mill Model



MEASUR – Pulp & Paper Mill Model

RESULTS | SANKEY | HELP

	Baseline	Condensate Flash Tanks
Percent Savings (%)	— —	1.0%
Fuel Usage (MMBtu/yr)	1,288,195.7	1,266,614.1
Fuel Cost ($/yr)	$6,440,979	$6,333,070
Electricity Usage (kW/yr)	43,800,000	43,800,000
Electricity Cost ($/yr)	$2,190,000	$2,190,000
Water Usage (gal/yr)	50,272,661.5	50,295,192.6
Water Cost ($/yr)	$502,727	$502,952
Power Generated (kW/yr)	499.6	499.6
Process Use (MMBtu/yr)	89.5	89.5
Stack Loss (MMBtu/yr)	31.3	30.8
Vent Losses (MMBtu/yr)	0	0
Unrecycled Condensate Losses (MMBtu/yr)	11.8	11.8
Turbine Losses (MMBtu/yr)	0.1	0.1
Other Losses (MMBtu/yr)	9.6	7.6
Annual Cost ($/yr)	**$9,133,705**	**$9,026,022**
Annual Savings ($/yr)	**—**	**$107,683**

MEASUR – Pulp & Paper Mill Model

COST SUMMARY

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Generation	499.6 kW
Demand	5,499.6 kW
Import	5,000 kW
Unit Cost	$0.05 /kWh
Total $/yr	$2,190,000

Fuel Balance	
Boiler	144.59 MMBtu/hr
Unit Cost	$5.00 /MMBtu
Total $/yr	$6,333,070

Make-Up Water	
Flow	95.69 gpm 50,295,192.62 gal
Unit Cost	$0.01 /gal
Total $/yr	$502,952

MARGINAL STEAM COST

High Pressure	$8.27 /klb
Medium Pressure	$8.64 /klb
Low Pressure	$9.04 /klb

Energy Efficiency Opportunities (Distribution, Recovery)

- **Ultrasonic Steam Trap testing**

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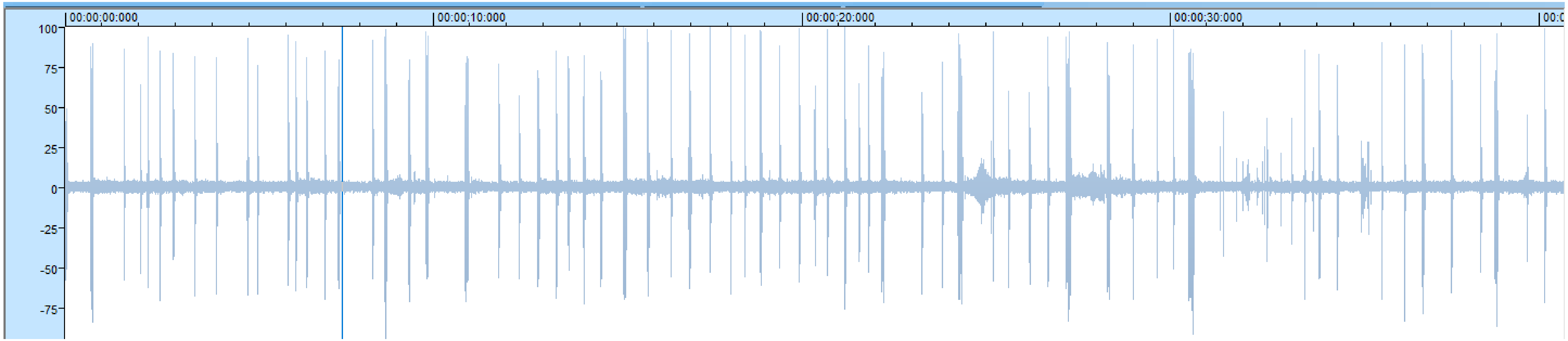
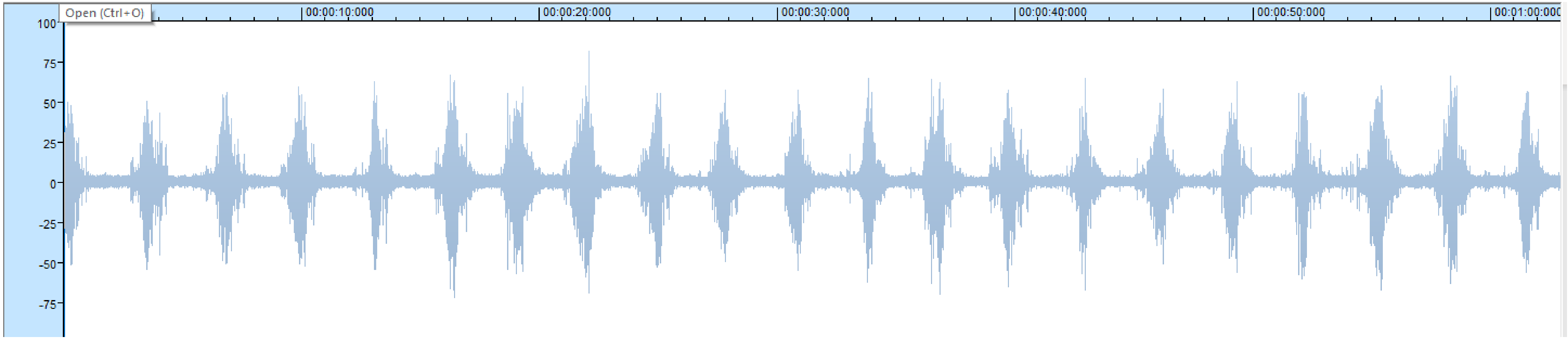
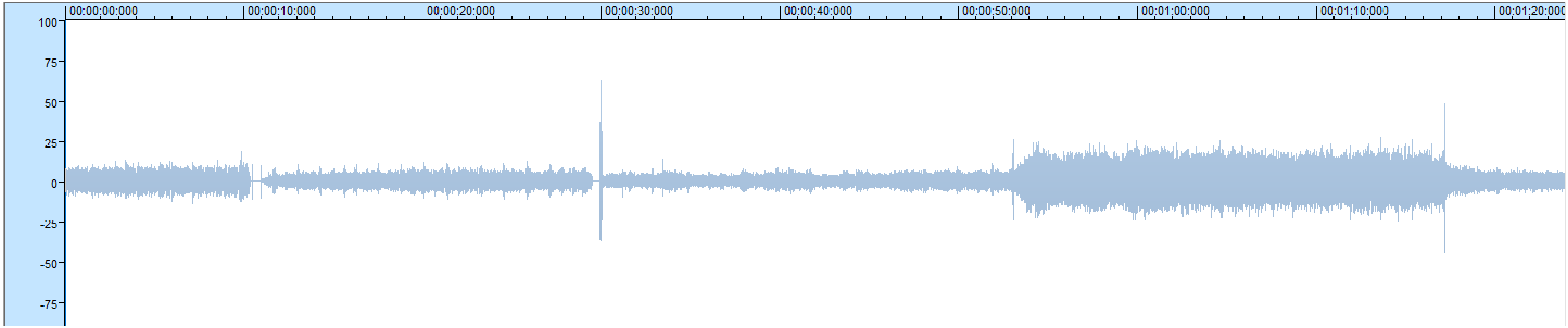
Steam Traps - Working

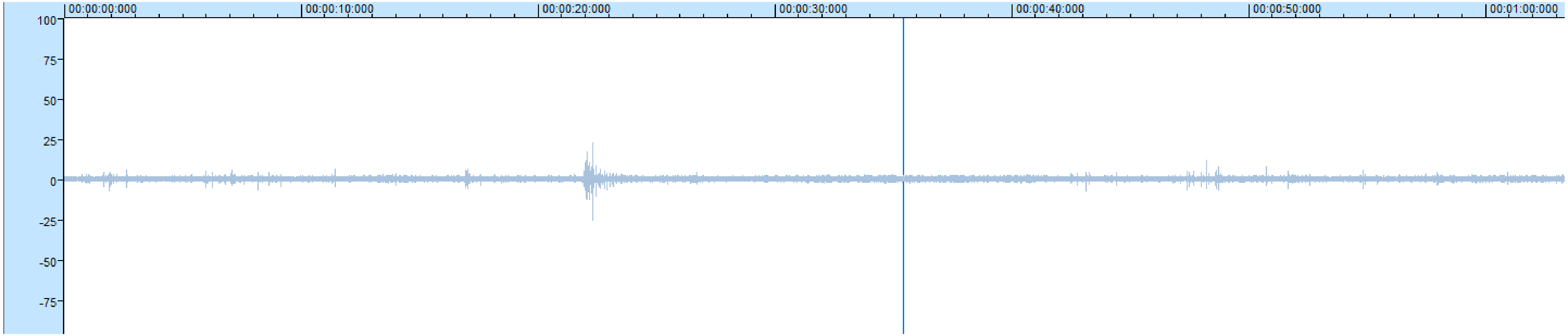


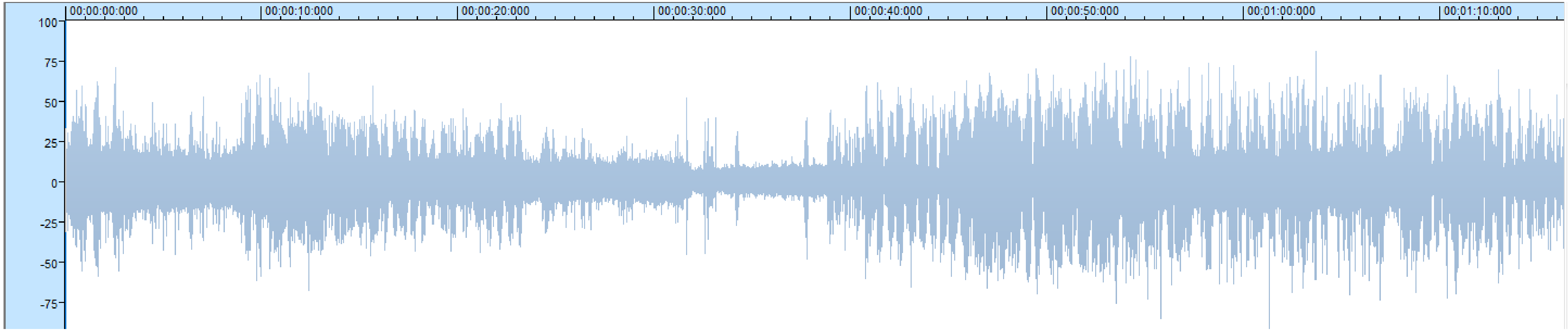


Steam Traps - Working



Steam Traps – **NOT** Working





Desuperheaters

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Letdowns / PRVs

- Pressure Reducing Valves (PRVs) are most prevalent method of reducing pressure in a steam system
- A steam system will have one or more PRVs between two headers
- Not all PRVs maybe controlling header pressures

Letdowns / PRVs

- Steam temperature at the outlet of the PRVs is controlled by feedwater (Desuperheaters)

- Mainly done for
  - Protecting equipment
  - Design conditions
  - Reducing pressure drop in header

MEASUR – Pulp & Paper Mill Model

Medium Pressure Header

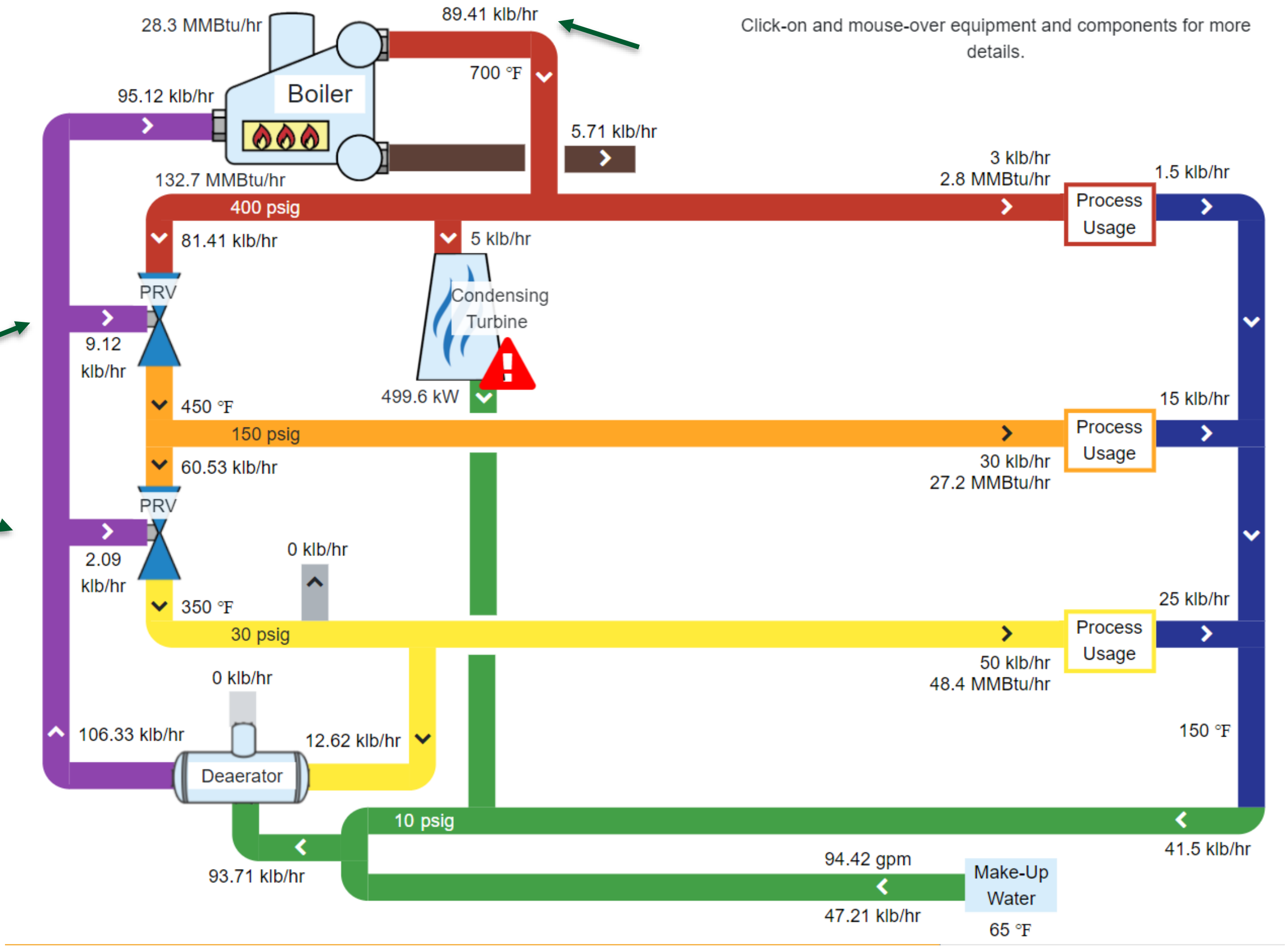
Pressure	150 psig
Process Steam Usage	30 klb/hr
Condensate Recovery Rate	50 %
Flash Condensate Into Header	No
Heat Loss	0 %
Desuperheat Steam out of Highest Pressure Header	Yes
Desuperheat Temperature	450 °F

Low Pressure Header

Pressure	30 psig
Process Steam Usage	50 klb/hr
Condensate Recovery Rate	50 %
Flash Condensate Into Header	No
Heat Loss	0 %
Desuperheat Steam out of Medium Pressure Header	Yes
Desuperheat Temperature	350 °F

MEASUR – Pulp & Paper Mill Model

Desuperheaters



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MEASUR – Pulp & Paper Mill Model

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Generation	499.6 kW
Demand	5,499.6 kW
Import	5,000 kW
Unit Cost	$0.05 /kWh
Total $/yr	$2,190,000

Fuel Balance	
Boiler	132.73 MMBtu/hr
Unit Cost	$5.00 /MMBtu
Total $/yr	$5,813,514

Make-Up Water	
Flow	94.42 gpm 49,625,118.87 gal
Unit Cost	$0.01 /gal
Total $/yr	$496,251

Total Operating Cost
$8,499,765

MARGINAL STEAM COST

High Pressure	$9.04 /klb
Medium Pressure	$8.28 /klb
Low Pressure	$8.05 /klb

Steam System Pressure Reduction

- Is it an Opportunity?

Steam Pressure Reduction

- When steam is produced for **heating** purposes only, what benefit would be gained if boiler pressure were reduced?
  - Boiler efficiency improvement
  - Heat transfer losses reduced
  - Leak losses reduced
  - Condensate system flash steam losses reduced
    - If steam loads receive reduced pressure steam

Pressure Reduction Case Study

- Saturated steam boiler initially operating at 54 psig and 301°F steam conditions
- Steam pressure was reduced to 30 psig (274°F)
  - Steam temperature decreased 27°F
- Flue gas temperature decreased 25°F
  - This reduced the stack loss approximately 1.0%
    - Fuel requirement is 99% of the original fuel requirement for the same thermal energy supply
    - The boiler was burning number 2 fuel oil

Pressure Reduction Case Study -Continued

- Heat transfer loss from a properly insulated pipe should decrease by more than 10%
  - This is developed from 3E Plus
- A steam leak would reduce by more than 30%

Steam Pressure Reduction

- What are the major problems associated with reducing system pressure?
  - Boiler carryover potential increases
    - Water-hammer
    - Increased water treatment costs
    - Poor boiler water chemistry control
    - Equipment fouling
      - Equipment corrosion
    - Equipment erosion
    - Energy loss

Steam Pressure Reduction

- What are the major problems associated with reducing system pressure?
  - Steam supply problems resulting from increased frictional loss
    - Pipe diameter may not be sufficient to supply the steam demand
    - Valve size
  - Condensate recovery and return issues resulting from reduced driving pressure
  - Heat exchanger temperature difference reduces limiting heat transfer

Steam Pressure Reduction

- **Exercise caution when implementing this activity**
  - **There maybe potential SYSTEM problems**

- **System pressure reduction is a very common recommendation**
    - **This recommendation may not receive as much evaluation as necessary**

Energy Efficiency Opportunities (Generation)

- **Waste Heat Recovery Boilers**

Waste Heat Recovery Boilers

- Waste Heat Recovery (WHR) boilers can take several forms depending on the source of waste heat
  - Heat Recovery Steam Generators (HRSGs) on exhaust of combustion turbines
  - Exothermic reaction in a process
  - Heat of combustion of burning waste liquids, etc. in an incinerator
  - Recovery of chemicals
  - Stack loss from a process heater, furnace, etc.
- In most cases, WHR boilers are NOT Impact boilers
- In several cases, WHR boilers may be generating steam at a medium or lower pressure

Waste Heat Recovery Boilers

- The main questions that need to be answered in an analysis with WHR boilers
  - Can more steam be produced from the WHR boilers?
  - If yes, then is the steam system still balanced from a demand and supply perspective?
  - Can steam produced from the WHR boiler offset steam produced from a fuel-fired boiler?

- From a modeling perspective, WHR boilers are best handled by Steam demand savings, if there is a fuel-fired impact boiler in the plant whose load can be reduced due to the steam produced by the WHR boiler

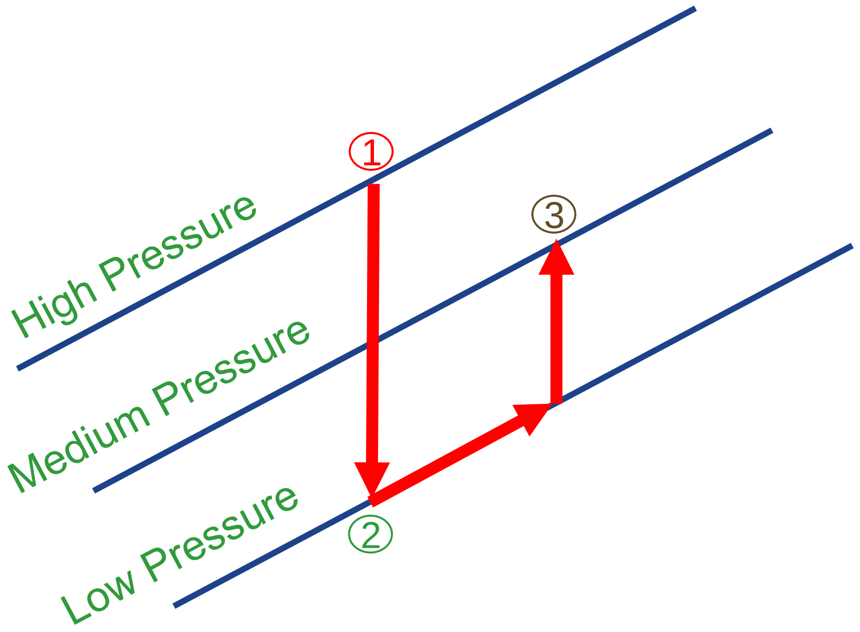
Energy Efficiency Opportunities

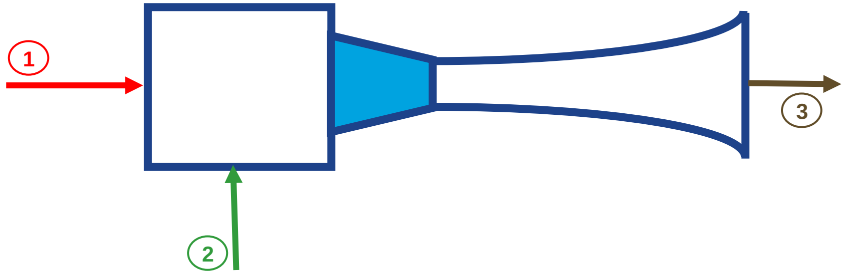
- Thermocompressors

Thermocompressors

- Provide the ability to upgrade low pressure (waste) steam to medium pressure steam thereby reducing the amount of high pressure steam required

- Mechanical vapor compression can also be an alternate option for thermocompressor applications



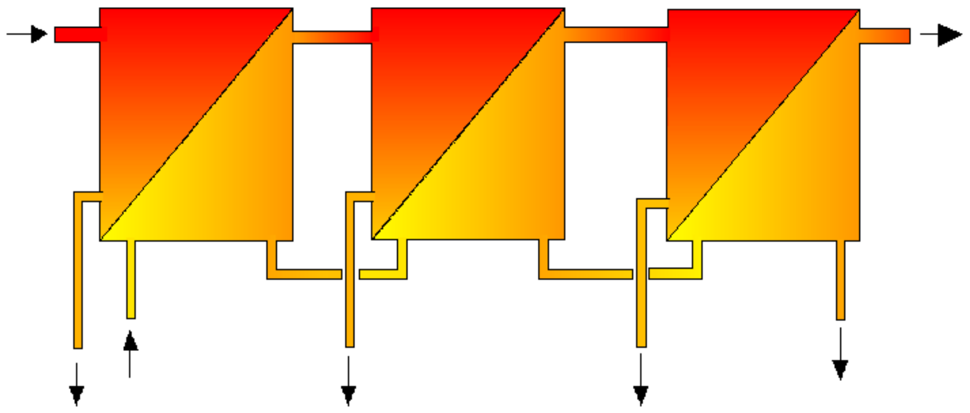


Thermocompressor Analysis

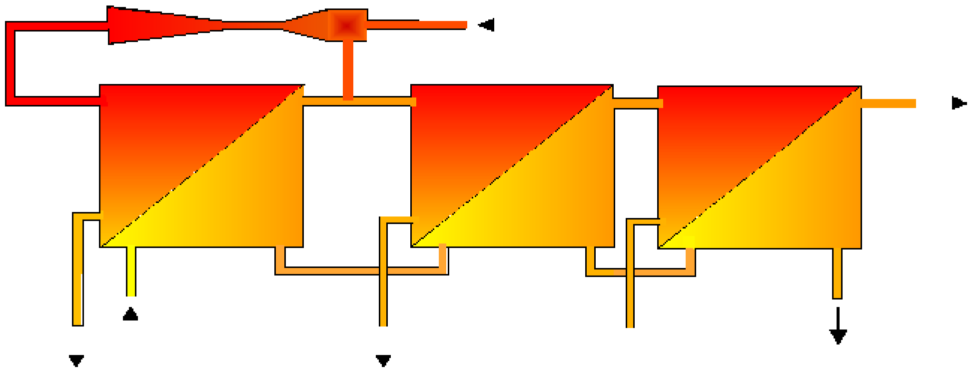
- Thermocompressor analysis requires a thorough understanding of process needs
- Identify the source of waste (or low pressure) steam that is currently vented
- Identify a process that requires steam and is currently using high or medium pressure steam
- Identify motive steam (typically, highest pressure steam) available in the plant
- Work with a manufacturer to select a thermocompressor based on
  - Pressure ratios
  - Steam flows

Evaporators & Use of Thermocompressors

Typical – 3 Effect



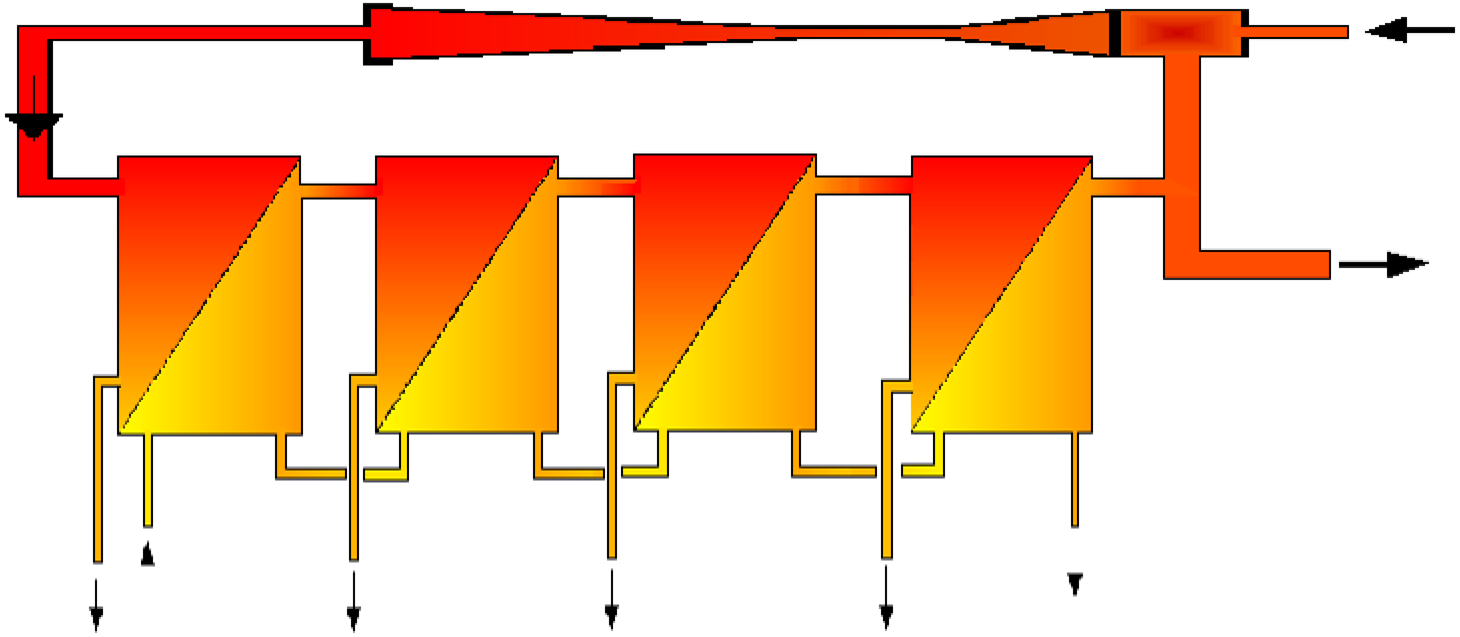
With Thermocompressor



Credit: Jim Munch, JMPS

4-Effect Thermocompressor

- Contamination in condensate?
- Temperature difference / Pressure ratio
- Very application and site specific



Credit: Jim Munch, JMPS

Thermocompressor Analysis

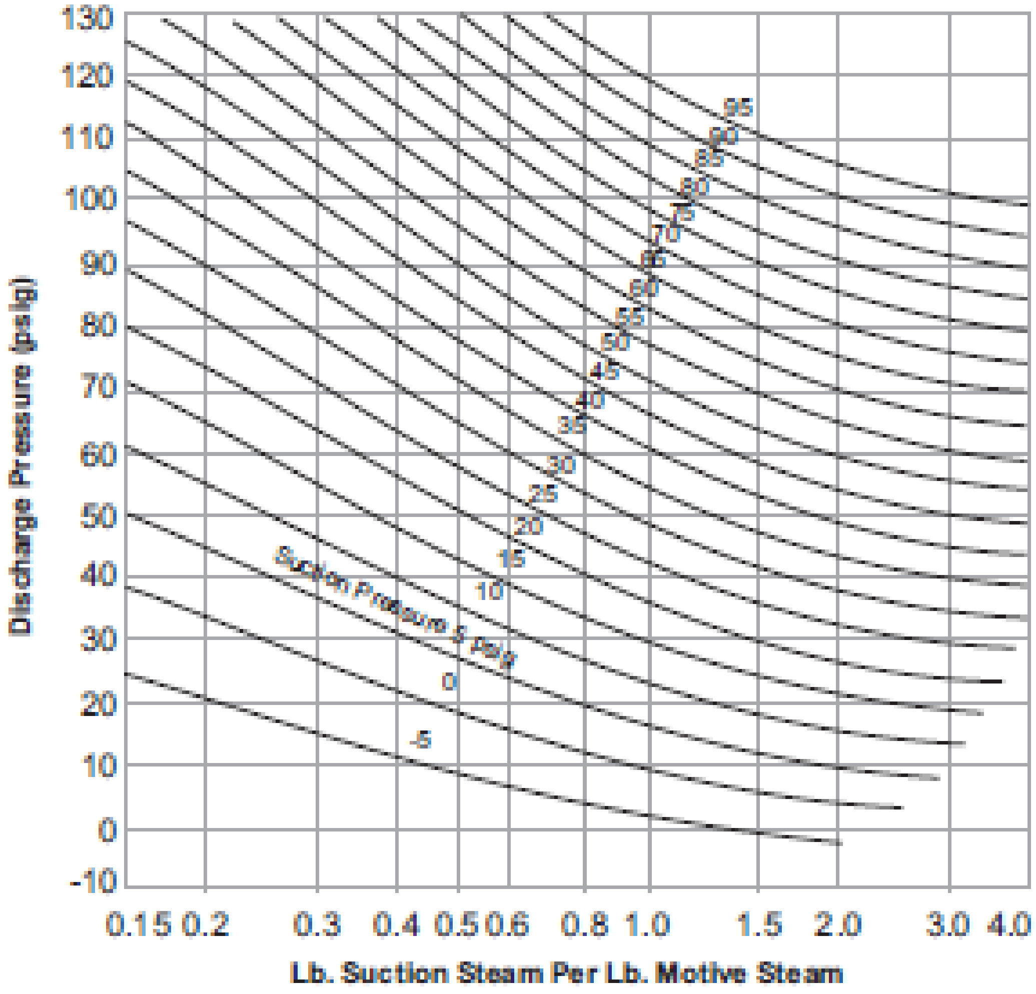
- Mass balance
- Energy balance
- Bernoulli's equation

- Motive steam
  - Eg. 300 psig

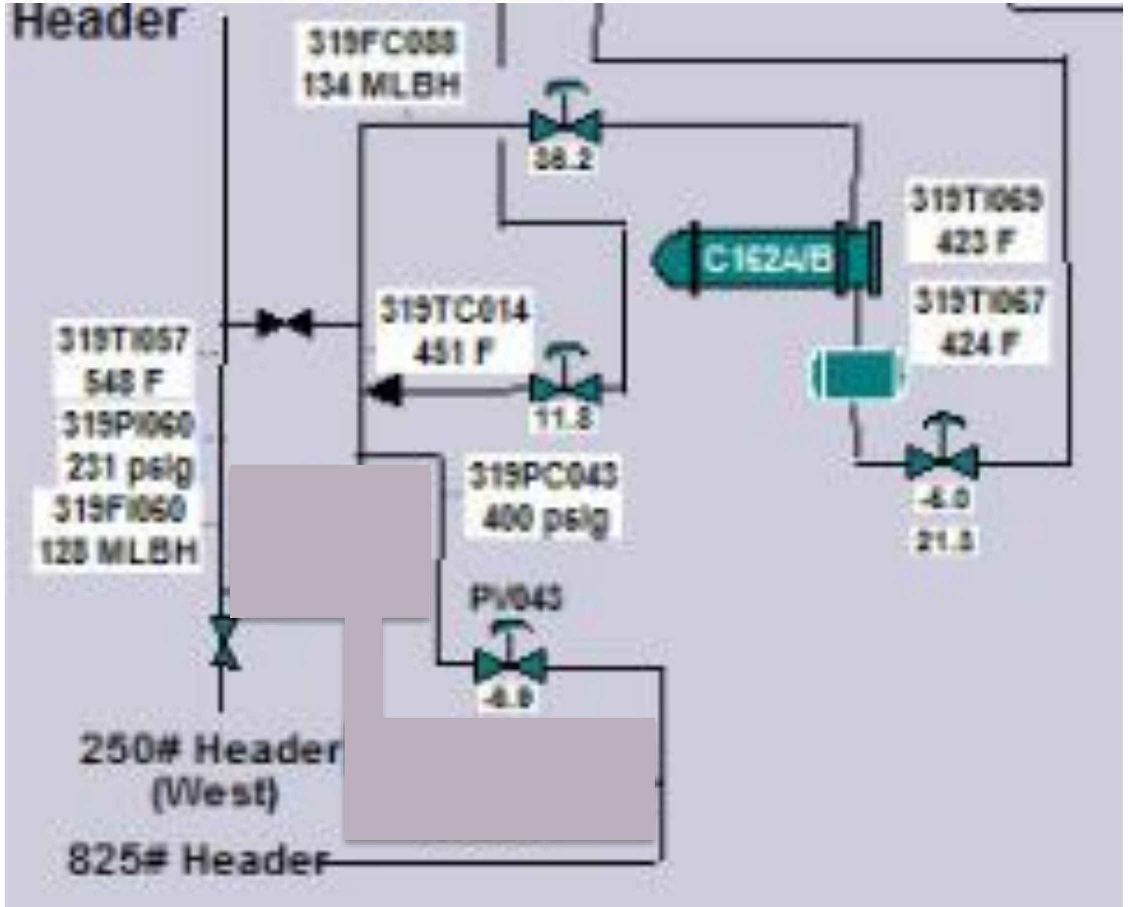
- Suction pressure

- Ratio

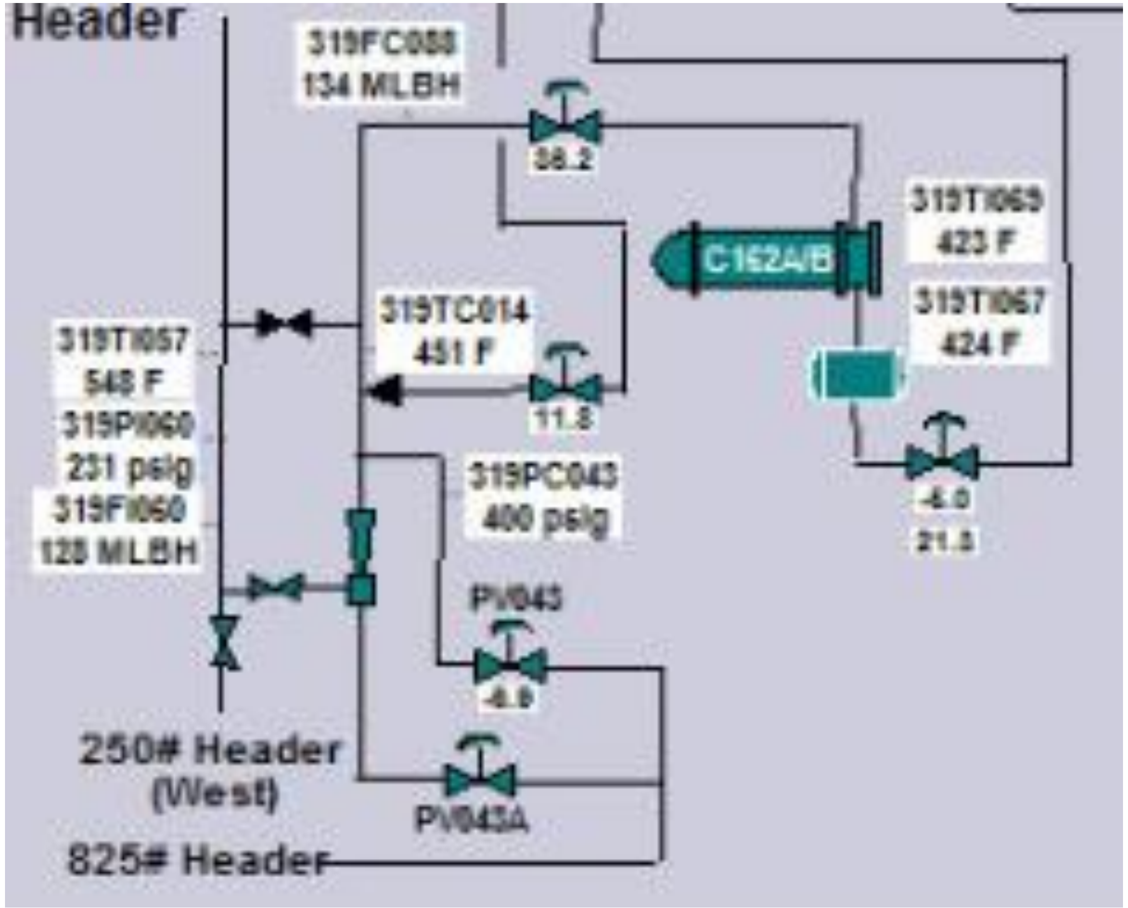
- Discharge pressure



Case Study: Thermocompressor



Case Study: Thermocompressor



Case Study: Thermocompressor

- Petrochemical plant and oil refinery

- Steam demand
  - Pressure ~400 psig
  - Temperature ~425°F
  - Flow rate ~120 klb/hr

- Current Operation
  - Use Pressure Reducing Valve
  - HP steam header ~ 825 psig; 850°F superheated
  - Desuperheating with boiler feedwater

Case Study: Thermocompressor

- Energy assessment revealed that the process has exothermic reactions and generates 250 psig saturated steam

- New Operation
  - Use a thermocompressor
  - Motive steam - HP steam header ~ 825 psig; 850°F superheated
  - Suction steam – 250 psig
  - Discharge steam – 400 psig; 425°F
  - Desuperheating, if needed, with feedwater

Case Study: Thermocompressor

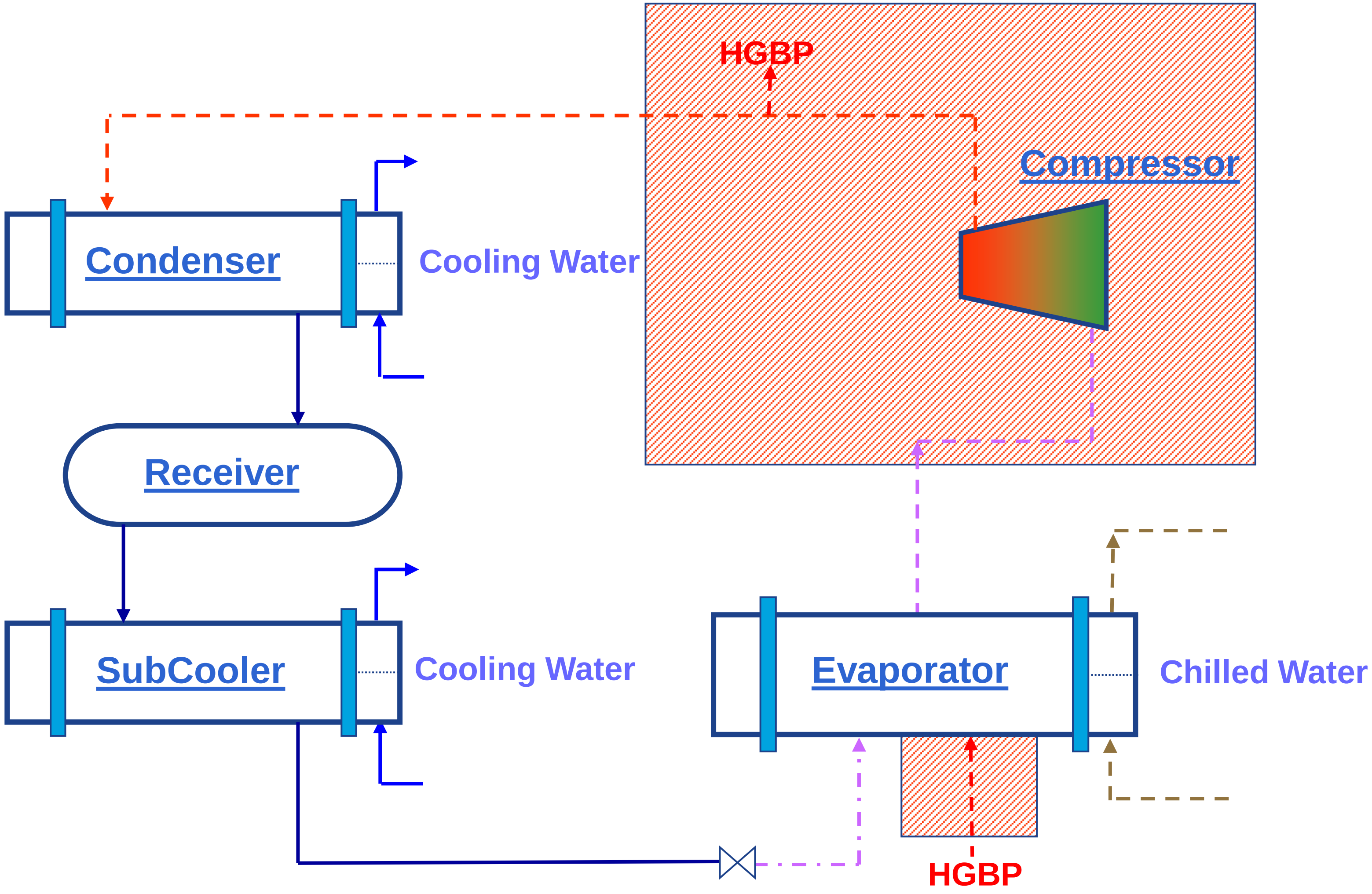
Benefits

- Reduction in HP steam generation
  - Fuel: Natural gas ($8/MMBtu)
  - Energy savings ~ 6.4 MMBtu/hr
  - Annual Cost savings ~$450,000
- Installed cost ~$150,000
  - Explosion proof refinery environment
- No moving parts – no maintenance costs for life
- Reduced feedwater usage
  - Estimated savings ~$20,000

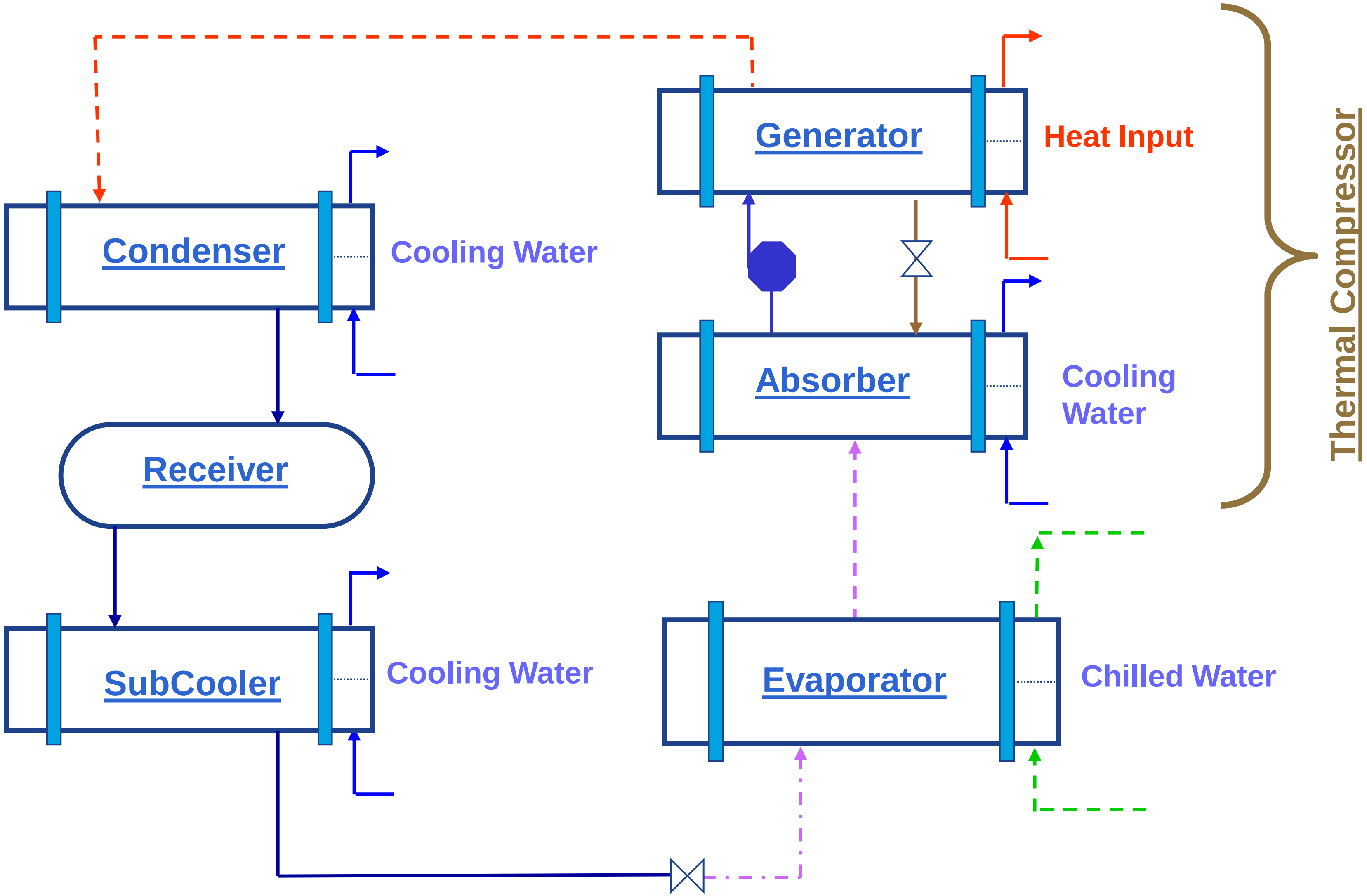
Energy Efficiency Opportunities

- **Absorption Chillers**

Absorption Chillers



Absorption Chillers



Absorption Chiller Systems

- Absorption systems have a pair of working fluids

- Working Fluids
  - Refrigerant side
    - Ammonia
    - Water
    - Other organic fluids

  - Solution (Absorbent) side
    - Water
    - Lithium Bromide
    - Other salts

- Nomenclature – refers to level of refrigerant concentration of the solution
  - Rich / Strong
  - Poor / Weak / Dilute
  - Intermediate

Absorption Chiller Systems

- What impacts the choice of LiBr/H_2O absorption chillers?
  - Driving Generator Temperature – Heat Source

- Single effect
  - Generator Temperature – 180 – 300°F
  - Waste heat fired
  - Hot water fired (180 – 220°F)
  - Steam fired (< 15 psig)
  - COP ~ 0.4-0.5

- Double effect
  - Generator Temperature – 275 – 350°F
  - Steam fired (> 50 psig)
  - Direct natural gas fired
  - COP ~ 0.9-1.0

- Triple effect
  - Generator Temperature – 350 – 400°F
  - Steam fired (> 100 psig)
  - Direct natural gas fired
  - COP ~ 1.2-1.4
  - NOT commercialized yet

Ammonia Water Absorption

- Nevertheless, ammonia water absorption systems do exist all across the world
- They are mainly custom engineered for applications and this maybe one of the reasons that they may become more expensive then comparable LiBr/H_2O systems and mechanical vapor compression systems
- One of the biggest advantage is the ability to produce chill temperatures **below 32°F**
- Refrigerant – Ammonia; Absorbent – Water
- Both substances are naturally available
- Ammonia has no GHG emissions or Global Warming impacts!

Ammonia Water Absorption

- These systems can be designed to be fueled by:
  - Direct-fired (natural gas)
  - Steam
  - Hot water
  - Process waste heat
  - Exhaust waste heat
  - Geothermal
  - Solar
- High pressure depends on whether air-cooled or water-cooled condenser (range – 175-250 psig)
- Low pressure depends on the chilling temperature required

Case Study - 100 RT Heat Pump/Chiller in Livingston, California, USA

- The unit supplies 100 RT of chilling and 3.2 MMBtu/hr water heating
- Driving force - Steam – 2.2 klb/hr at 50 psig

Credit: Energy Concepts Co.

Case Study - 100 RT Heat Pump/Chiller

- The hot water and chilled water are required 20 hours per day, five days per week at a processing plant
- 44ºF chilled water and 140ºF hot water
- Saves 30% of water heating energy and 80% of chilling energy
- Operating cost savings ~$120K per year
- Installation cost ~$200K

Credit: Energy Concepts Co.

Thank You all for attending today's webinar and US DOE Better Plants VINPLT Steam Webinar Series

If you have specific questions, please stay online and we will try and answer them.

Alternately, you can email questions to me at rapapar@c2asustainable.com

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