CEM|CEA

BOILERS and STEAM SYSTEMS

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A. Overview

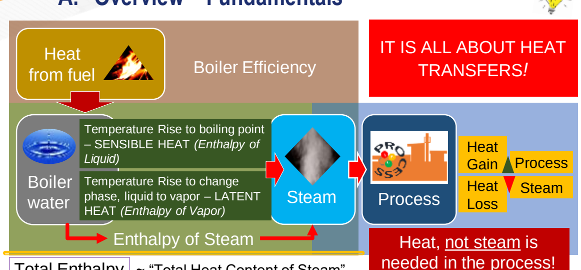
- Steam excellently convey a large mass of heat. It is always the heat, not steam that is wanted, and the heat is needed not at the boiler or in the mains or anywhere else but at the machines where heating processes are carried out.
- The elements in a boiler and steam systems are generation, distribution and utilization. Optimal energy conversion at each element is necessary in the industry.
- CEM and CEA can lead / direct a successful energy management system and program with full knowledge of the science and technology of the steam systems.

HEAT TRANSFER

ENERGY EFFICIENCY

STEAM ENGINEERING

A. Overview – Fundamentals



A. Overview – Goals of Energy Optimization

[1]Environment, Health and Safety [2]Corporate Social Responsibility

B. Learning Objectives

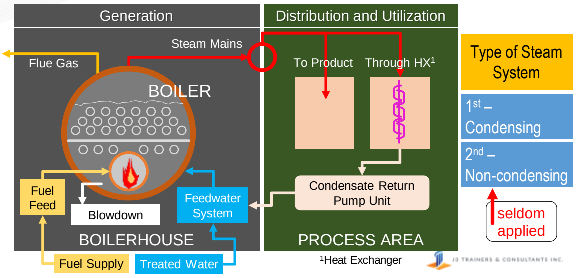
At the end of this course you will be able to:

- Examine the boilers and their steam systems;
- Grasp the components of a steam plant, their functions and effects to the energy efficiency;
- Identify and prioritize key areas with corresponding actions to improve the energy efficiency of boiler and the steam systems, and;
- Align your self to the requirements and capabilities of a CEM or CEA in this area of energy management.

C. Course Outline

A. Overview
B. Learning Objectives
C. Course Outline
D. Introduction
E. Steam Plant Components
F. Boiler Efficiency
Practice
Knowledge Review

D. Introduction – Steam System Configuration



E. Steam Plant Components

TYPICAL STEAM SYSTEM SET-UP

A. BOILER

B. ANCILLARY SYSTEM

B.1 Treatment System

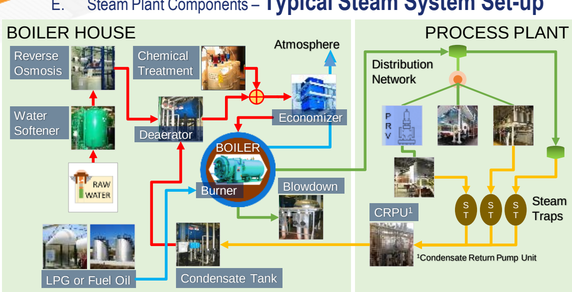
Feedwater Treatment
- Make-up Water
- Feedwater
  - Condensate Tank
  - Deaerator Tank
  - Economizer
  - Boiler Blowdown

B.2 Distribution Network

Heat Loss and Recovery Units
- Heat Transfer Barriers
- Radiation and Convection
- Heat Recoveries

B.3 Integrated Control

E. Steam Plant Components – Typical Steam System Set-up



E. Steam Plant Components – A. Boiler

Categories of Boilers

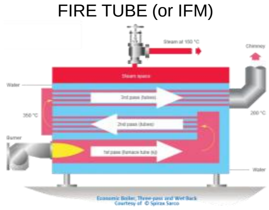
- 1st – IFM (Internally Fired Multi-tubular) Boiler ► "Shell Boiler" ► "Fire Tube Boiler"
- 2nd – WT (Water Tube) Boiler

IFM	COMPARISON	WT
▪ Robust and heavy ▪ Tolerate poor quality feed water ▪ Have large reserve of steam capacity ▪ Longer response to demands of steam ▪ Usually cheaper		▪ More efficient ▪ Weigh less for given output ▪ Less water for same power ▪ Generate steam faster ▪ High pressure / temperature ▪ Better at fluctuating demands ▪ More expensive ▪ High maintenance standard

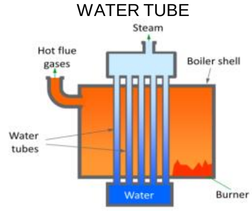
Boiler images courtesy of © Cleaver Brooks

E. Steam Plant Components – A. Boiler

FIRE TUBE (or IFM)



WATER TUBE



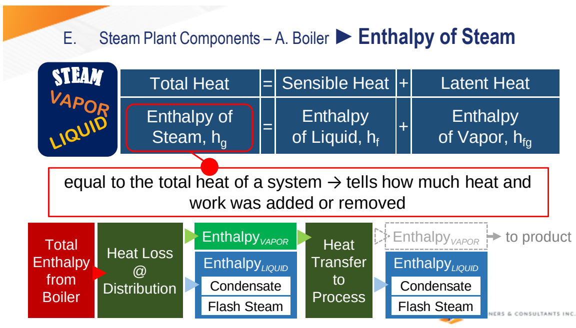
E. Steam Plant Components – A. Boiler

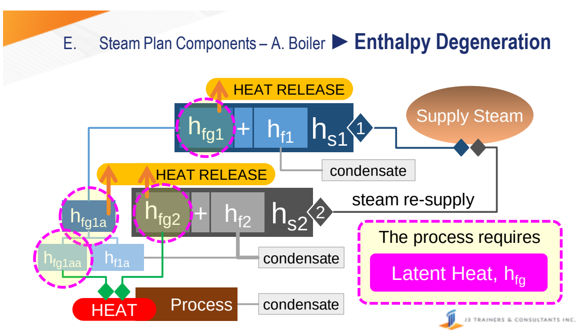
Sizing is measured in Joules (►Mega-Joules)

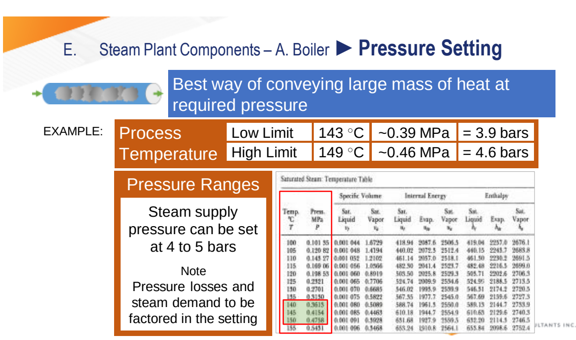
Measured in kgs of steam per hour @ design pressure

converted to Watts

Energy from Fuel = Energy required to convert water to100 ◦C, and then to steam from/at 100 ◦C up to the desired pressure + Energy due from Boiler Efficiency + LOSSES (Heat transfer | Operational | Others)





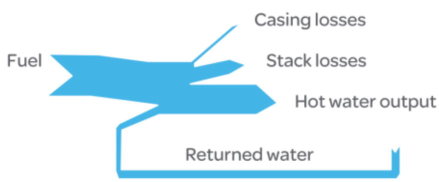


Saturated Steam: Temperature Table

Temp. °C T	Press. MPa P	Specific Volume Sat. Liquid v_f	Specific Volume Sat. Vapor v_g	Internal Energy Sat. Liquid u_f	Internal Energy Evap. u_{fg}	Internal Energy Sat. Vapor u_g	Enthalpy Sat. Liquid h_f	Enthalpy Evap. h_{fg}	Enthalpy Sat. Vapor h_g
100	0.101 35	0.001 044	1.6729	418.94	2087.6	2506.5	419.04	2257.0	2676.1
105	0.120 82	0.001 048	1.4194	440.02	2072.3	2512.4	440.15	2243.7	2683.8
110	0.143 27	0.001 052	1.2102	461.14	2057.0	2518.1	461.30	2230.2	2691.5
115	0.169 06	0.001 056	1.0366	482.30	2041.4	2523.7	482.48	2216.5	2699.0
120	0.198 53	0.001 060	0.8919	503.50	2025.8	2529.3	503.71	2202.6	2706.3
125	0.2321	0.001 065	0.7706	524.74	2009.9	2534.6	524.99	2188.5	2713.5
130	0.2701	0.001 070	0.6685	546.02	1993.9	2539.9	546.31	2174.2	2720.5
135	0.3130	0.001 075	0.5822	567.35	1977.7	2545.0	567.69	2159.6	2727.3
140	0.3613	0.001 080	0.5089	588.74	1961.3	2550.0	589.13	2144.7	2733.9
145	0.4154	0.001 085	0.4463	610.18	1944.7	2554.9	610.63	2129.6	2740.3
150	0.4758	0.001 091	0.3928	631.68	1927.9	2559.5	632.20	2114.3	2746.5
155	0.5431	0.001 096	0.3468	653.24	1910.8	2564.1	653.84	2098.6	2752.4

E. Steam Plant Components – A. Boiler ▶ **Energy Flow**

TYPICAL FOR HOT WATER BOILER



Sankey Diagram courtesy of © DDD Ltd

E. Steam Plant Components – **B. Ancillary Systems**

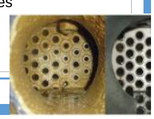
B. ANCILLARY SYSTEM

B.1 Treatment System

Feedwater Treatment
- Make-up Water
- Feedwater
  - Condensate Tank
  - Deaerator Tank
  - Economizer
  - Boiler Blowdown

B.2 Distribution Network

Heat Loss and Recovery Units
- Heat Transfer Barriers
- Radiation and Convection
- Heat Recoveries

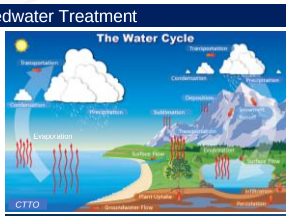


B.3 Integrated Control

Photo source: https://marinerspointpro.com/boiler-corrosion/

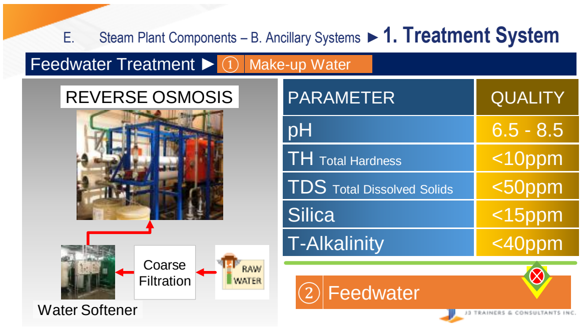
E. Steam Plant Components – B. Ancillary Systems ▶ **1. Treatment System**

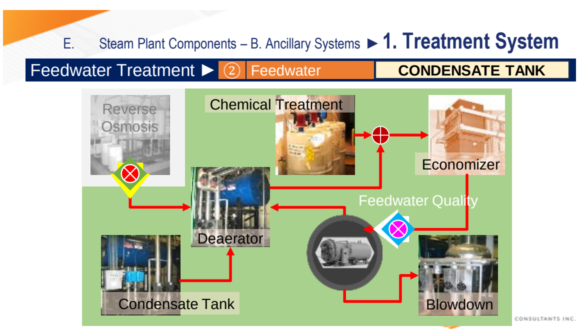
Feedwater Treatment

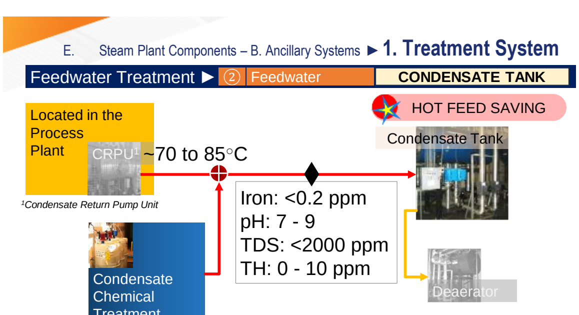


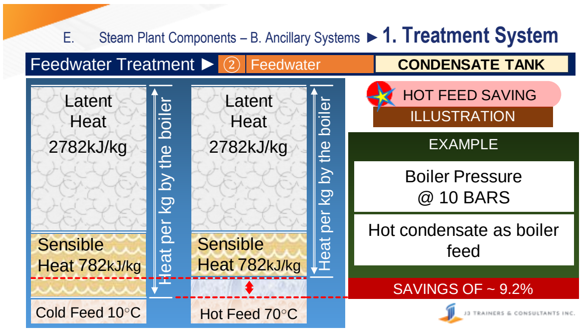
RAW WATER
- Hardness
- Silica
- Alkalinity
- Acidity
- Dissolved Solids
- Suspended Solids

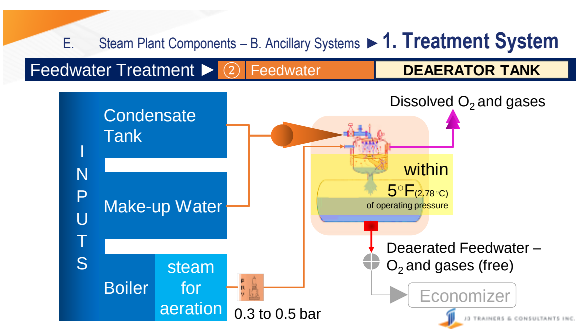
WATER TREATMENT
① Make-up Water ② Feedwater

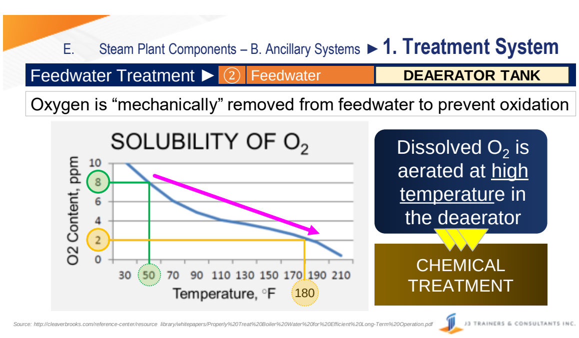

E. Steam Plant Components – B. Ancillary Systems ► 1. Treatment System
Feedwater Treatment ► ① Make-up Water
REVERSE OSMOSIS
Coarse Filtration
RAW WATER
Water Softener
PARAMETER | QUALITY
pH | 6.5 - 8.5
TH Total Hardness | <10ppm
TDS Total Dissolved Solids | <50ppm
Silica | <15ppm
T-Alkalinity | <40ppm
② Feedwater

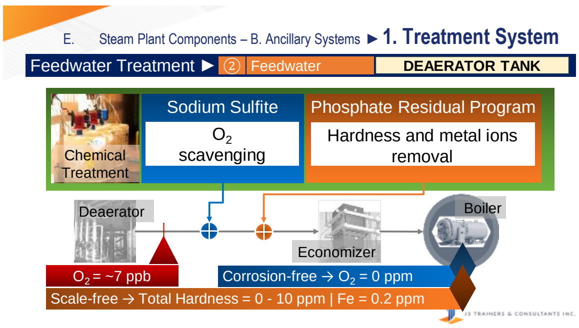

E. Steam Plant Components – B. Ancillary Systems ► 1. Treatment System
Feedwater Treatment ► ② Feedwater
CONDENSATE TANK
Reverse Osmosis
Chemical Treatment
Economizer
Feedwater Quality
Deaerator
Condensate Tank
Blowdown

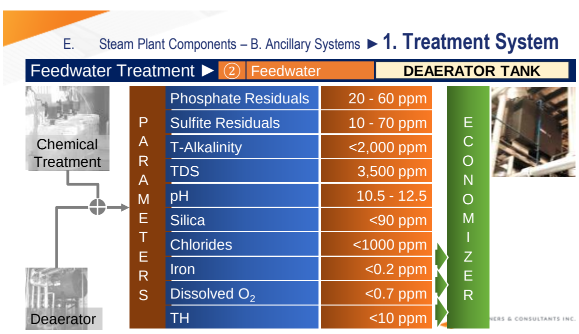

E. Steam Plant Components – B. Ancillary Systems ► 1. Treatment System
Feedwater Treatment ► ② Feedwater
CONDENSATE TANK
HOT FEED SAVING
Located in the Process Plant
CRPU[1]
~70 to 85°C
Condensate Tank
Iron: <0.2 ppm
pH: 7 - 9
TDS: <2000 ppm
TH: 0 - 10 ppm
[1]Condensate Return Pump Unit
Condensate Chemical Treatment
Deaerator


E. Steam Plant Components – B. Ancillary Systems ► 1. Treatment System
Feedwater Treatment ► ② Feedwater
CONDENSATE TANK
Latent Heat 2782kJ/kg
Sensible Heat 782kJ/kg
Heat per kg by the boiler
Cold Feed 10°C
Latent Heat 2782kJ/kg
Sensible Heat 782kJ/kg
Heat per kg by the boiler
Hot Feed 70°C
HOT FEED SAVING
ILLUSTRATION
EXAMPLE
Boiler Pressure @ 10 BARS
Hot condensate as boiler feed
SAVINGS OF ~ 9.2%

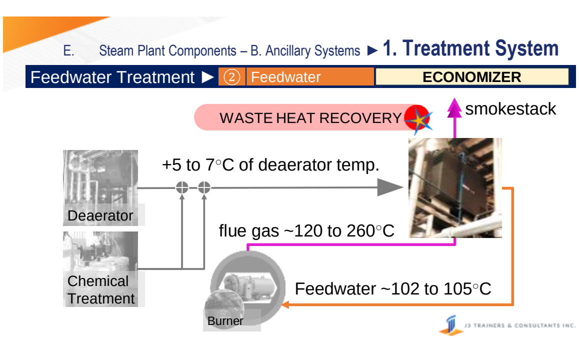

E. Steam Plant Components – B. Ancillary Systems ► 1. Treatment System
Feedwater Treatment ► ② Feedwater
DEAERATOR TANK
INPUTS
Condensate Tank
Make-up Water
Boiler
steam for aeration
0.3 to 0.5 bar
Dissolved O2 and gases
within 5°F(2.78°C) of operating pressure
Deaerated Feedwater – O2 and gases (free)
Economizer

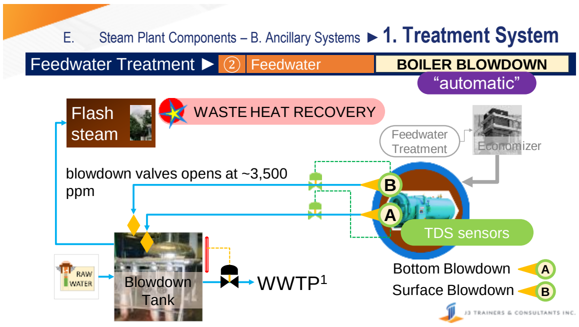

E. Steam Plant Components – B. Ancillary Systems ► 1. Treatment System
Feedwater Treatment ► ② Feedwater
DEAERATOR TANK
Oxygen is “mechanically” removed from feedwater to prevent oxidation
SOLUBILITY OF O2
O2 Content, ppm
10
8
6
4
2
0
30 50 70 90 110 130 150 170 190 210
Temperature, °F
180
Dissolved O2 is aerated at high temperature in the deaerator
CHEMICAL TREATMENT

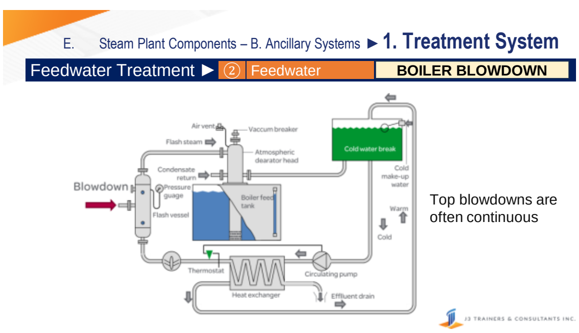




Phosphate Residuals	20 - 60 ppm
Sulfite Residuals	10 - 70 ppm
T-Alkalinity	<2,000 ppm
TDS	3,500 ppm
pH	10.5 - 12.5
Silica	<90 ppm
Chlorides	<1000 ppm
Iron	<0.2 ppm
Dissolved O_2	<0.7 ppm
TH	<10 ppm




E. Steam Plant Components – B. Ancillary Systems ► 1. Treatment System
Feedwater Treatment ► ② Feedwater
BOILER BLOWDOWN
"automatic"
Flash steam
WASTE HEAT RECOVERY
Feedwater Treatment
Economizer
blowdown valves opens at ~3,500 ppm
B
A
TDS sensors
RAW WATER
Blowdown Tank
WWTP¹
Bottom Blowdown A
Surface Blowdown B
J3 TRAINERS & CONSULTANTS INC.


E. Steam Plant Components – B. Ancillary Systems ► 1. Treatment System
Feedwater Treatment ► ② Feedwater
BOILER BLOWDOWN
Air vent
Vaccum breaker
Flash steam
Atmospheric deareator head
Condensate return
Cold water break
Blowdown
Pressure guage
Flash vessel
Boiler feed tank
Cold make-up water
Warm
Cold
Thermostat
Circulating pump
Heat exchanger
Effluent drain
Top blowdowns are often continuous
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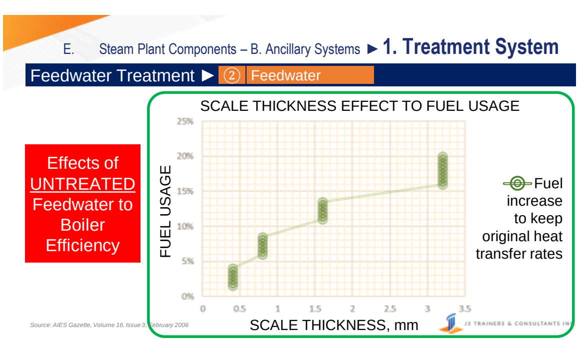
E. Steam Plant Components – B. Ancillary Systems ► 1. Treatment System
Feedwater Treatment ► ② Feedwater
Effects of UNTREATED Feedwater to Boiler Efficiency
SCALE THICKNESS EFFECT TO FUEL USAGE
FUEL USAGE
25%
20%
15%
10%
5%
0%
0
0.5
1
1.5
2
2.5
3
3.5
SCALE THICKNESS, mm
Fuel increase to keep original heat transfer rates
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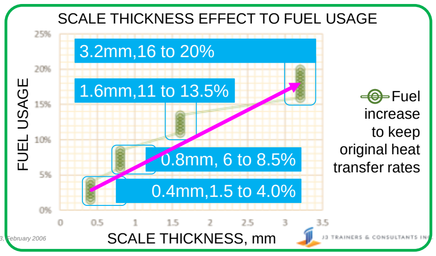
E. Steam Plant Components – B. Ancillary Systems ► **1. Treatment System**

Feedwater Treatment ► ② Feedwater

Effects of UNTREATED Feedwater to Boiler Efficiency



Source: AIES Gazette, Volume 16, Issue 3, February 2006

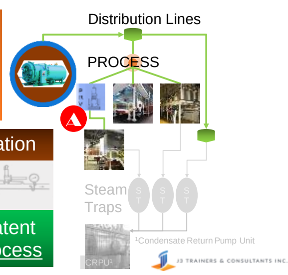
D. Steam Plant Components – B. Ancillary Systems ► **B.2. Distribution Network**

Supply Pressure

High operating pressure prevents wet steam

Pressure Reducing Station

makes available more latent heat → more heat to process



E. Steam Plant Components – B. Ancillary Systems ► **2. Distribution Network**

OPTIMIZATION FROM PRESSURE REDUCTION

Saturated Steam: Temperature Table

Temp. °C T	Press. MPa P	Enthalpy: Sat. Liquid h_f	Enthalpy: Evap. h_{fg}	Enthalpy: Sat. Vapor h_g
100	0.101 35	419.04	2257.0	2676.1
105	0.120 82	440.15	2243.7	2683.8
110	0.143 27	461.30	2230.2	2691.5
115	0.169 06	482.48	2216.5	2699.0
120	0.198 53	503.71	2202.6	2706.3
125	0.2321	524.99	2188.5	2713.5
130	0.2701	546.31	2174.2	2720.5
135	0.3130	567.69	2159.6	2727.3
140	0.3613	589.13	2144.7	2733.9
145	0.4154	610.63	2129.6	2740.3
150	0.4758	632.20	2114.3	2746.5
155	0.5431	653.84	2098.6	2752.4

Press. MPa	Enthalpy Sat. Vapor, h_g
0.3130	2727.3
0.3613	2733.9
% Change	% Change
(0.361 - 0.313) / 0.3130	(2734 - 2727) / 2727.3
15.43%	0.2419%

heat optimization from pressure reduction

1 bar steam pressure reduction

0.5% reduction in heat required

E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network

Heat Loss and Recovery Units

PROSPECTIVE AREAS

- Heat Transfer Barriers
- Radiation and Convection
- Heat Recoveries

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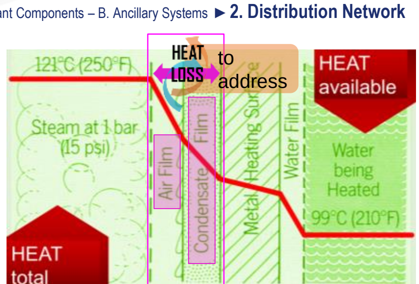
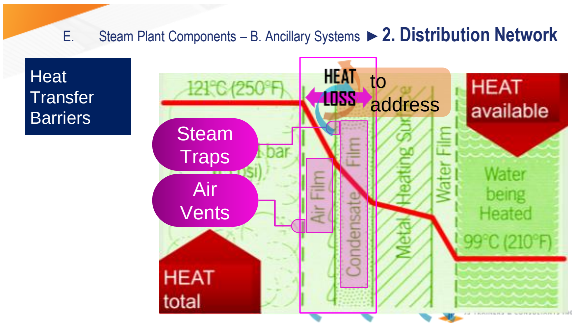
E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network

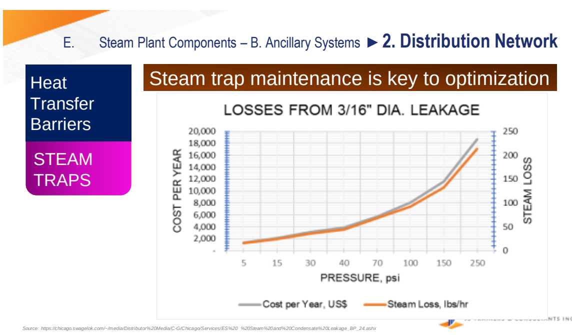
Heat Transfer Barriers

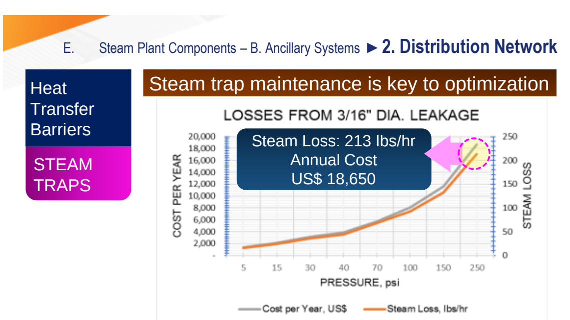
E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network

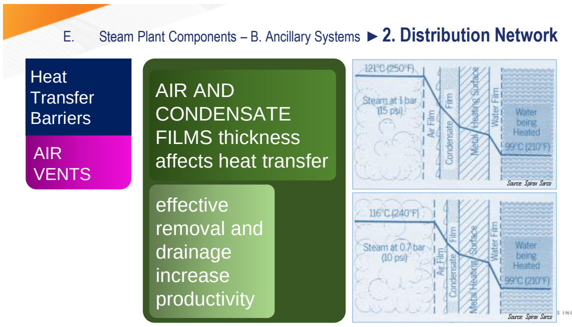
Heat Transfer Barriers

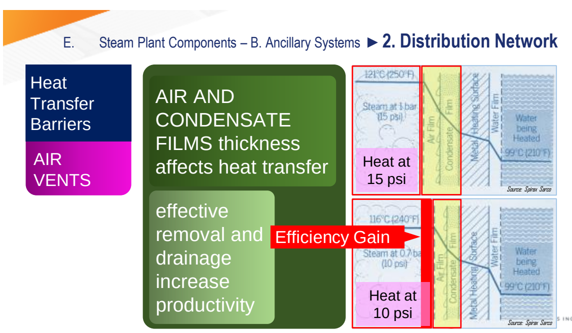


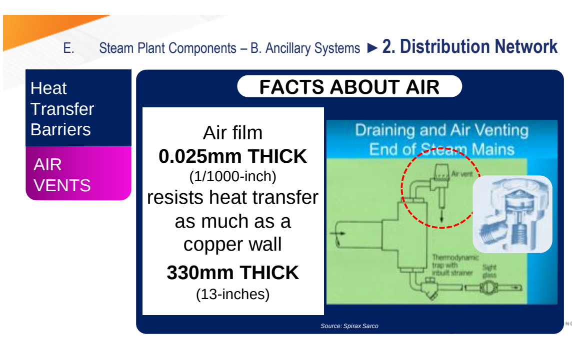

E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network
Heat Transfer Barriers
121°C (250°F)
HEAT LOSS
to address
HEAT available
Steam Traps
Air Vents
Air Film
Condensate Film
Metal Heating Surface
Water Film
Water being Heated
99°C (210°F)
HEAT total


E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network
Heat Transfer Barriers
STEAM TRAPS
Steam trap maintenance is key to optimization
LOSSES FROM 3/16" DIA. LEAKAGE
COST PER YEAR
STEAM LOSS
PRESSURE, psi
Cost per Year, US$
Steam Loss, lbs/hr


E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network
Heat Transfer Barriers
STEAM TRAPS
Steam trap maintenance is key to optimization
LOSSES FROM 3/16" DIA. LEAKAGE
Steam Loss: 213 lbs/hr
Annual Cost
US$ 18,650
COST PER YEAR
STEAM LOSS
PRESSURE, psi
Cost per Year, US$
Steam Loss, lbs/hr


E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network
Heat Transfer Barriers
AIR VENTS
AIR AND CONDENSATE FILMS thickness affects heat transfer
effective removal and drainage increase productivity
121°C (250°F)
Steam at 1 bar (15 psi)
Air Film
Condensate Film
Metal Heating Surface
Water Film
Water being Heated
99°C (210°F)
116°C (240°F)
Steam at 0.7 bar (10 psi)


E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network
Heat Transfer Barriers
AIR VENTS
AIR AND CONDENSATE FILMS thickness affects heat transfer
effective removal and drainage increase productivity
Efficiency Gain
Heat at 15 psi
Heat at 10 psi
121°C (250°F)
116°C (240°F)
Water being Heated
99°C (210°F)


E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network
Heat Transfer Barriers
AIR VENTS
FACTS ABOUT AIR
Air film
0.025mm THICK
(1/1000-inch)
resists heat transfer as much as a copper wall
330mm THICK
(13-inches)
Draining and Air Venting End of Steam Mains
Air vent
Source: Spirax Sarco


E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network
Radiation and Convection
Combustion Leakages
Uninsulated Steam Lines
Damaged Refractory
Unused Steam Lines
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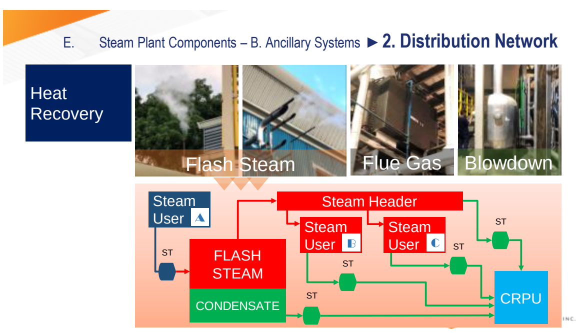
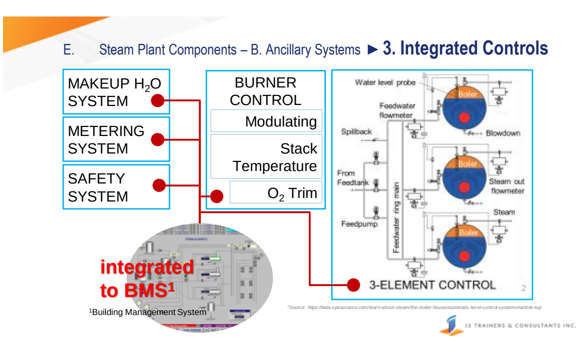

E. Steam Plant Components – B. Ancillary Systems ► 2. Distribution Network
Heat Recovery
Flash Steam
Flue Gas
Blowdown
Steam User A
Steam Header
Steam User B
Steam User C
FLASH STEAM
CONDENSATE
ST
CRPU


E. Steam Plant Components – B. Ancillary Systems ► 3. Integrated Controls
MAKEUP H_2O SYSTEM
METERING SYSTEM
SAFETY SYSTEM
BURNER CONTROL
Modulating
Stack Temperature
O_2 Trim
Water level probe
Feedwater flowmeter
Spillback
From Feedtank
Feedpump
Boiler
Blowdown
Steam out flowmeter
Steam
3-ELEMENT CONTROL
integrated to BMS[1]
[1]Building Management System
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F. Boiler Efficiency

Calculation Methods

Combustion	Fuel-to-Steam	Thermal
amounts of unburned fuel and excess air in the exhaust	True Boiler Efficiency considers the effectiveness as HX plus radiation and convection losses	heat transfers from combustion to water (as HX[1])

[1]Heat Exchanger

ASME Power Test Code (PTC 4.1) 2-Methods

- Input-Output (Direct)
- Heat Loss (Indirect)

Source: Cleaver Brooks Boiler Efficiency Guide

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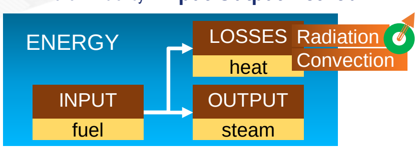
F. Boiler Efficiency – Input-Output Method



$$\text{Boiler Efficiency} = \frac{(\text{Heat of Steam, } Q_s + \text{Losses})}{\text{Heat of Fuel, } Q_f} \times 100\%$$

$$Q_s = W_s \times (h_g - h_f)$$

$$Q_f = W_f \times HHV$$

W_s, weight of steam, kg/hr
h_f, enthalpy of liquid at feedwater temperature, kJ/kg
h_g, enthalpy of vapor at operating pressure, kJ/kg
W_f, weight of fuel, kg/hr
HHV, high heating value of fuel, kJ/kg

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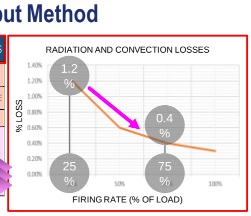
F. Boiler Efficiency – Input-Output Method

Radiation and Convection Losses

MODEL CB 4-PASS BOILER - RADIATION AND CONVECTION LOSSES

FIRING RATE (% of Load)	100-350 BHp OPERATING PRESSURE 10 PSIG	100-350 BHp OPERATING PRESSURE 125 PSIG	400-800 BHp OPERATING PRESSURE 10 PSIG	400-800 BHp OPERATING PRESSURE 125 PSIG
25%	1.6%	1.9%	1.0%	1.2%
50%	0.7%	1.0%	0.5%	0.6%
75%	0.5%	0.7%	0.3%	0.4%
100%	0.4%	0.5%	0.2%	0.3%

Based on still air conditions and 80 °F



HIGH firing rate (% of load)
LOW radiation and convection losses

Source: Cleaver Brooks Boiler Efficiency Guide

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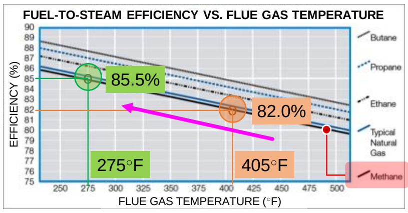
F. Boiler Efficiency – Input-Output Method

Flue Gas Temperature Effect to Fuel-to-Steam Efficiency

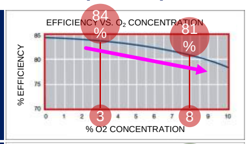


LOW flue gas temperature → HIGH fuel-to-steam efficiency

Source: Cleaver Brooks Boiler Efficiency Guide

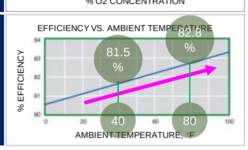
F. Boiler Efficiency – Input-Output Method

High O_2 Concentration in Combustion Air



HIGH O_2 concentration → LOW fuel-to-steam efficiency

Ambient Temperature in Boiler House



HIGH ambient temperature → HIGH fuel-to-steam efficiency

Source: Cleaver Brooks Boiler Efficiency Guide

F. Boiler Efficiency – Input-Output Method

TURNDOWN RATIO

Maximum Heat Output OVER Minimum Heat Output

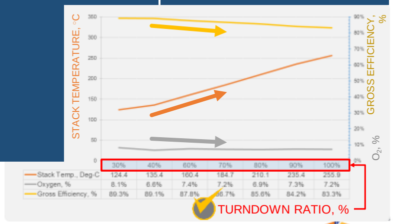
HEAT SOURCE is gradually:

- TURNED DOWN when temperature / pressure approaches the setpoint
- TURNED UP when temperature / pressure falls below the setpoint

Source: Clayton Steam Generator

F. Boiler Efficiency – **Input-Output Method**

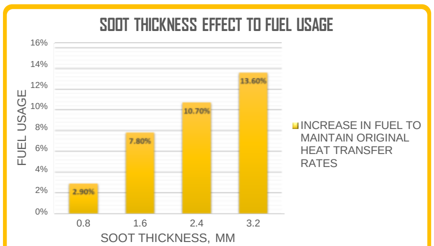
TURNDOWN RATIO | 75 BO. HP CLAYTON



Source: Clayton Steam Generator

F. Boiler Efficiency – **Input-Output Method**

Soot presence – a manifestation of maintenance effectiveness



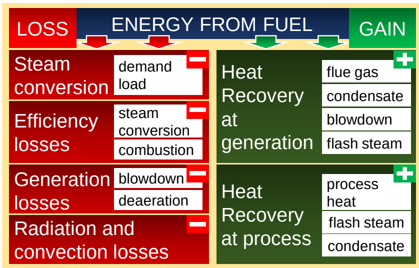
Source: AIES Gazette, Volume 16, Issue 3, February 2006

G. Optimization Checklist

- √ Proper boiler operation
- √ Metering and mass balance
- √ Steam distribution
- √ Condensate and air removal
- √ Flash steam, condensate, and waste heat recovery
- √ Process methods

Inputs to the Process Steam Optimization Program

G. Optimization Checklist – Plant Energy Balance



G. Optimization Checklist – Energy Efficiency Actions (some)

Energy Efficiency Measures

1. Sequence control and firing strategies
2. Variable speed drives
3. Boiler cladding and insulation of pipework and fittings
4. Combustion air preheat
5. Fuel to air ratio
6. Steam accumulators to recover residual heat from blowdowns
7. Removal of redundant steam line
8. Cost-benefit analysis re: water tube vs. fire tube boiler
9. Alternative fuel source: LPG / LNG vs. fuel oil vs. cheaper fuel
10. Start up procedures for boilers

PROBLEMS

Example: Let's calculate the heat saved by using an economizer to preheat the feedwater for the boiler

Assumptions:

- Initial feedwater temperature without economizer: 20°C
- Desired preheat temperature with economizer: 60°C
- Boiler operating pressure: 10 bar (saturated steam temperature ≈ 180°C)
- $Latent_{vapor}$, L_v * @100°C = 2257 kJ/kg
- Specific heat capacity of water, c: 4.18 kJ/kg-°C
- Boiler efficiency without economizer: 85%
- Flue gas temperature exiting the boiler: 220°C
- Mass flow rate of steam, m: 5000 kg/hr = 1.39 kg/s

$Latent_{vapor}$, L_v is also Enthalpy of Vapor, h_{fg}

1 KJ/s ~ 1KW

► Solve for $Q_{sensible}$ before having economizer

$Q_{sensible} = m \times c \times \Delta T$

$Q = \left(1.39 \frac{kg}{s}\right) x \left(4.18 \frac{kJ}{kg{\cdot}°C}\right) x\ (180°C - 20°C)$

Q = 930.44 KW

► Solve for Q_{latent} before having economizer

$Q_{latent} = m \times L_v$

$Q = \left(1.39 \frac{kg}{s}\right) x \left(2257 \frac{kJ}{kg}\right)$

Q = 3134.73 KW

► Solve for Total $Q_{sensible}$ before having economizer

$Q_{total} = Q_{sensible} + Q_{latent}$

Q = 930.44 KW + 3134.73KW

Q = 4065.17 KW

PROBLEMS

Example: Let's calculate the heat saved by using an economizer to preheat the feedwater for the boiler

ASSUMPTIONS:

- Initial feedwater temperature without economizer: 20°C
- Desired preheat temperature with economizer: 60°C
- Boiler operating pressure: 10 bar (saturated steam temperature ≈ 180°C)
- $Latent_{vapor}$, L_v @100°C = 2257 kJ/kg
- Heat capacity of water, CP: 4.18 kJ/kg-°C
- Boiler efficiency without economizer: 85%
- Flue gas temperature exiting the boiler: 220°C
- Mass flow rate of steam: 5000 kg/hr = 1.39 kg/s

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PROBLEMS

Example: Let's calculate the heat saved by using an economizer to preheat the feedwater for the boiler

►Solve for $Q_{sensible}$ **before** having economizer:

$$Q = m \times C \times \Delta T$$

$$Q = \left(1.39\frac{kg}{s}\right) x \left(4.18\frac{kJ}{kg{\cdot}°C}\right) x\ (180°C - 20°C)$$

Q = 930.44 KW

Initial feedwater temperature without economizer = 20°C

10 bar (saturated steam temperature ≈ 180°C)

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PROBLEMS

Example: Let's calculate the heat saved by using an economizer to preheat the feedwater for the boiler

►Solve for Q_{latent} **before** having economizer:

$$Q = m \times L_{v\ @100°C}$$

$$Q = \left(1.39\frac{kg}{s}\right) x \left(2257\frac{kJ}{kg}\right)$$

Q = 3134.733 KW

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PROBLEMS Example: Let's calculate the heat saved by using an economizer to preheat the feedwater for the boiler

►Solve for Total $Q_{sensible}$ **before** having economizer:

$Q = Q_{sensible} + Q_{latent}$
Q =930.44 KW + 3134.73 KW
Q = 4065.17 KW

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PROBLEMS Example: Let's calculate the heat saved by using an economizer to preheat the feedwater for the boiler

►Solve for $Q_{sensible}$ **after** having economizer:

Q = m x Cp x ΔT

$$Q = \left(1.39\,\frac{\text{kg}}{\text{s}}\right) x \left(4.18\,\frac{\text{kJ}}{\text{kg}\cdot{}^{\circ}\text{C}}\right) x\ (180^{\circ}\text{C} - 60^{\circ}\text{C})$$

Q = 698.39 KW

Initial feedwater temperature with economizer = 60°C
10 bar (saturated steam temperature ≈ 180°C)

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PROBLEMS Example: Let's calculate the heat saved by using an economizer to preheat the feedwater for the boiler

►Solve for $Q_{sensible}$ **after** having economizer:

$Q = m \times L_v$

$$Q = \left(1.39\,\frac{\text{kg}}{\text{s}}\right) x \left(2257\,\frac{\text{kJ}}{\text{kg}}\right)$$

Q = 3134.733 KW

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PROBLEMS

Example: Let's calculate the heat saved by using an economizer to preheat the feedwater for the boiler

► Solve for Total Q_{Latent}:

$Q = 698.39\ KW + 3134.73KW$
$Q = 3833.11\ KW$

► Solve for Total KW Savings:

$Q_{savings} = Q_{without\ economizer} - Q_{with\ economizer}$
$Q_{savings} = 4065.17\ KW - 3833.11\ KW$
$\mathbf{Q_{savings} = 232.05\ KW}$

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KNOWLEDGE REVIEW

(Select the best answer)

1. What are the two main categories of boilers?
   - a. Fire tube and water tube
   - b. Combination and system
   - c. Condensing and non-condensing
   - d. High pressure and low pressure
2. What is the purpose of an economizer in a boiler system?
   - a. To preheat the combustion air
   - b. To pre-heat the feedwater
   - c. To reduce stack temperatures
   - d. To increase the amount of excess air

KNOWLEDGE REVIEW

(Select the best answer)

3. What is the recommended amount of excess air to achieve high thermal efficiency in a boiler system?
   - a. As much as possible
   - b. None
   - c. Only enough for complete combustion
   - d. It depends on the fuel used and other factors
4. What is a steam accumulator?
   - a. A device that stores steam for later use
   - b. A device that removes excess steam from a system
   - c. A device that measures steam flow rate
   - d. A device that regulates steam pressure

KNOWLEDGE REVIEW

(Select the best answer)

5. What is the difference between a fire tube and a water tube boiler?
   a. The direction of the water flow
   b. The type of fuel used
   c. The size of the boiler
   d. The location of the burner

KNOWLEDGE REVIEW

In a chemical plant, a flash evaporation process is used to separate a mixture. The process operates by partially vaporizing the feed at a constant pressure. The feed enters the flash drum at a rate of 1.2 kg/s with a temperature of 90°C and leaves as a saturated vapor at a pressure of 5 bar. The latent heat of vaporization for the mixture at 5 bar is 1,800 kJ/kg. Calculate the heat transfer rate required for the vaporization process.

KNOWLEDGE REVIEW

A steam generator in a small power plant produces superheated steam. Water at a flow rate of 2,000 kg/hr enters the generator at 120°C and exits as superheated steam at a temperature of 300°C. The specific enthalpy of liquid water at the inlet is 504 kJ/kg, and the specific enthalpy of superheated steam at the outlet is 3,080 kJ/kg. Calculate the heat transfer rate required in the steam generator.