CEM|CEA

BOILERS and STEAM SYSTEMS

Engr. Eugene Isidro B. Acosta, PME | CEA

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

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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.

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C. Course Outline

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

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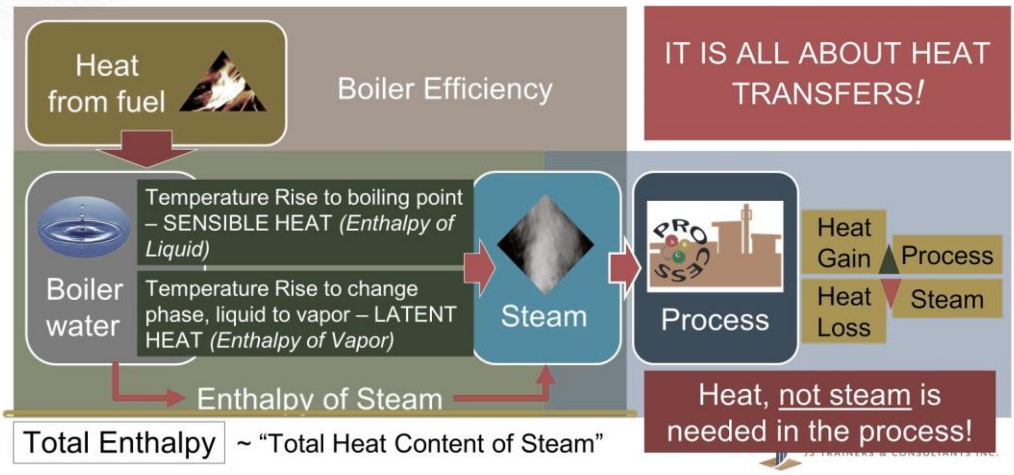
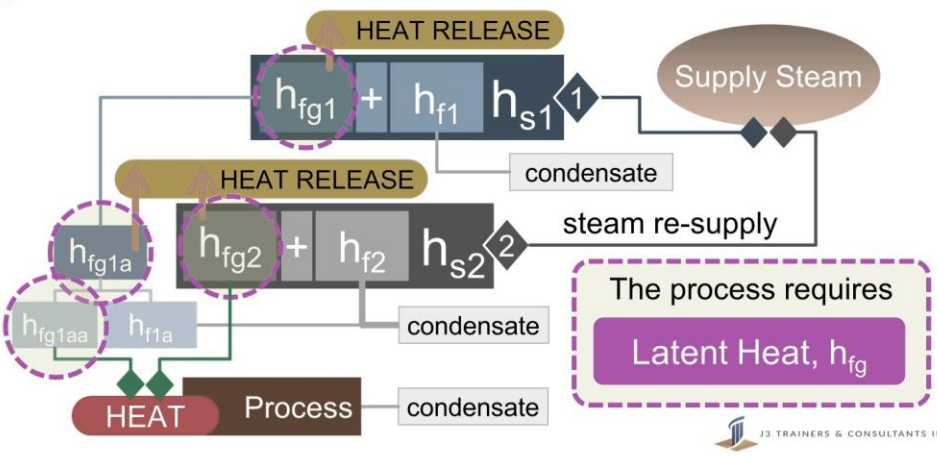
D. Introduction – Enthalpy and Heat Transfers



D. Introduction – Enthalpy Degeneration



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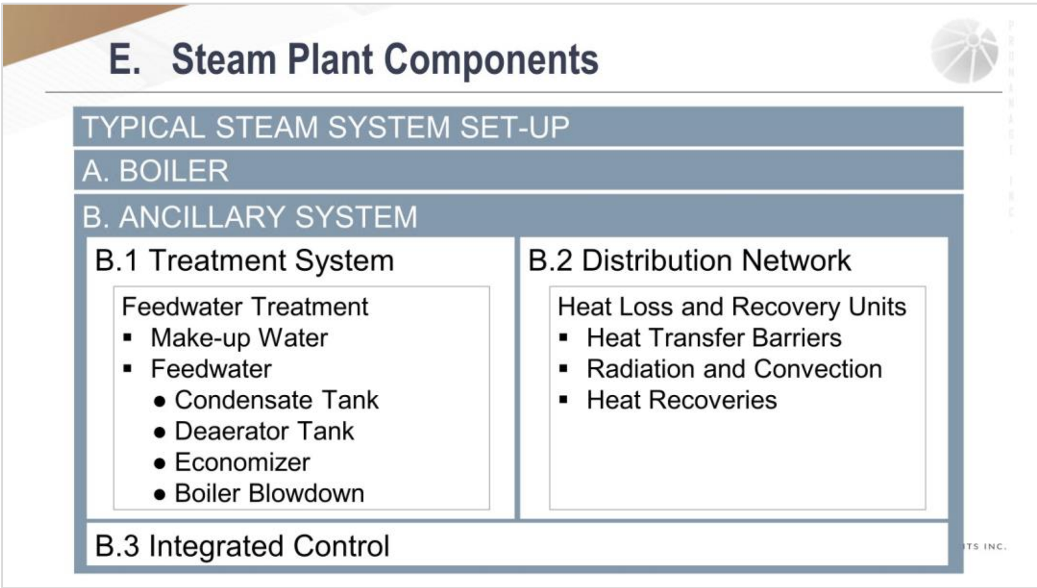
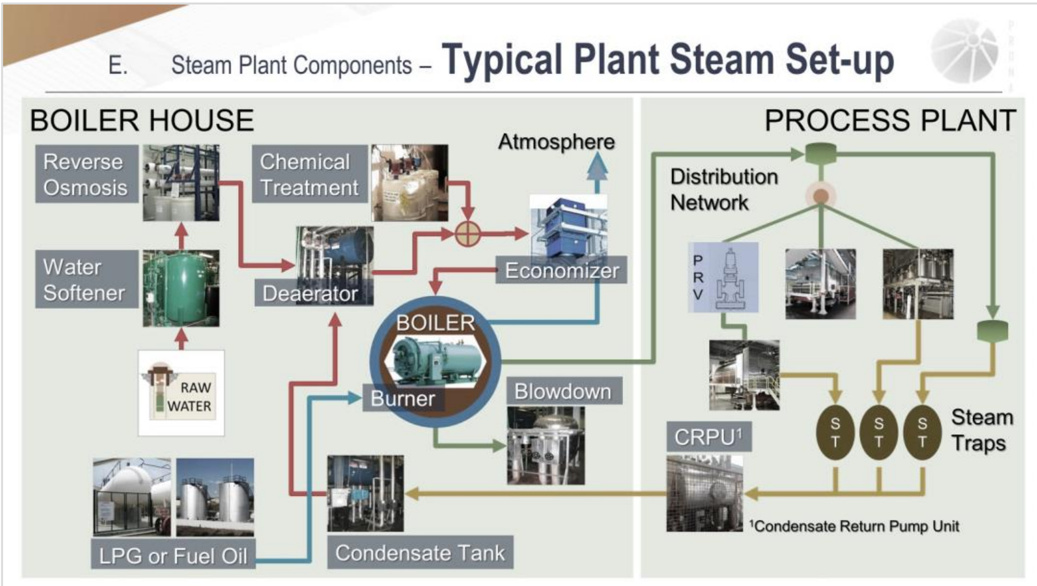
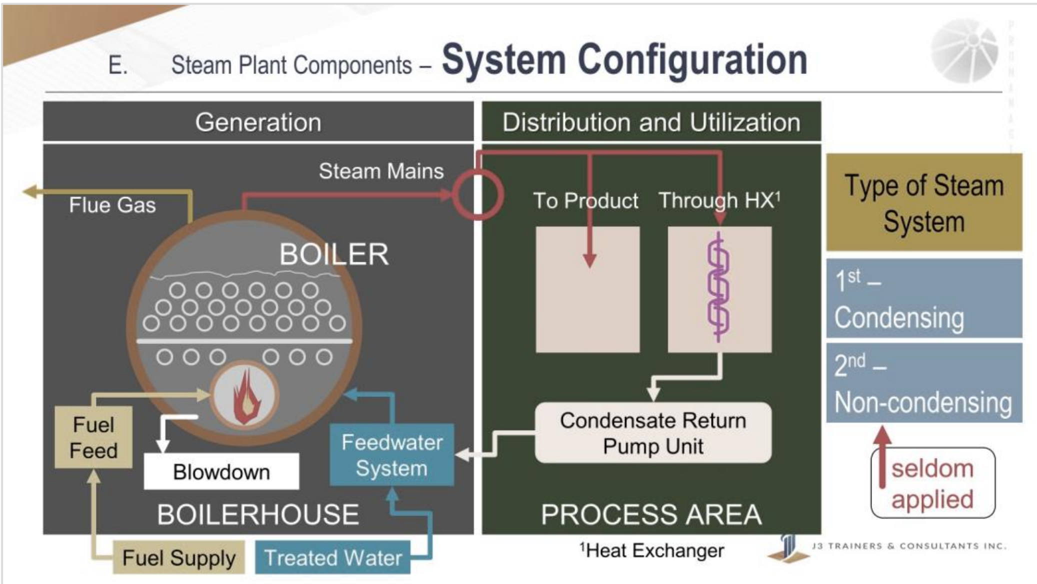

E. Steam Plant Components
TYPICAL STEAM SYSTEM SET-UP
A. BOILER
B. ANCILLARY SYSTEM
B.1 Treatment System
Feedwater Treatment
▪ Make-up Water
▪ Feedwater
● Condensate Tank
● Deaerator Tank
● Economizer
● Boiler Blowdown
B.2 Distribution Network
Heat Loss and Recovery Units
▪ Heat Transfer Barriers
▪ Radiation and Convection
▪ Heat Recoveries
B.3 Integrated Control


E. Steam Plant Components – Typical Plant Steam Set-up
BOILER HOUSE
Reverse Osmosis
Chemical Treatment
Atmosphere
Water Softener
Deaerator
Economizer
RAW WATER
BOILER
Burner
Blowdown
LPG or Fuel Oil
Condensate Tank
PROCESS PLANT
Distribution Network
P R V
CRPU1
S T
S T
S T
Steam Traps
1Condensate Return Pump Unit


E. Steam Plant Components – System Configuration
Generation
Distribution and Utilization
Steam Mains
Flue Gas
BOILER
Fuel Feed
Blowdown
Feedwater System
BOILERHOUSE
Fuel Supply
Treated Water
To Product
Through HX1
Condensate Return Pump Unit
PROCESS AREA
1Heat Exchanger
Type of Steam System
1st – Condensing
2nd – Non-condensing
seldom applied
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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

WT

Boiler images courtesy of © Cleaver Brooks

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

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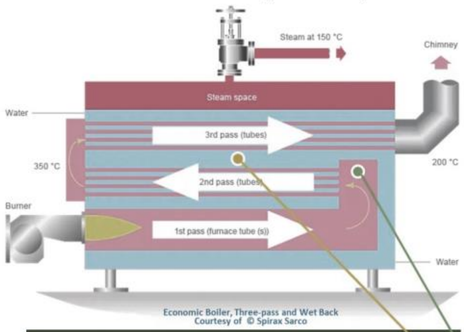
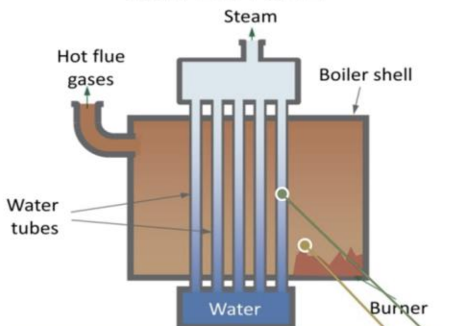
E. Steam Plant Components – A. Boiler

FIRE TUBE (or IFM)



- Fire inside the tubes
- Water flow outside the tubes

WATER TUBE



- Fire outside of tubes or coil
- Water flow inside the tubes or coil

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)

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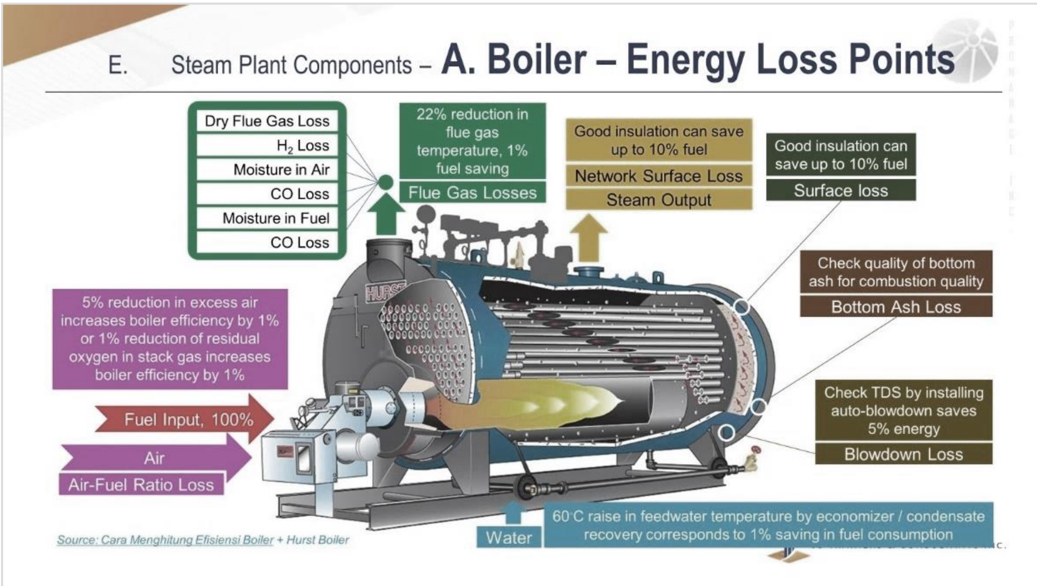
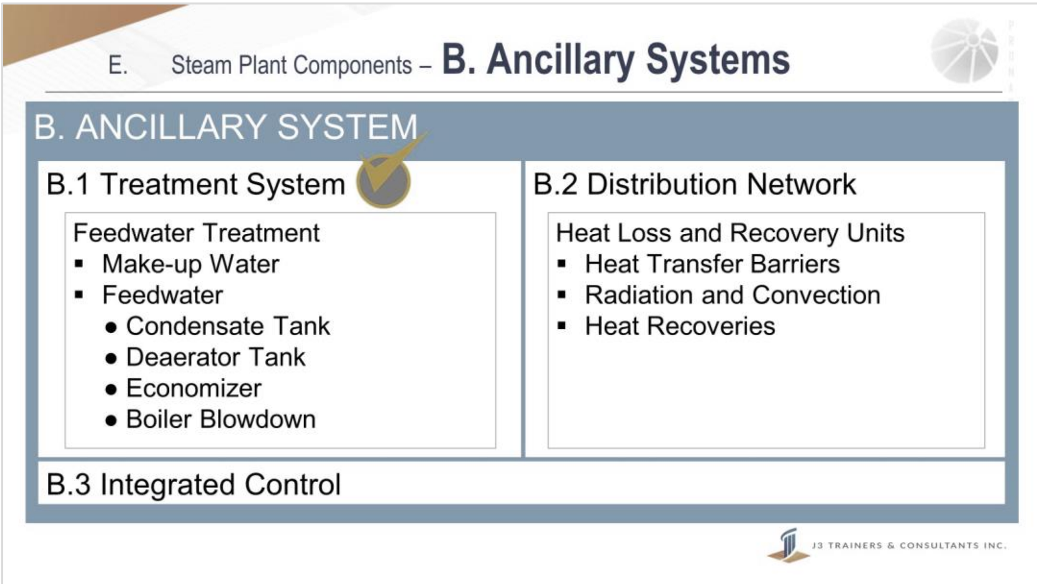

E. Steam Plant Components – A. Boiler – Energy Loss Points
Dry Flue Gas Loss
H2 Loss
Moisture in Air
CO Loss
Moisture in Fuel
CO Loss
22% reduction in flue gas temperature, 1% fuel saving
Flue Gas Losses
Good insulation can save up to 10% fuel
Network Surface Loss
Steam Output
Good insulation can save up to 10% fuel
Surface loss
Check quality of bottom ash for combustion quality
Bottom Ash Loss
5% reduction in excess air increases boiler efficiency by 1% or 1% reduction of residual oxygen in stack gas increases boiler efficiency by 1%
Fuel Input, 100%
Air
Air-Fuel Ratio Loss
Check TDS by installing auto-blowdown saves 5% energy
Blowdown Loss
Water
60°C raise in feedwater temperature by economizer / condensate recovery corresponds to 1% saving in fuel consumption
Source: Cara Menghitung Efisiensi Boiler + Hurst Boiler


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
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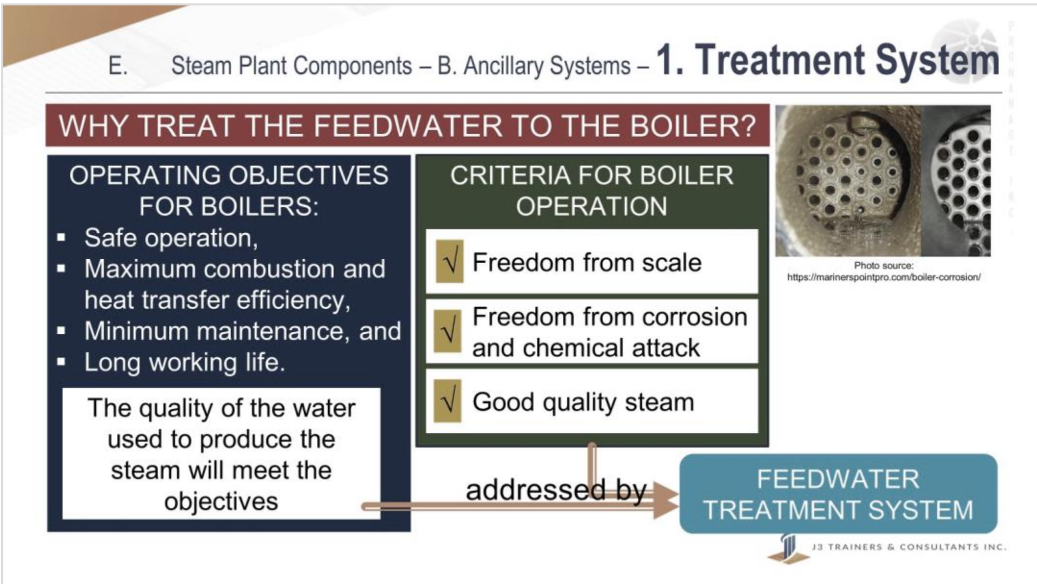
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
WHY TREAT THE FEEDWATER TO THE BOILER?
OPERATING OBJECTIVES FOR BOILERS:
▪ Safe operation,
▪ Maximum combustion and heat transfer efficiency,
▪ Minimum maintenance, and
▪ Long working life.
The quality of the water used to produce the steam will meet the objectives
CRITERIA FOR BOILER OPERATION
√ Freedom from scale
√ Freedom from corrosion and chemical attack
√ Good quality steam
addressed by
FEEDWATER TREATMENT SYSTEM
Photo source: https://marinerspointpro.com/boiler-corrosion/
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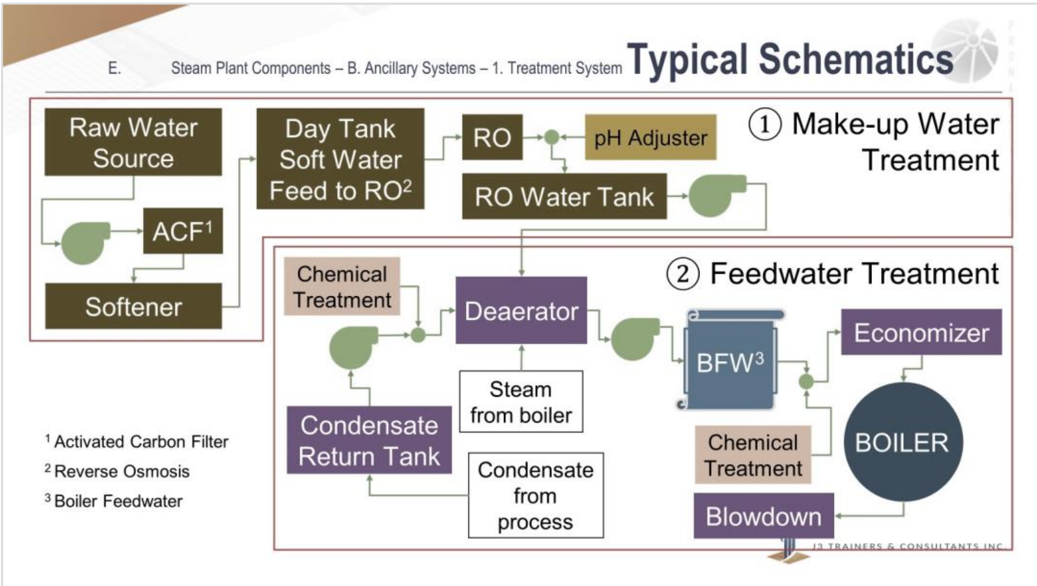
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
Typical Schematics
Raw Water Source
Day Tank Soft Water Feed to RO²
RO
pH Adjuster
① Make-up Water Treatment
RO Water Tank
ACF¹
Softener
② Feedwater Treatment
Chemical Treatment
Deaerator
Economizer
BFW³
Steam from boiler
Condensate Return Tank
Chemical Treatment
BOILER
Condensate from process
Blowdown
¹ Activated Carbon Filter
² Reverse Osmosis
³ Boiler Feedwater
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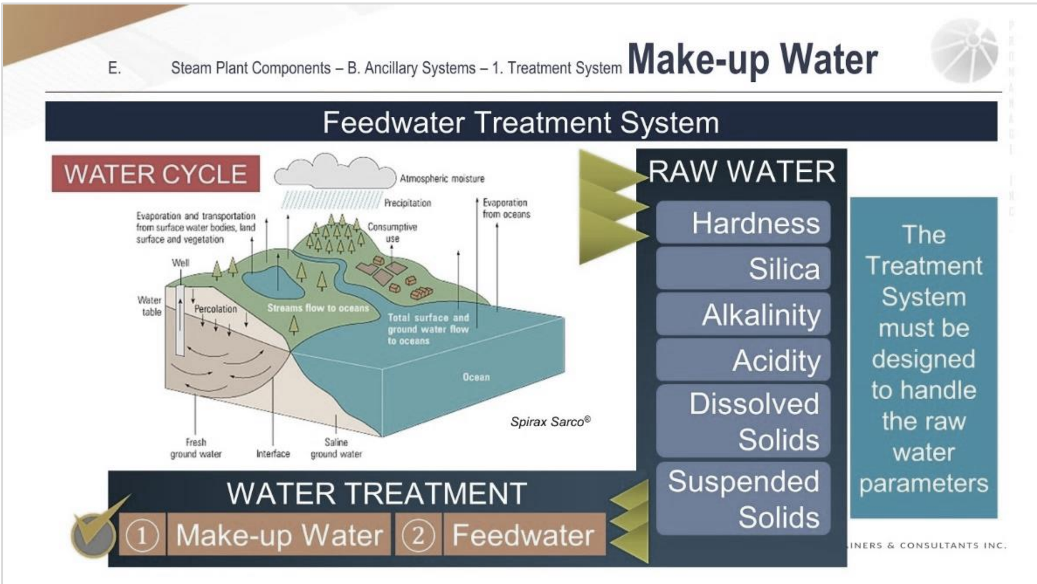
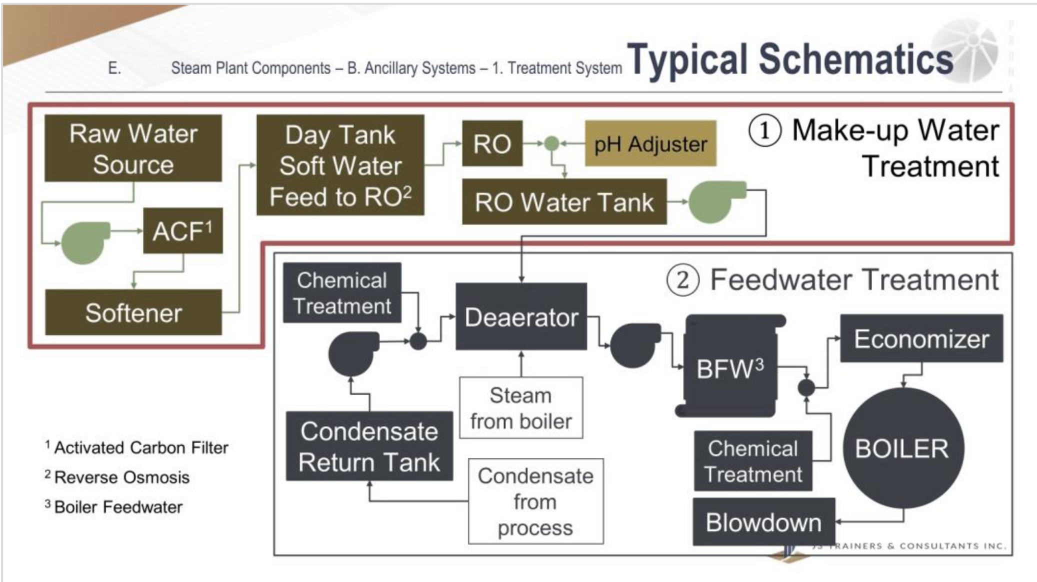

E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
Make-up Water
Feedwater Treatment System
WATER CYCLE
Atmospheric moisture
Precipitation
Evaporation from oceans
Evaporation and transportation from surface water bodies, land surface and vegetation
Consumptive use
Well
Water table
Percolation
Streams flow to oceans
Total surface and ground water flow to oceans
Ocean
Fresh ground water
Interface
Saline ground water
Spirax Sarco©
RAW WATER
Hardness
Silica
Alkalinity
Acidity
Dissolved Solids
Suspended Solids
The Treatment System must be designed to handle the raw water parameters
WATER TREATMENT
① Make-up Water
② Feedwater


E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
Typical Schematics
Raw Water Source
Day Tank Soft Water Feed to RO²
RO
pH Adjuster
① Make-up Water Treatment
RO Water Tank
ACF¹
Softener
② Feedwater Treatment
Chemical Treatment
Deaerator
Economizer
BFW³
Steam from boiler
Condensate Return Tank
Chemical Treatment
BOILER
Condensate from process
Blowdown
¹ Activated Carbon Filter
² Reverse Osmosis
³ Boiler Feedwater
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E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System

① Make-up Water

PARAMETER	QUALITY
pH	6.5 - 8.5
TH (Total Hardness)	<10ppm
TDS (Total Dissolved Solids)	<50ppm
Silica	<15ppm
T-Alkalinity	<40ppm

② Feedwater

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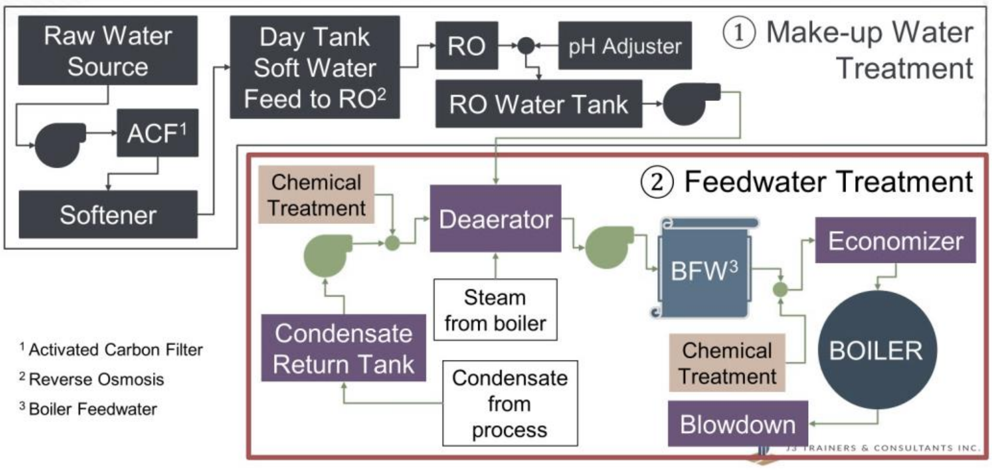
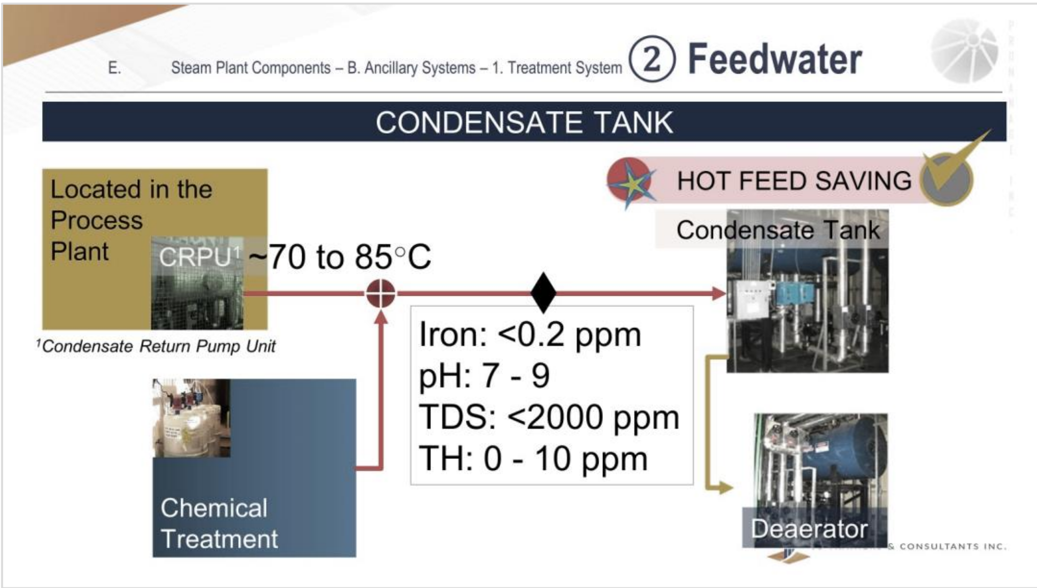
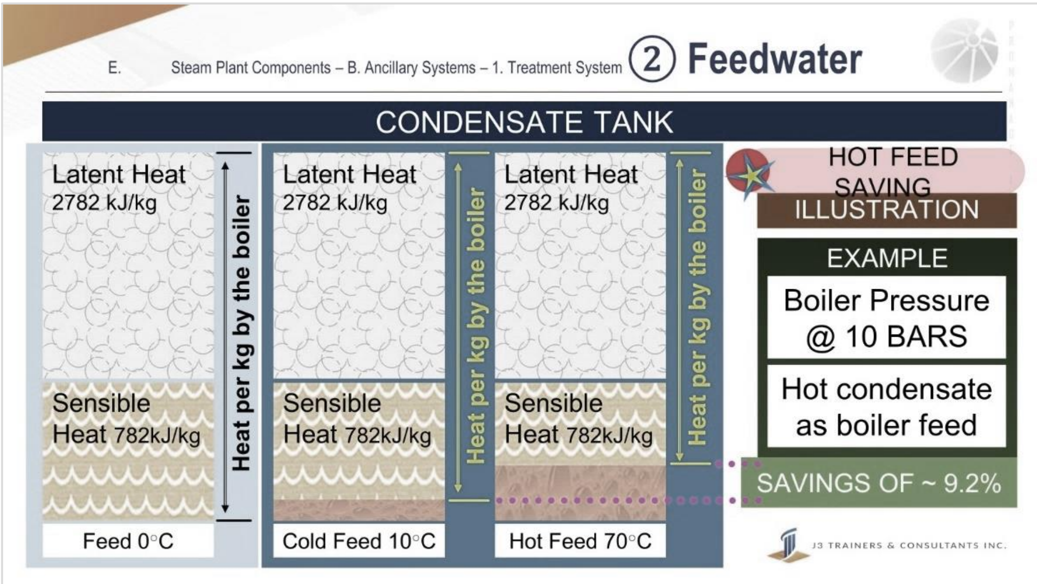
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System

Typical Schematics




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


E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
2 Feedwater
CONDENSATE TANK
Latent Heat 2782 kJ/kg
Sensible Heat 782kJ/kg
Heat per kg by the boiler
Feed 0°C
Latent Heat 2782 kJ/kg
Sensible Heat 782kJ/kg
Heat per kg by the boiler
Cold Feed 10°C
Latent Heat 2782 kJ/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%
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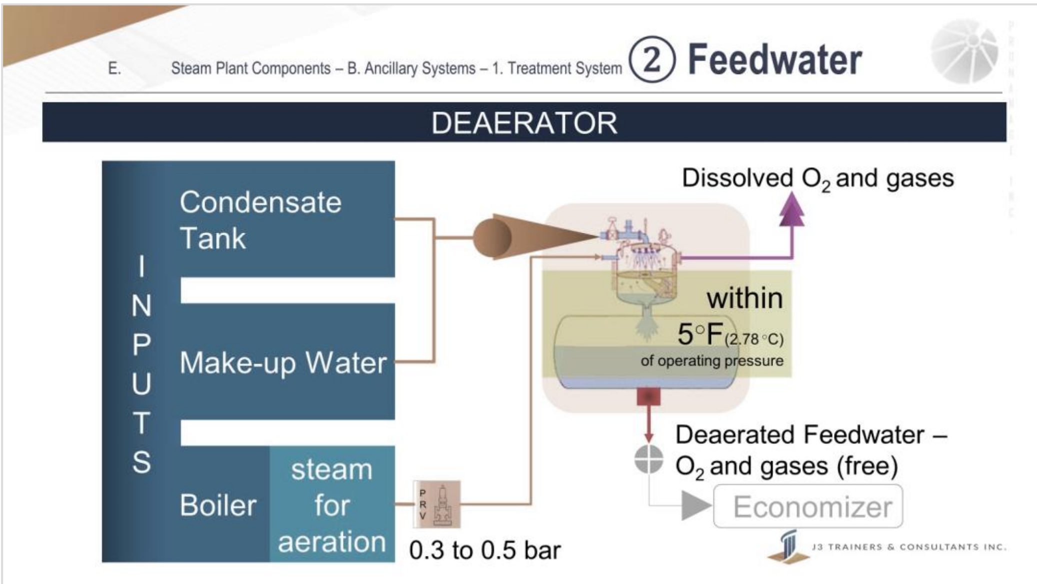
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
2 Feedwater
DEAERATOR
INPUTS
Condensate Tank
Make-up Water
Boiler
steam for aeration
PRV
0.3 to 0.5 bar
Dissolved O_2 and gases
within 5°F (2.78°C) of operating pressure
Deaerated Feedwater – O_2 and gases (free)
Economizer
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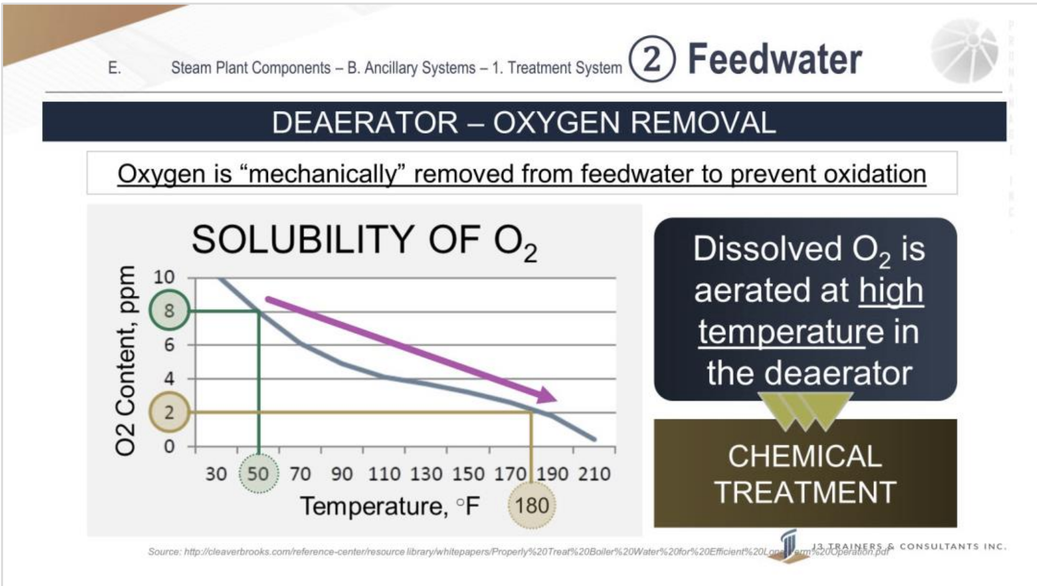
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
2 Feedwater
DEAERATOR – OXYGEN REMOVAL
Oxygen is "mechanically" removed from feedwater to prevent oxidation
SOLUBILITY OF O_2
O2 Content, ppm
10
8
6
4
2
0
30 50 70 90 110 130 150 170 190 210
Temperature, °F
180
Dissolved O_2 is aerated at high temperature in the deaerator
CHEMICAL TREATMENT
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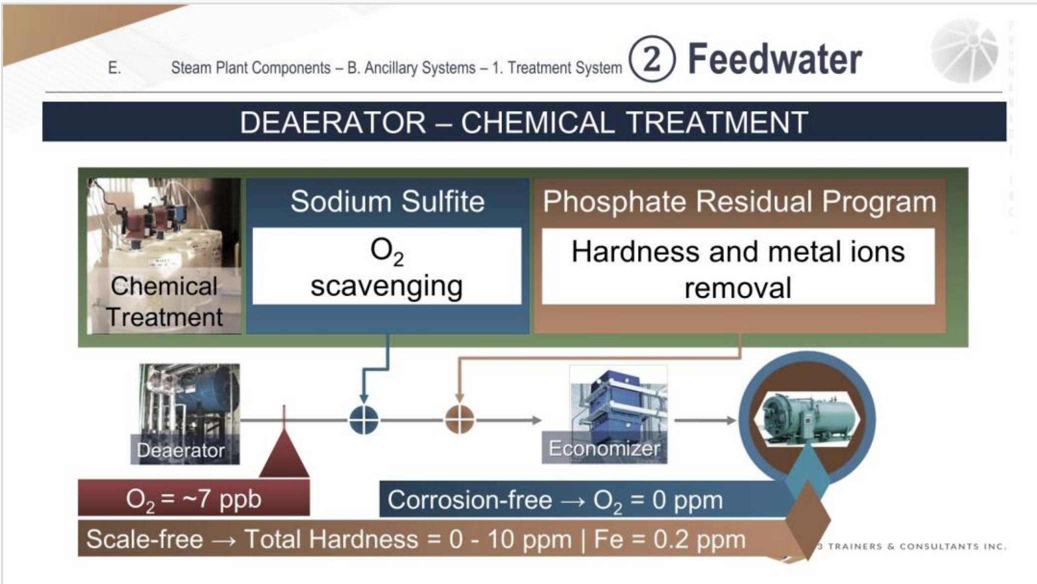
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
2 Feedwater
DEAERATOR – CHEMICAL TREATMENT
Chemical Treatment
Sodium Sulfite
O_2 scavenging
Phosphate Residual Program
Hardness and metal ions removal
Deaerator
Economizer
O_2 = ~7 ppb
Corrosion-free → O_2 = 0 ppm
Scale-free → Total Hardness = 0 - 10 ppm | Fe = 0.2 ppm
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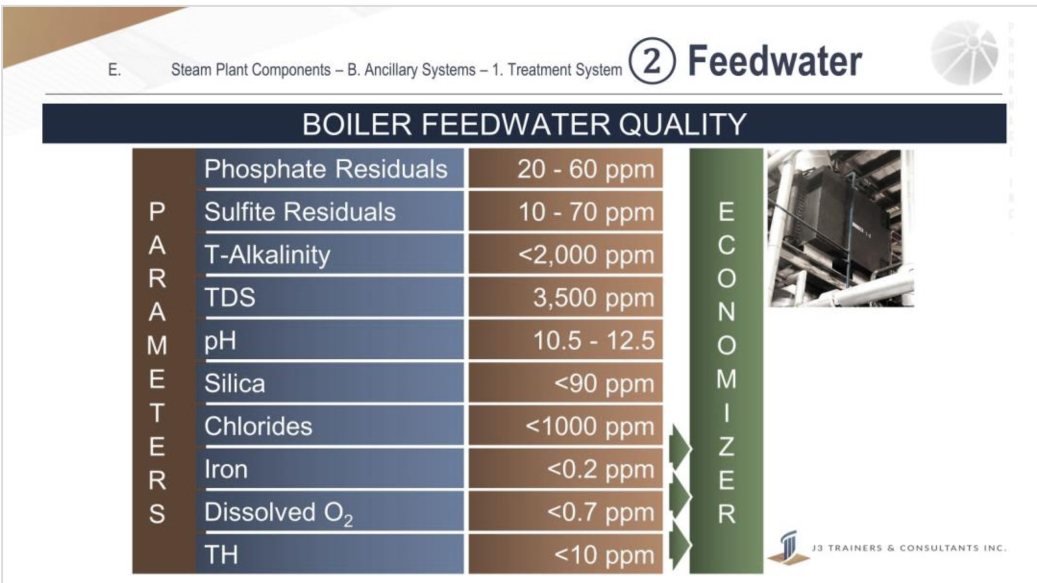
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
2 Feedwater
BOILER FEEDWATER QUALITY
PARAMETERS
Phosphate Residuals 20 - 60 ppm
Sulfite Residuals 10 - 70 ppm
T-Alkalinity <2,000 ppm
TDS 3,500 ppm
pH 10.5 - 12.5
Silica <90 ppm
Chlorides <1000 ppm
Iron <0.2 ppm
Dissolved O_2 <0.7 ppm
TH <10 ppm
ECONOMIZER
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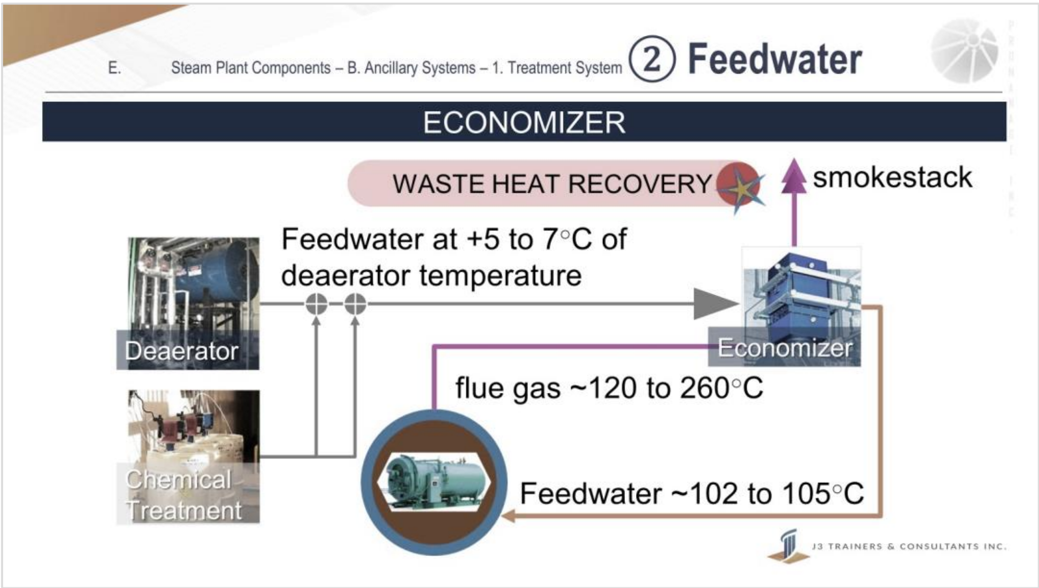
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
2 Feedwater
ECONOMIZER
WASTE HEAT RECOVERY
smokestack
Feedwater at +5 to 7°C of deaerator temperature
Deaerator
Economizer
Chemical Treatment
flue gas ~120 to 260°C
Feedwater ~102 to 105°C
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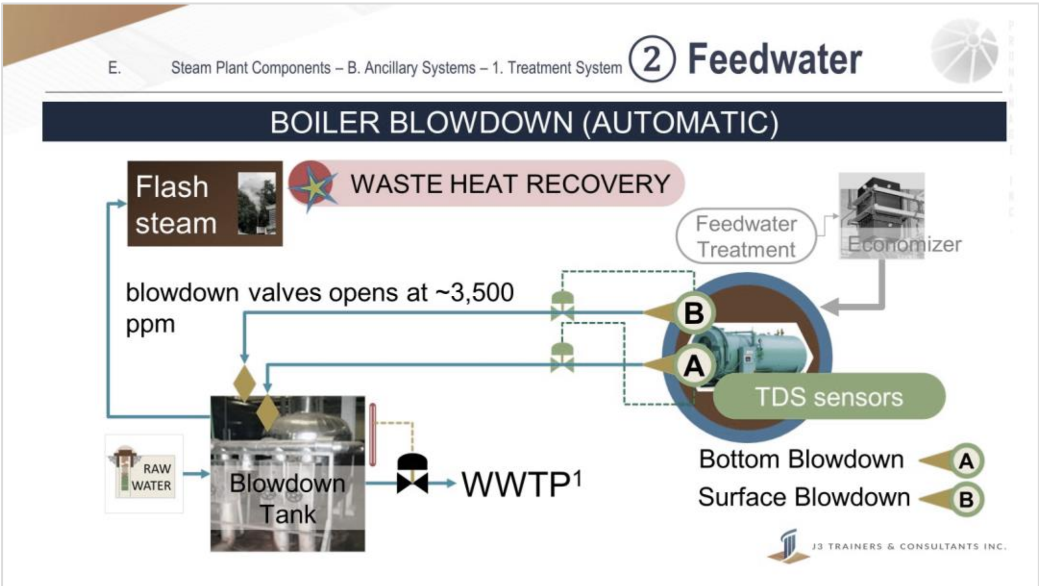
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
2 Feedwater
BOILER BLOWDOWN (AUTOMATIC)
Flash steam
WASTE HEAT RECOVERY
Feedwater Treatment
Economizer
blowdown valves opens at ~3,500 ppm
B
A
TDS sensors
RAW WATER
Blowdown Tank
WWTP1
Bottom Blowdown A
Surface Blowdown B
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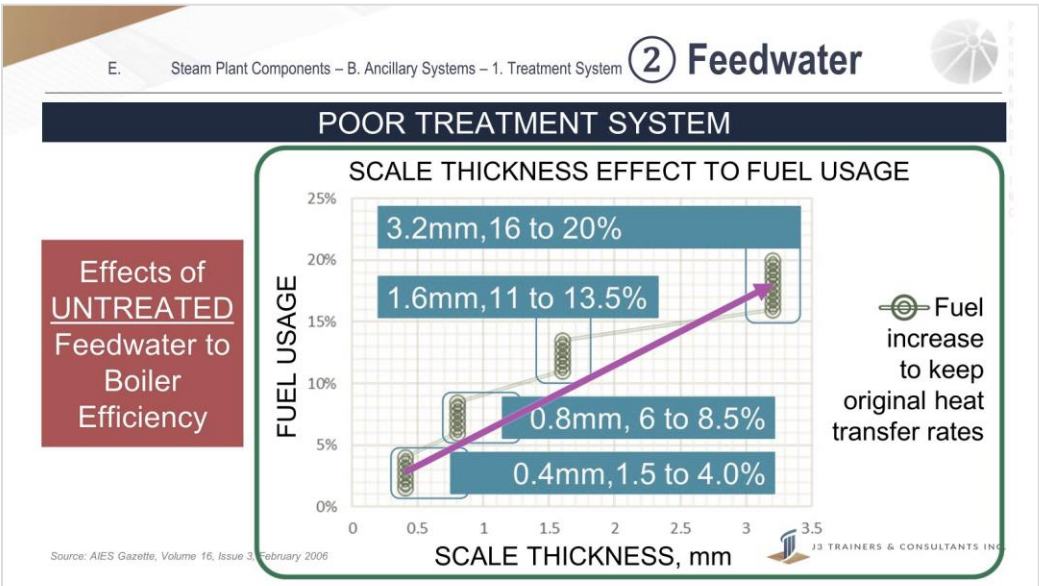
E. Steam Plant Components – B. Ancillary Systems – 1. Treatment System
2 Feedwater
POOR TREATMENT SYSTEM
Effects of UNTREATED Feedwater to Boiler Efficiency
SCALE THICKNESS EFFECT TO FUEL USAGE
FUEL USAGE
0%
5%
10%
15%
20%
25%
3.2mm,16 to 20%
1.6mm,11 to 13.5%
0.8mm, 6 to 8.5%
0.4mm,1.5 to 4.0%
0
0.5
1
1.5
2
2.5
3
3.5
SCALE THICKNESS, mm
Fuel increase to keep original heat transfer rates
Source: AIES Gazette, Volume 16, Issue 3, February 2006
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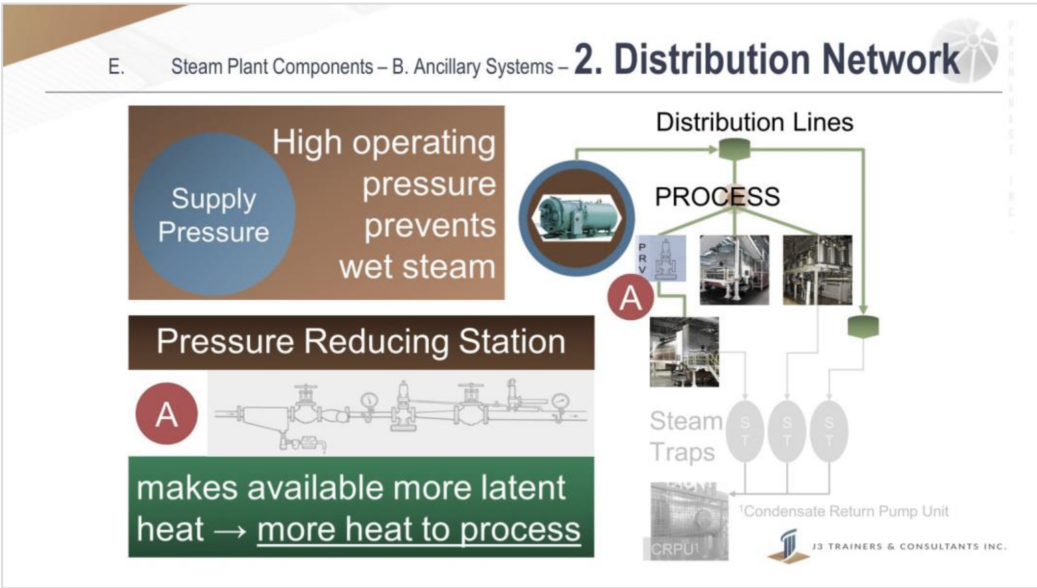

E. Steam Plant Components – B. Ancillary Systems – **2. Distribution Network**

PRESSURE SETTING	Best way of conveying large mass of heat at required pressure

EXAMPLE:

Process Temperature				
	Low Limit	143 °C	~0.39 MPa	= 3.9 bars
	High Limit	149 °C	~0.46 MPa	= 4.6 bars

Pressure Ranges

Steam supply pressure can be set at 4 to 5 bars

Note
Pressure losses and steam demand to be factored in the setting

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

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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

PRESSURE REDUCTION (BENEFITS)

Press. MPa	Enthalpy Sat. Vapor, h_g
0.313	2727.3
0.361	2733.9
% Change	% Change
0.361 - 0.313	2734 - 2727
0.313	2727.3
15.43%	0.2419%

heat optimization from pressure reduction

1 bar steam pressure reduction

0.5% reduction in heat required

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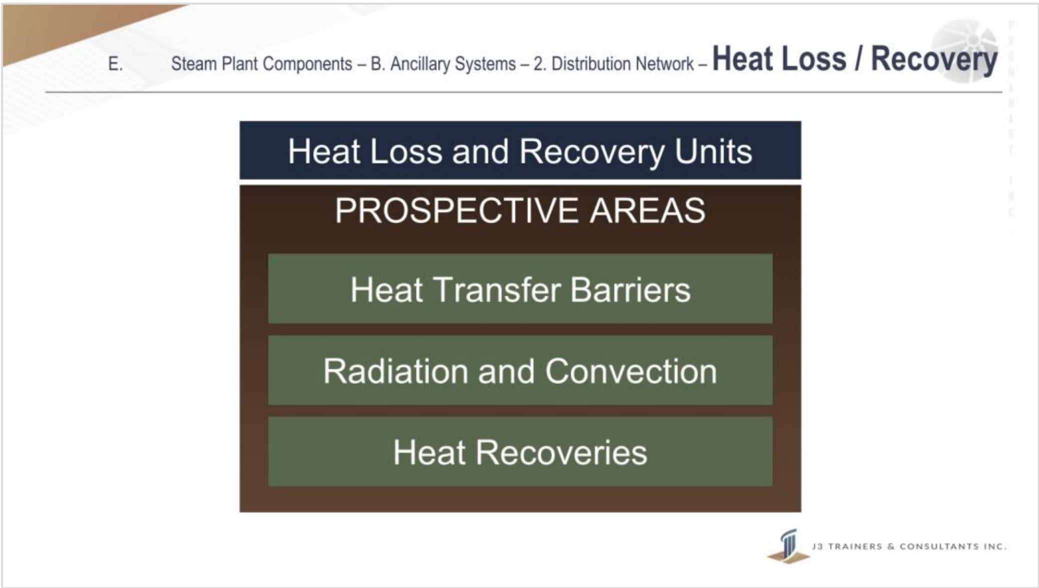
E. Steam Plant Components – B. Ancillary Systems – 2. Distribution Network – Heat Loss / Recovery
Heat Loss and Recovery Units
PROSPECTIVE AREAS
Heat Transfer Barriers
Radiation and Convection
Heat Recoveries
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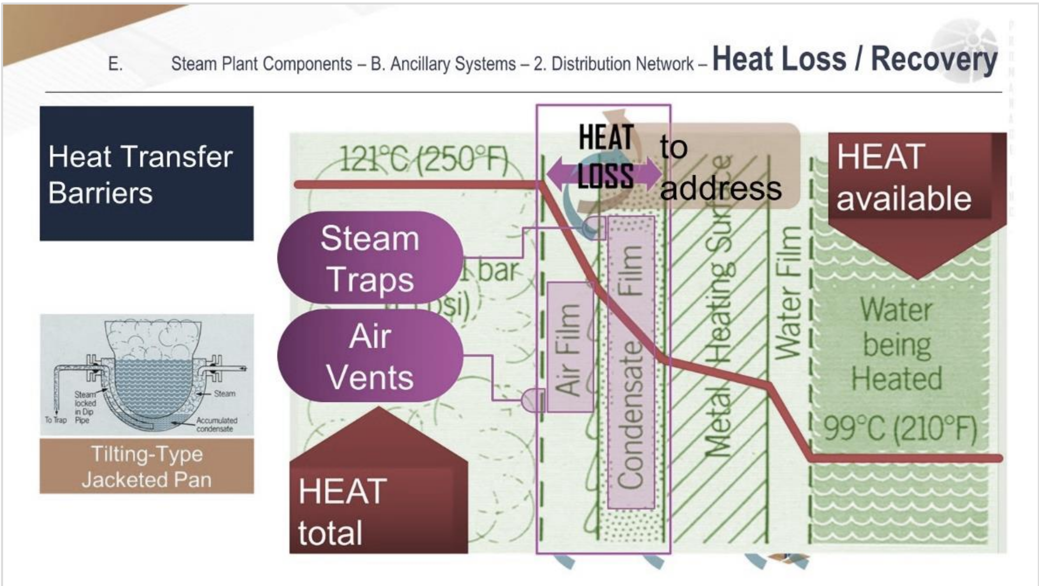
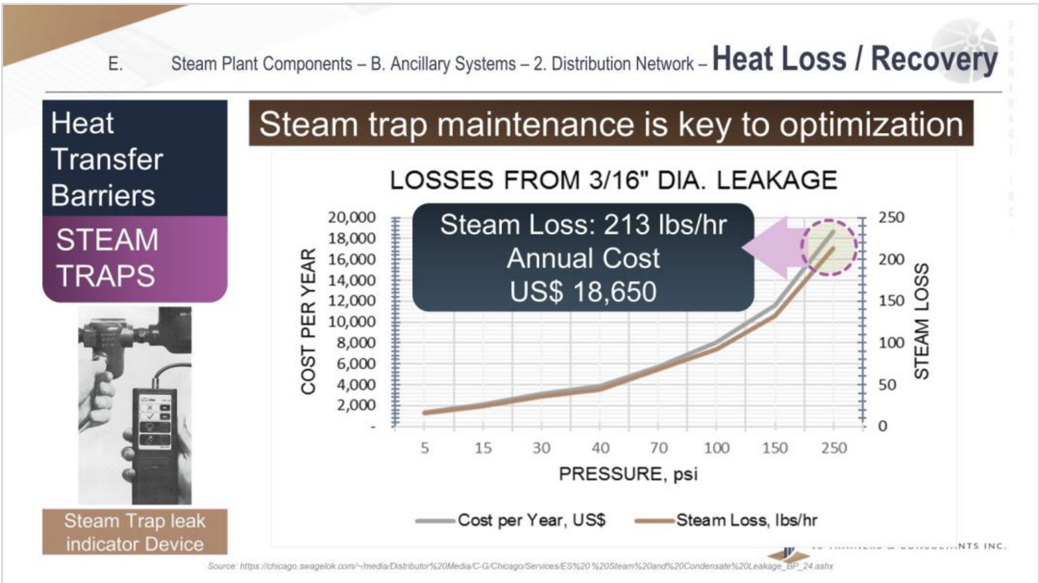
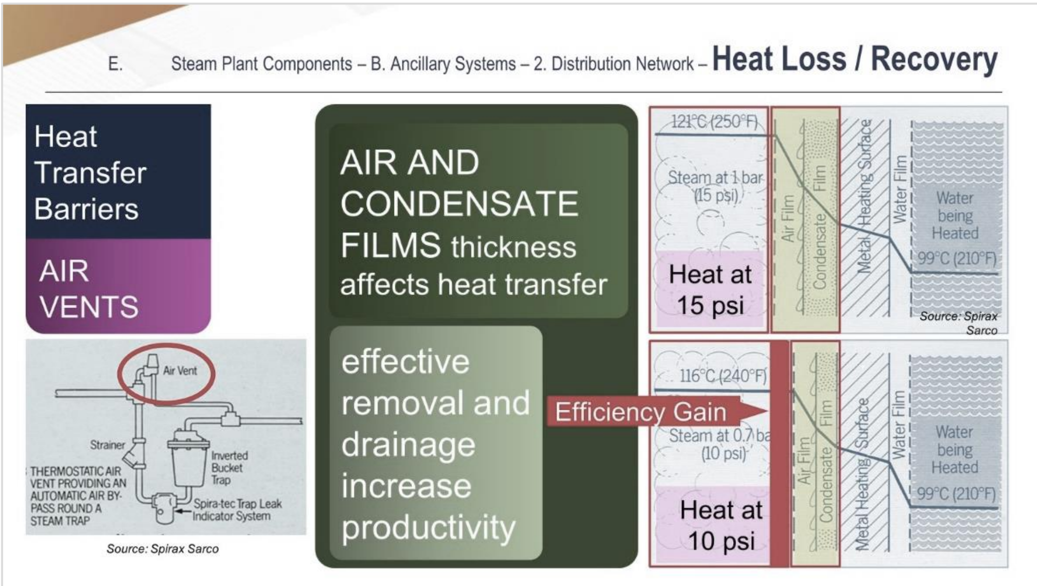
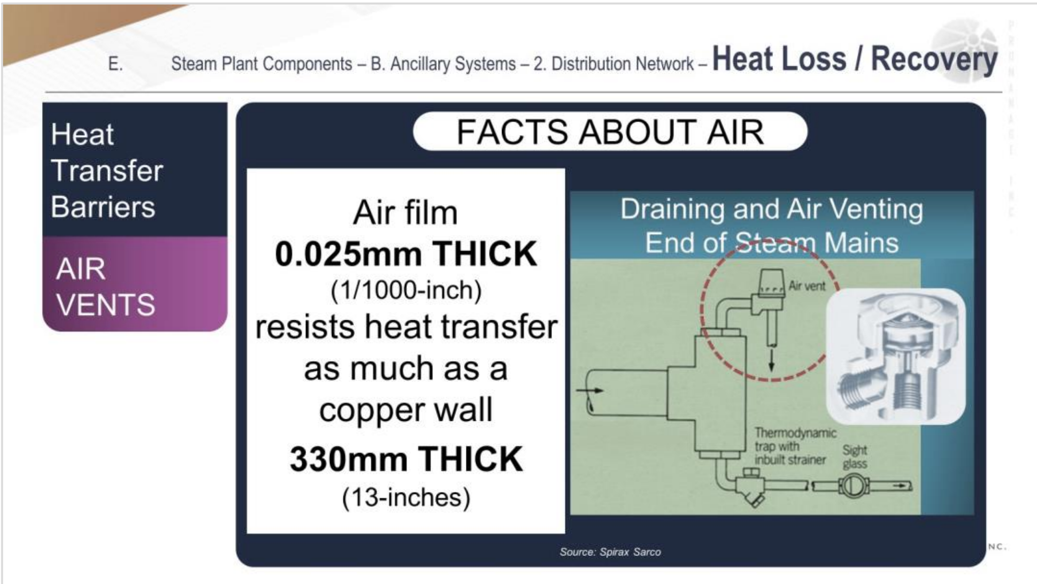
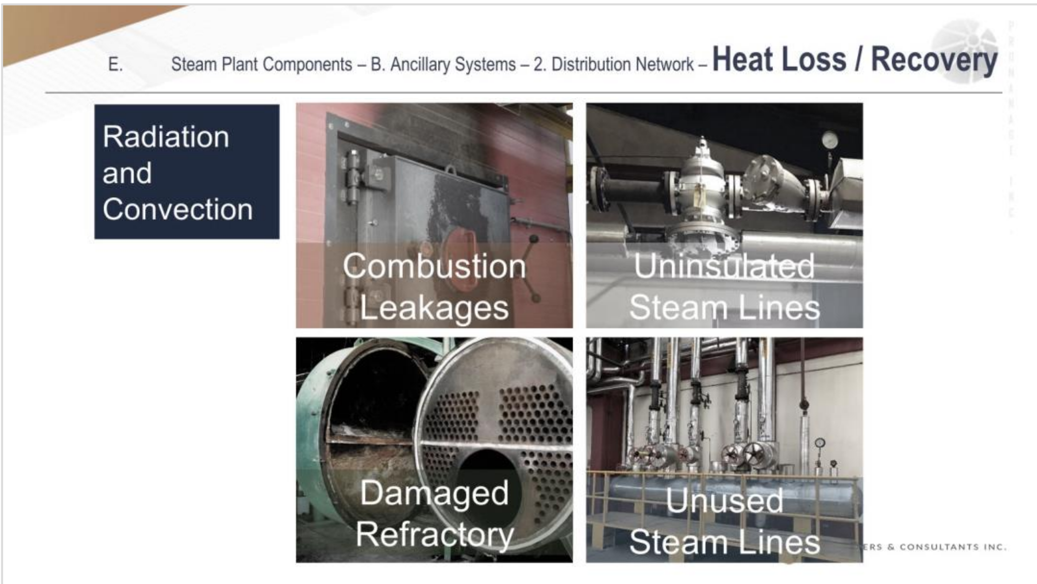
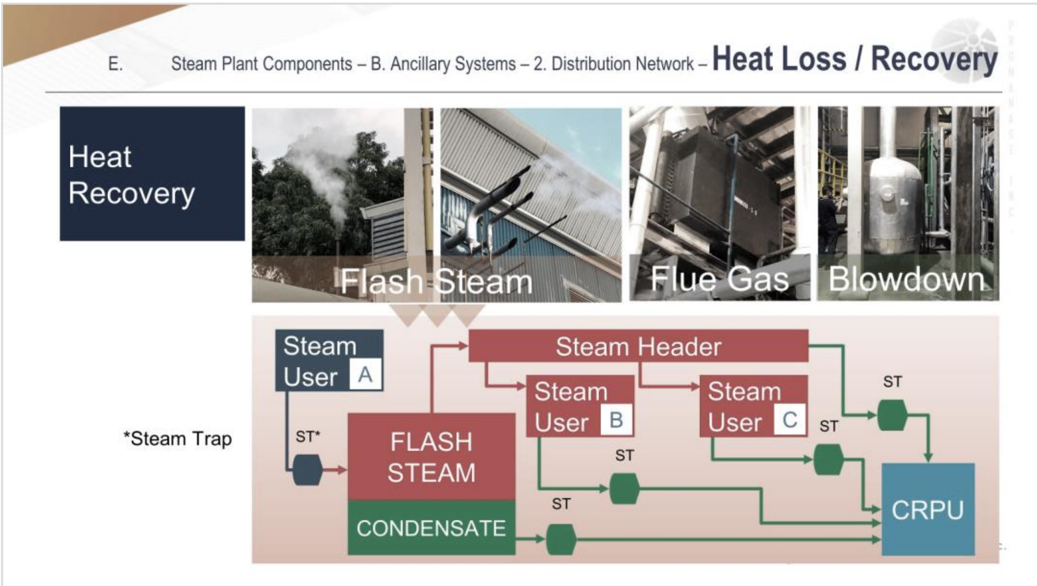

E. Steam Plant Components – B. Ancillary Systems – 2. Distribution Network – Heat Loss / Recovery
Heat Transfer Barriers
Tilting-Type Jacketed Pan
121°C (250°F)
HEAT LOSS to address
HEAT available
Steam Traps
Air Vents
Air Film
Condensate Film
Metal Heating Surface
Water Film
Water being Heated
99°C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

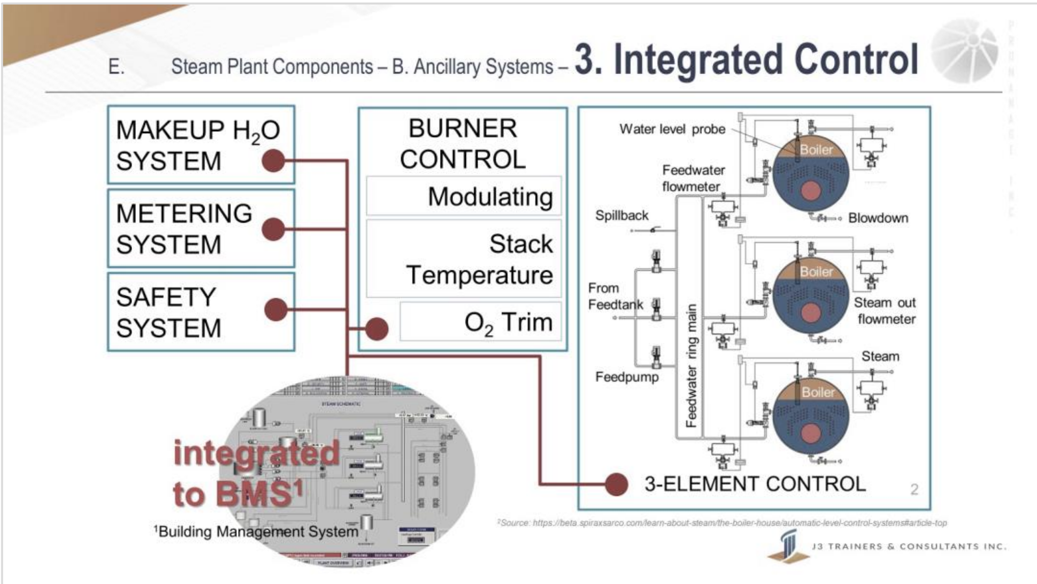

E. Steam Plant Components – B. Ancillary Systems – 2. Distribution Network – Heat Loss / Recovery
Heat Transfer Barriers
STEAM TRAPS
Steam trap maintenance is key to optimization
LOSSES FROM 3/16" DIA. LEAKAGE
Steam Loss: 213 lbs/hr
Annual Cost
US$ 18,650
COST PER YEAR
STEAM LOSS
PRESSURE, psi
Cost per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


E. Steam Plant Components – B. Ancillary Systems – 2. Distribution Network – Heat Loss / Recovery
Heat Transfer Barriers
AIR VENTS
Air Vent
Strainer
Inverted Bucket Trap
THERMOSTATIC AIR VENT PROVIDING AN AUTOMATIC AIR BY-PASS ROUND A STEAM TRAP
Spira-tec Trap Leak Indicator System
Source: Spirax Sarco
AIR AND CONDENSATE FILMS thickness affects heat transfer
effective removal and drainage increase productivity
Efficiency Gain
121°C (250°F)
Steam at 1 bar (15 psi)
Heat at 15 psi
Air Film
Condensate Film
Metal Heating Surface
Water Film
Water being Heated
99°C (210°F)
Source: Spirax Sarco
116°C (240°F)
Steam at 0.7 bar (10 psi)
Heat at 10 psi


E. Steam Plant Components – B. Ancillary Systems – 2. Distribution Network – Heat Loss / Recovery
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
Thermodynamic trap with inbuilt strainer
Sight glass
Source: Spirax Sarco


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


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


E. Steam Plant Components – B. Ancillary Systems – 3. Integrated Control
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
Feedwater ring main
Boiler
Blowdown
Steam out flowmeter
Steam
3-ELEMENT CONTROL
integrated to BMS[1]
[1]Building Management System
[2]Source: https://beta.spiraxsarco.com/learn-about-steam/the-boiler-house/automatic-level-control-systems#article-top
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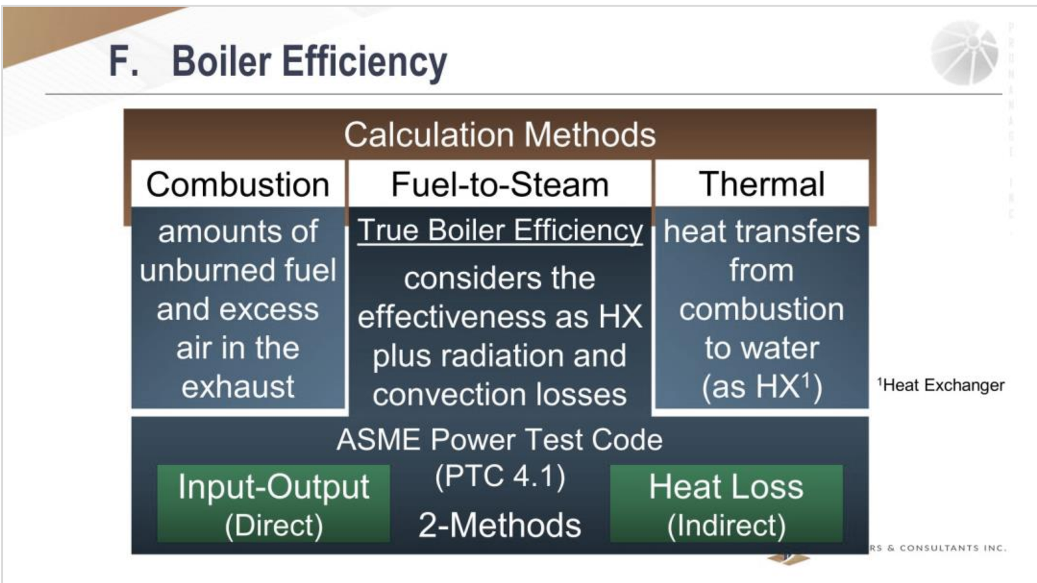
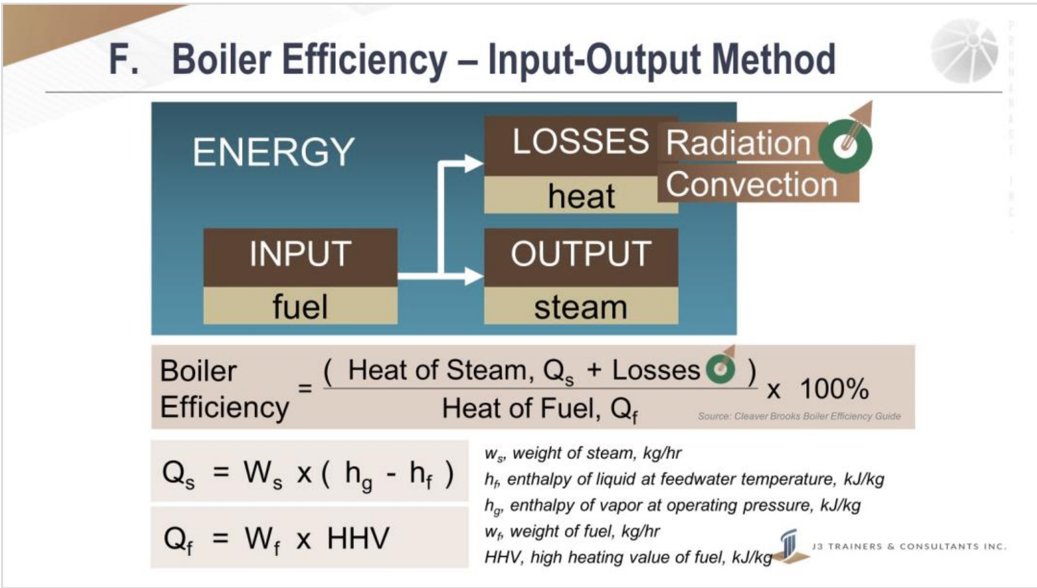
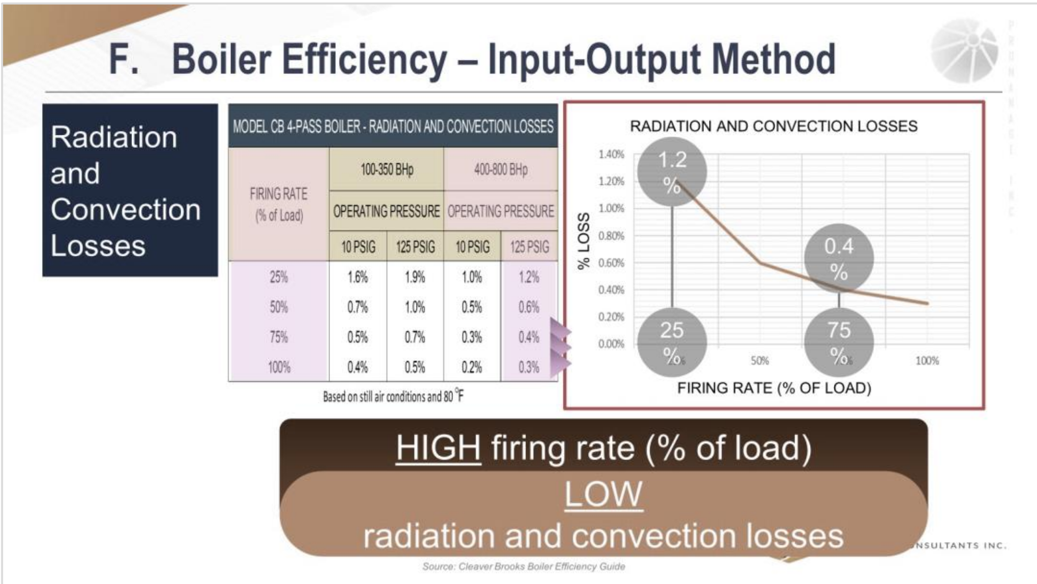
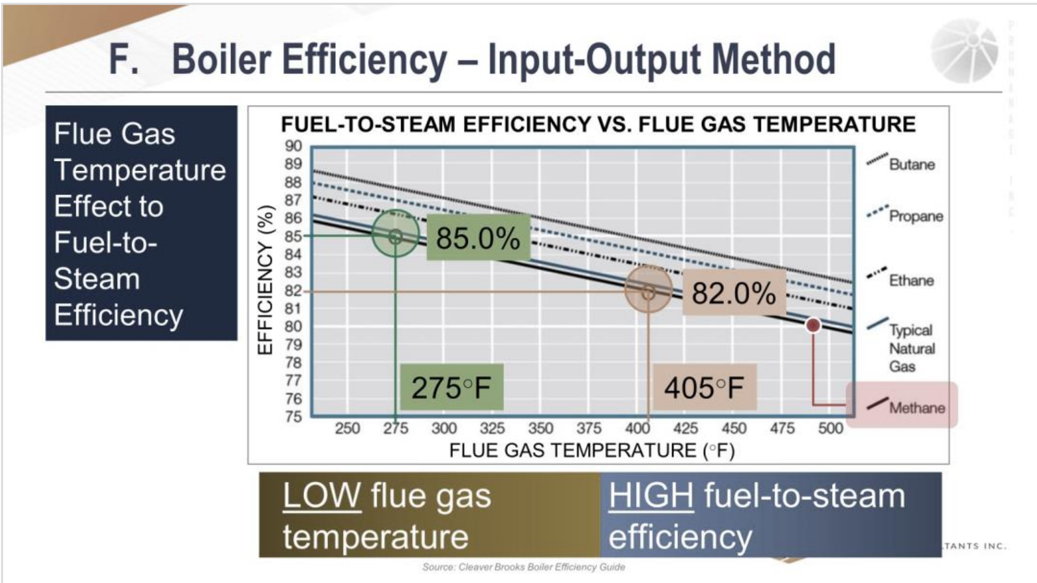
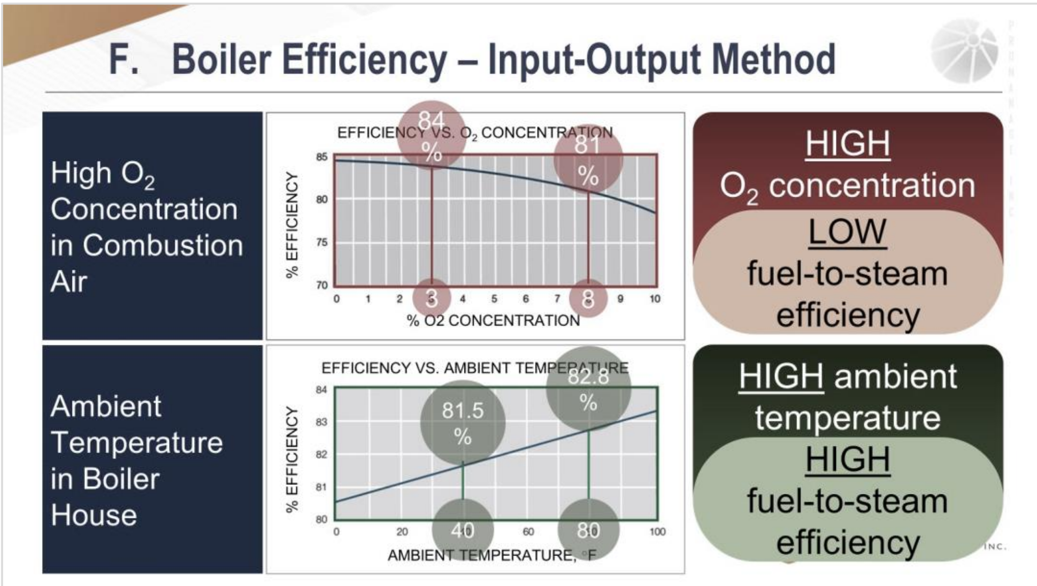

F. Boiler Efficiency
Calculation Methods
Combustion
amounts of unburned fuel and excess air in the exhaust
Fuel-to-Steam
True Boiler Efficiency considers the effectiveness as HX plus radiation and convection losses
Thermal
heat transfers from combustion to water (as HX[1])
[1]Heat Exchanger
ASME Power Test Code (PTC 4.1) 2-Methods
Input-Output (Direct)
Heat Loss (Indirect)

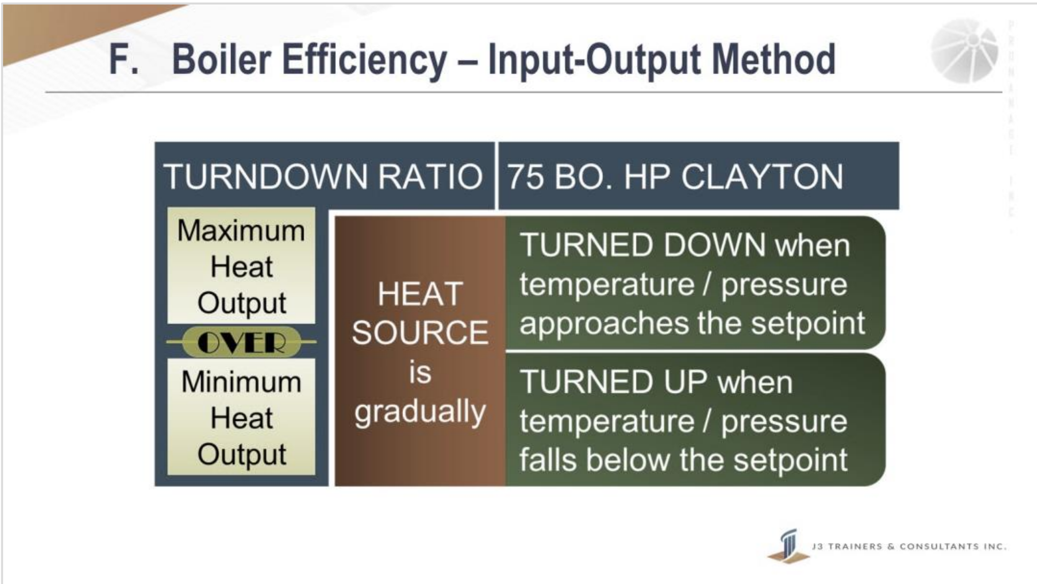




FIRING RATE (% of Load)	100-350 BHp		400-800 BHp	
	OPERATING PRESSURE		OPERATING PRESSURE	
	10 PSIG	125 PSIG	10 PSIG	125 PSIG
25%	1.6%	1.9%	1.0%	1.2%
50%	0.7%	1.0%	0.5%	0.6%
75%	0.5%	0.7%	0.3%	0.4%
100%	0.4%	0.5%	0.2%	0.3%




F. Boiler Efficiency – Input-Output Method
High O2 Concentration in Combustion Air
EFFICIENCY VS. O2 CONCENTRATION
% EFFICIENCY
% O2 CONCENTRATION
84 %
81 %
3
8
HIGH O2 concentration
LOW fuel-to-steam efficiency
Ambient Temperature in Boiler House
EFFICIENCY VS. AMBIENT TEMPERATURE
% EFFICIENCY
AMBIENT TEMPERATURE, °F
81.5 %
82.8 %
40
80
HIGH ambient temperature
HIGH fuel-to-steam efficiency


F. Boiler Efficiency – Input-Output Method
TURNDOWN RATIO
75 BO. HP CLAYTON
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
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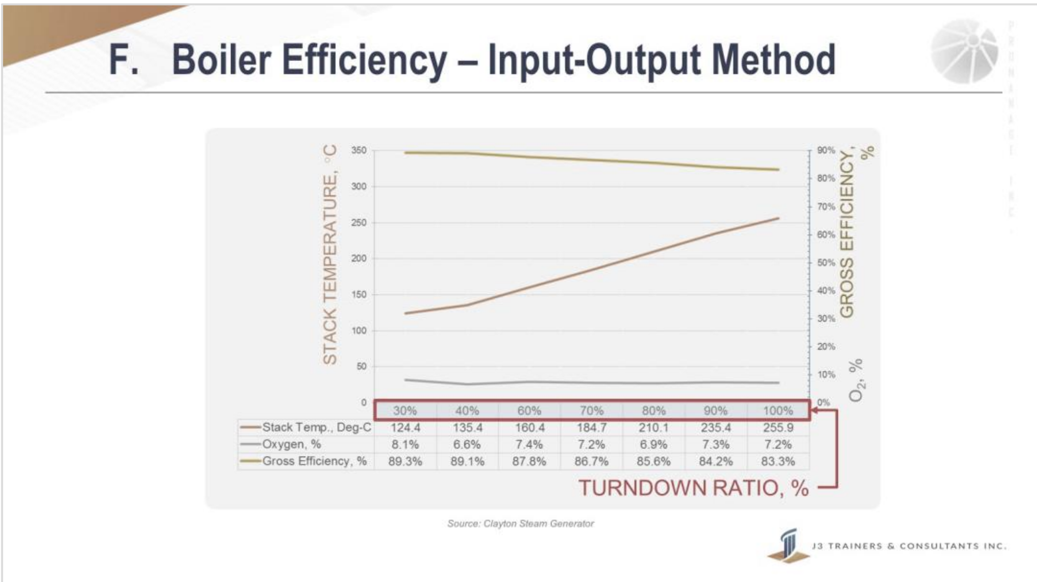
F. Boiler Efficiency – Input-Output Method
STACK TEMPERATURE, °C
GROSS EFFICIENCY, %
O2, %
30% 40% 60% 70% 80% 90% 100%
Stack Temp., Deg-C 124.4 135.4 160.4 184.7 210.1 235.4 255.9
Oxygen, % 8.1% 6.6% 7.4% 7.2% 6.9% 7.3% 7.2%
Gross Efficiency, % 89.3% 89.1% 87.8% 86.7% 85.6% 84.2% 83.3%
TURNDOWN RATIO, %
Source: Clayton Steam Generator
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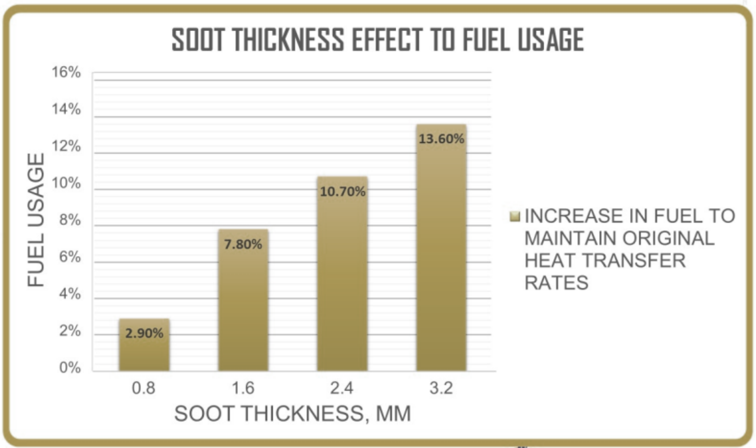
F. Boiler Efficiency – Input-Output Method

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

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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 (% Oxygen control / Excess air provision)
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
11. Fuel conditioning re: coal or biomass, etc.

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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 x c x ΔT

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

Q = 930.44 KW

► Solve for Q_{latent} before having economizer

Q_{latent} = m x 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

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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
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- 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 x C x ΔT

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

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:

$Q = m \times L_{v\ @100°C}$

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

Q = 3134.733 KW

PROBLEMS

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

► Solve for Total Q **before** having economizer:

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

Q =930.44 KW + 3134.73 KW

Q = 4065.17 KW

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:

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

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

Q = 698.39 KW

Initial feedwater temperature with economizer = 60°C

10 bar (saturated steam temperature ≈ 180°C)

PROBLEMS

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

► Solve for Total Q **after** having economizer:

Q_{latent} BEFORE = Q_{latent} AFTER

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

► Solve for Total KW Savings **after** having economizer:

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

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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

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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

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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

6. What is the purpose of the water treatment in the boiler?
   a. To produce good quality steam
   b. To ensure efficient combustion of fuel
   c. To prevent corrosion and scaling
   d. To increase cycle of concentration

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KNOWLEDGE REVIEW Solve the problem.

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.

Use the formula: Q = m x h_{fg}

$$Q = \left(1.2\,\frac{kg}{s}\right) x \left(1,800\,\frac{kJ}{kg}\right)$$

Q = 2,160 kw

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KNOWLEDGE REVIEW Solve the problem.

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.

Use the formula: Q = m x ($h_g - h_f$)

$$Q = \left(2000\,\frac{kg}{hr}\right) x \left(3,080\,\frac{kJ}{kg} - 504\,\frac{kJ}{kg}\right) x\ \frac{1hr}{3600s}$$

Q = 1,429.25 kw

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THANK YOU!
eugeneibacosta@yahoo.com
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