STEAM BOILERS

Steam Boilers

1. Uses for Steam
2. Types of Steam Boiler
3. Problem areas
4. Principles of Boiler Water Treatment

Uses for Steam

Overview

1 Uses list

2 Summary of uses

3 Purpose of a boiler

4 Steam Generation System

5 The age of steam is not dead!

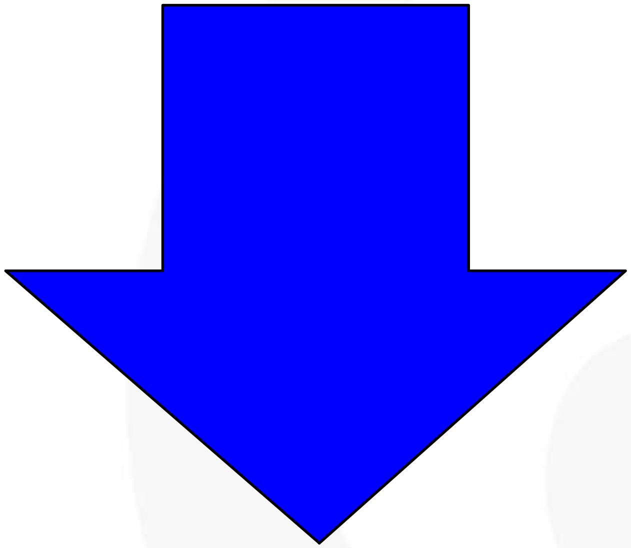
Uses for Steam?

Summary of uses

- Heating
- As a Raw Material
- Motive Force
- Cleaning/Disinfection/Sterilisation

Purpose of a boiler

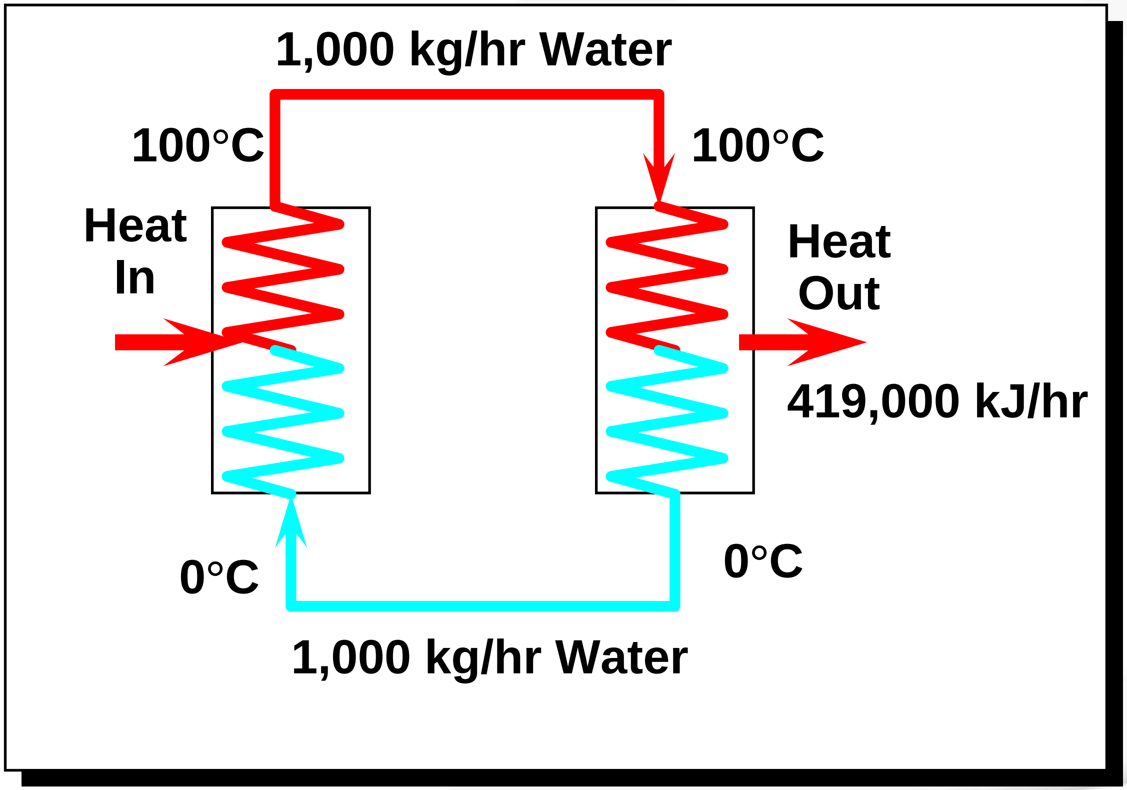
Heat Source



Heat Sink

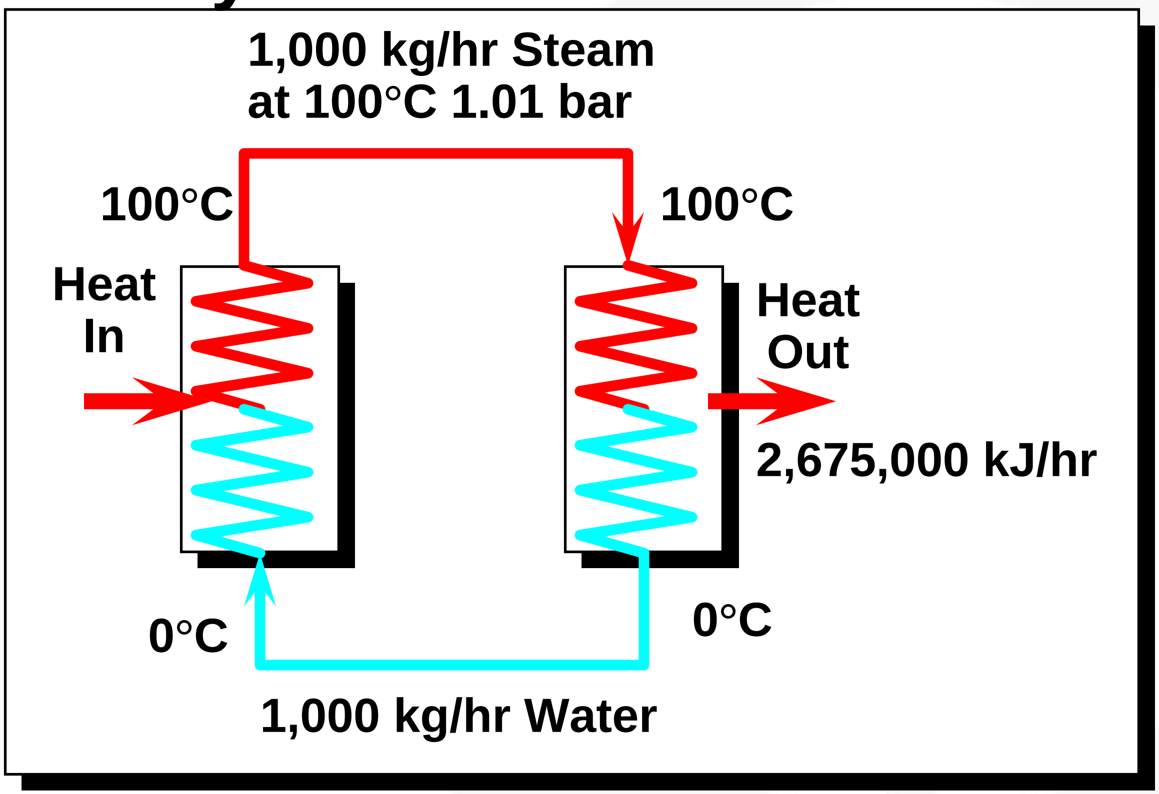
Why is water used so widely?

(a) Hot Water System



Why is water used so widely?

(b) Steam System



6 times the heat transfer - same mass transfer!

Definition of a Steam Boiler

"A device for converting water to steam under controlled conditions of temperature & pressure."

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Definition of a Cooling Tower

"A device which provides optimum air/water contact in order to cool that water by evaporation".

Importance of Latent Heat of Evaporation

Boiler & cooling tower both cool by evaporation.

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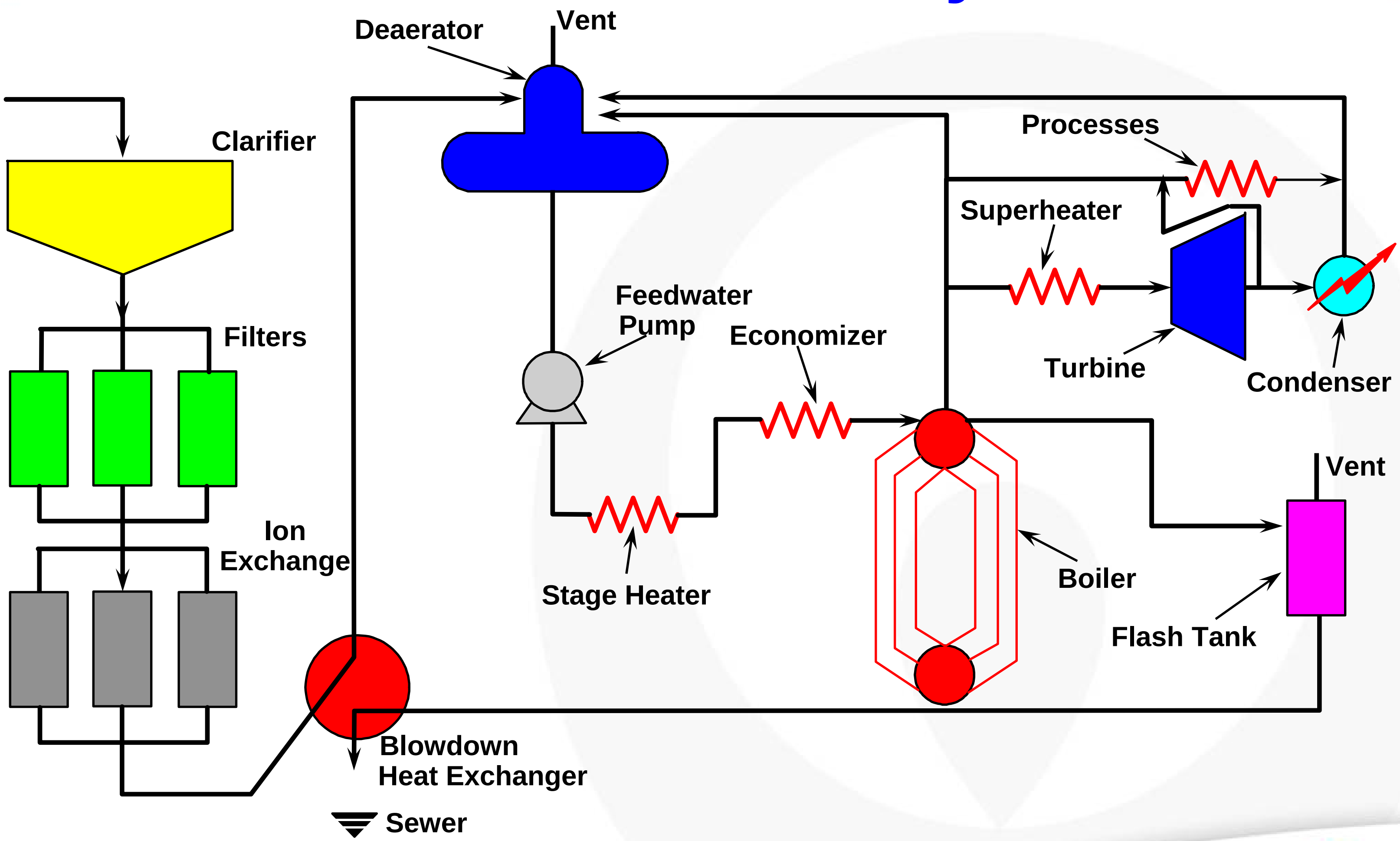
Steam Generation System



THE AGE OF STEAM IS NOT DEAD!

- Nuclear Power Stations
- Refineries
- Paper mills
- Nuclear Submarines
- Pharmaceutical Industries
- Food & beverage
- Dairies
- Petrochemicals/fertilizers/basic chemicals
- etc. etc.

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Types of Steam Boiler

Overview

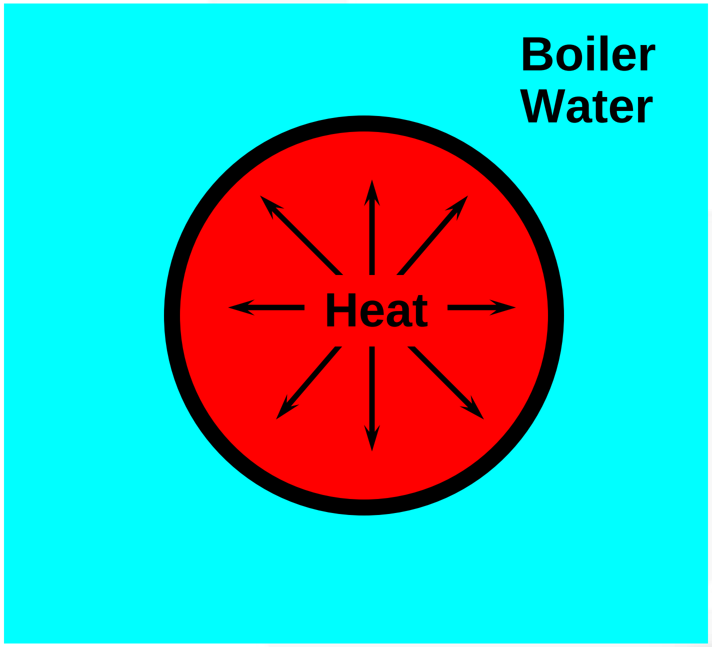
1 Fire/Smoke Tube

2 Water Tube

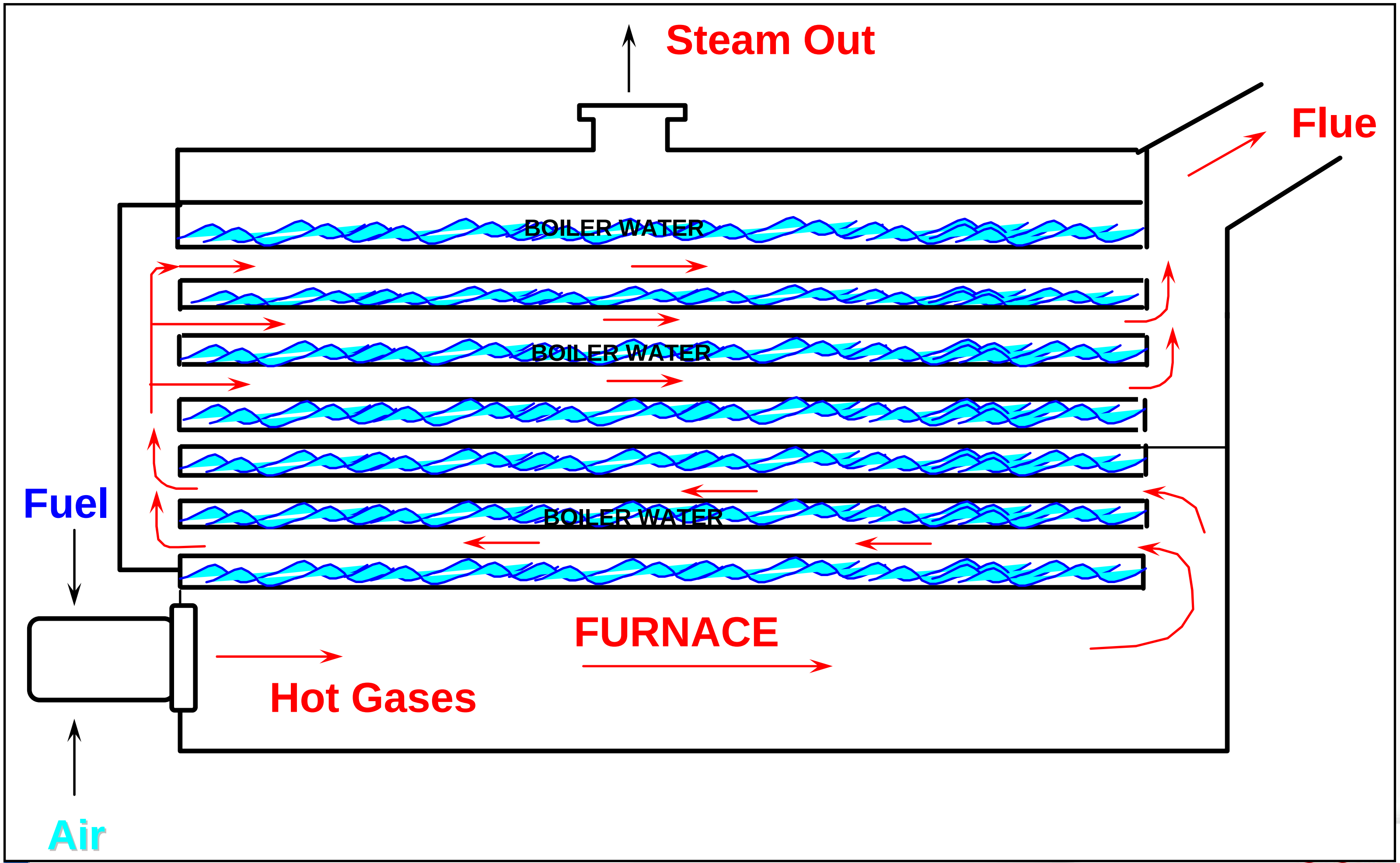
3 Once-through/coil generators

Fire Tube Boilers

Heat Source inside tubes, water in pressure vessel heated by tubes



Basic Construction



Applications

- Low Pressures (<120 psig)
- Low - Medium Outputs (<10,000 kg/hr)
- Portable
- Low efficiency

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Fire Tube Boiler

Bulk boiler water surrounds the fire (energy) in the tube

Capacity is generally rated as horsepower

1 horsepower will generate 34.5 pounds of steam per hour

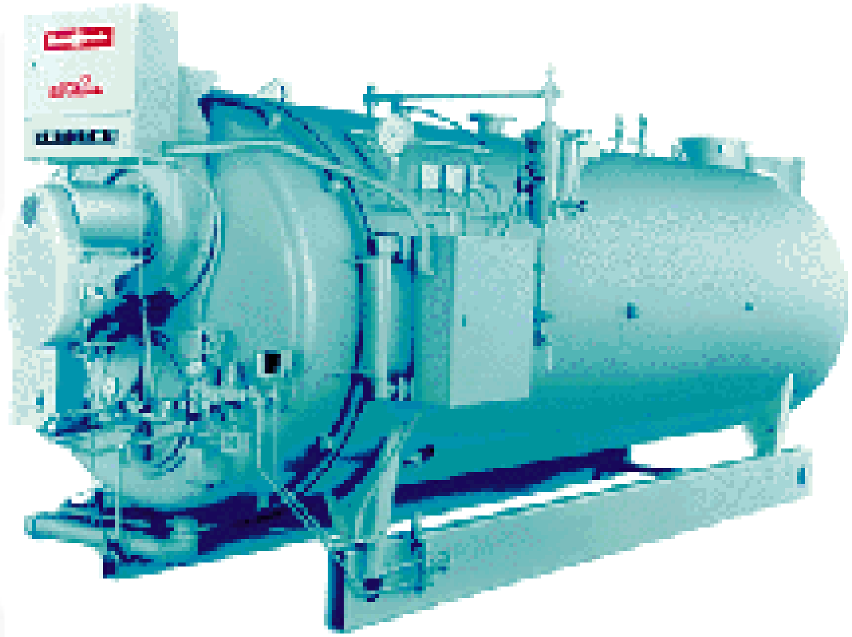
Fire tube boilers are normally “multi-pass”

Fire Tube Boiler

- Most fire tube boilers are sold as package units
- The large, main fire tube is referred to as the Morrison tube.
- Fire tube capacities range from 5-1500 HP
- The steam bubbles are produced on the top half of the tube
- The tubes are in staggered rows

Fire Tube Boiler

- Dryback/Wetback style
- 15-800 hp
- Heating or Processing
- Steam (15-250 psi) or
- Hot Water (30 lbs. and up)
- Oil, Natural Gas or combination
- Alternate fuel capability
- Low NOx capability



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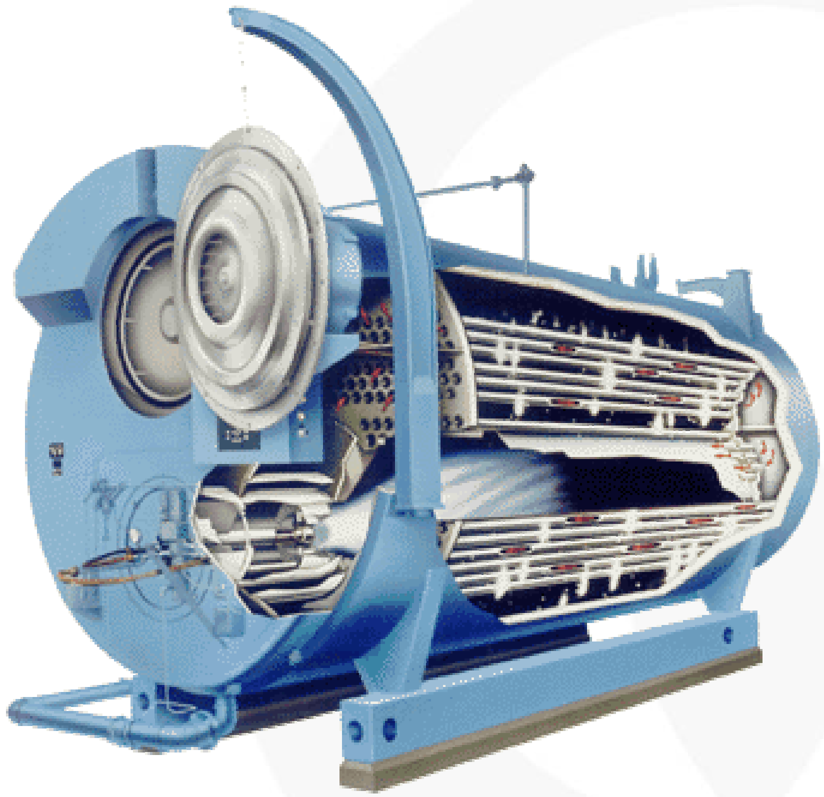
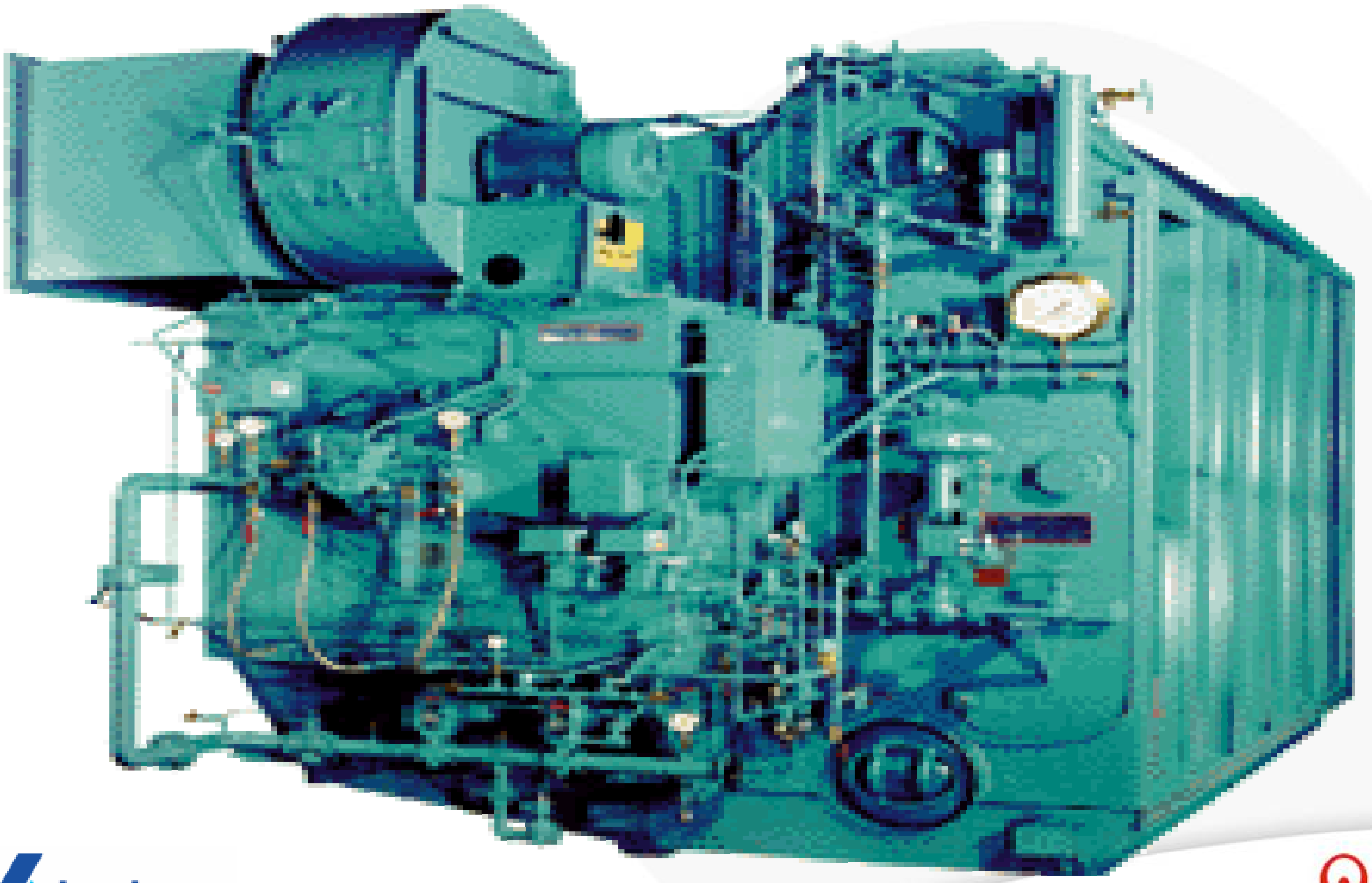
Fire Tube Boiler



Water Tube Boiler



Water Tube Boiler

- **Bulk boiler water is inside the tubes**
- **Capacity is normally expressed in pounds or kilograms per hour of steam**
- **Generally have a** Steam **drum and a** Mud **drum**
- **Types are normally "A", "D", & "O"**

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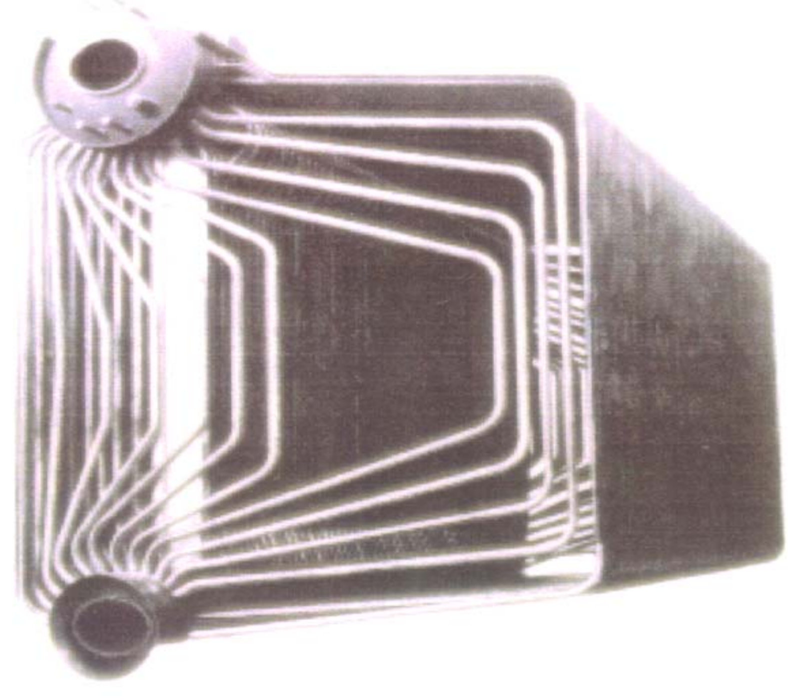
Water Tube Boiler

- Capacities range from 4500 kg/hr (10,000 lbs/hr) to large utility boilers
- Steam bubbles produced in the tube and cause circulation throughout the boiler
- Designed to run at full load

Water Tube Boiler

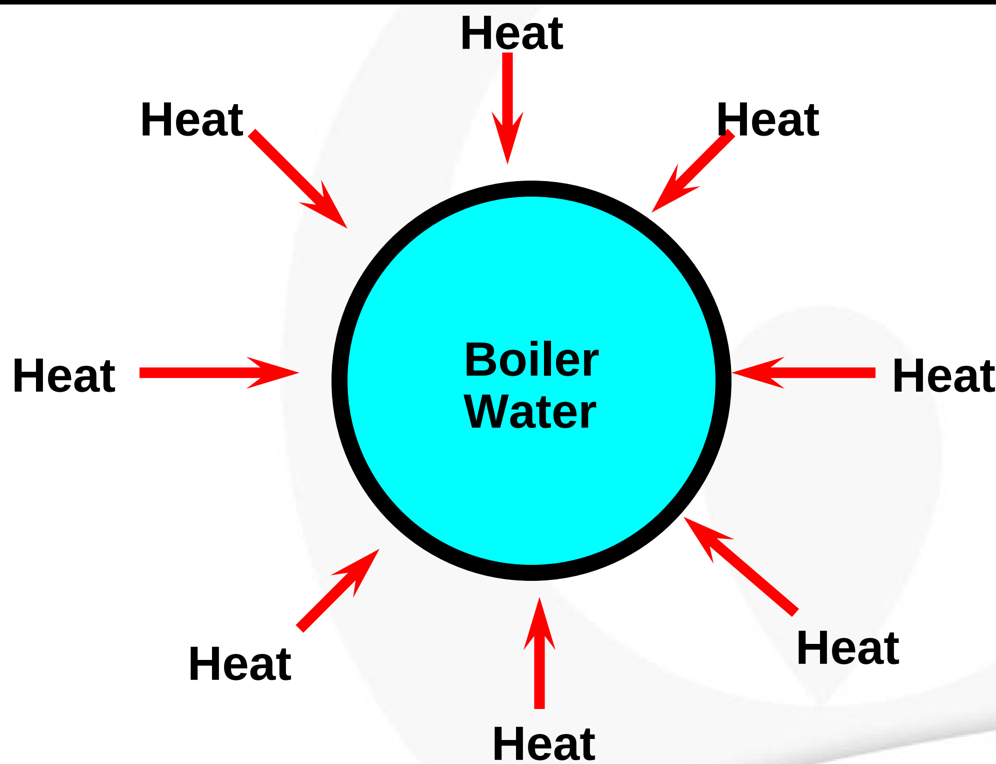
Tubes Names:
Generating,
Downcomer,
Wall, *and*
Floor tubes



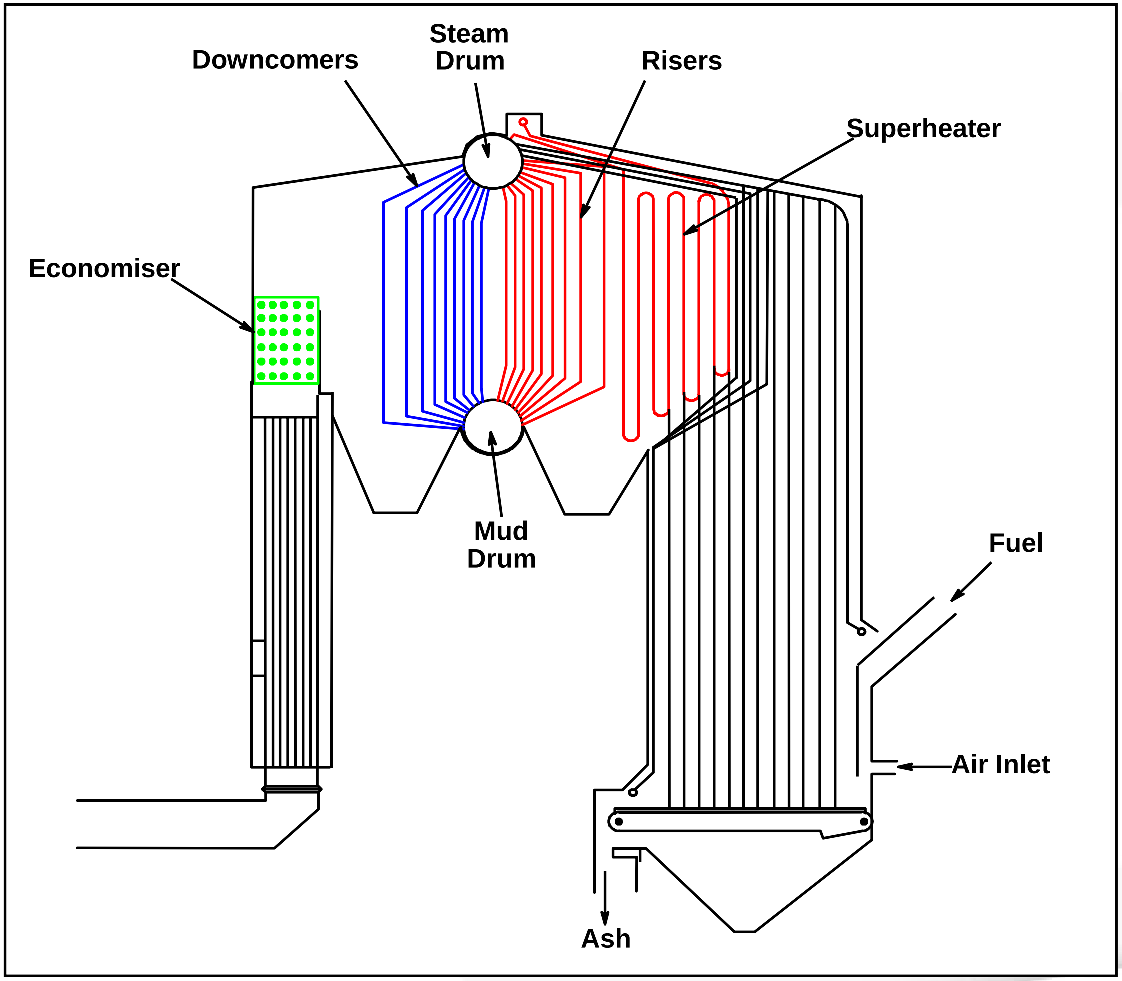
WATERTUBE BOILER (CUTAWAY DRAWING)

Water Tube Boilers

Heat source on outside, water enclosed in tube



Basic Elements & Nomenclature



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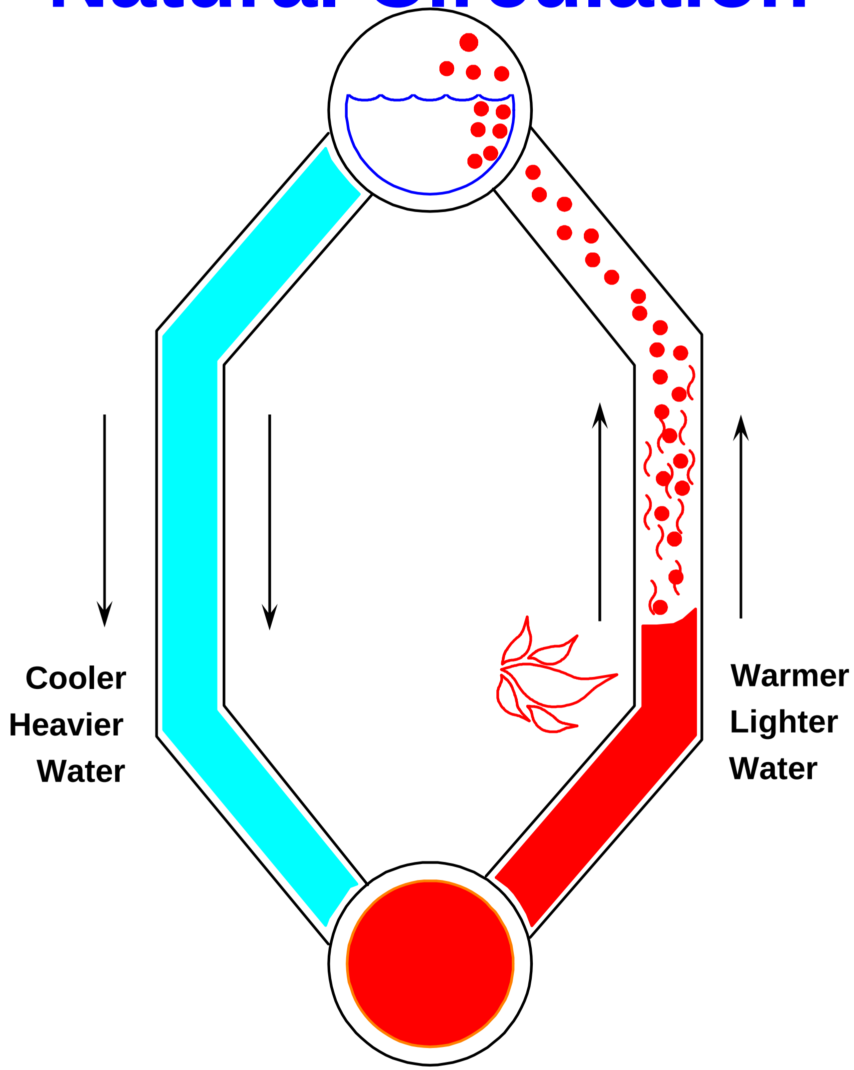
Natural Circulation



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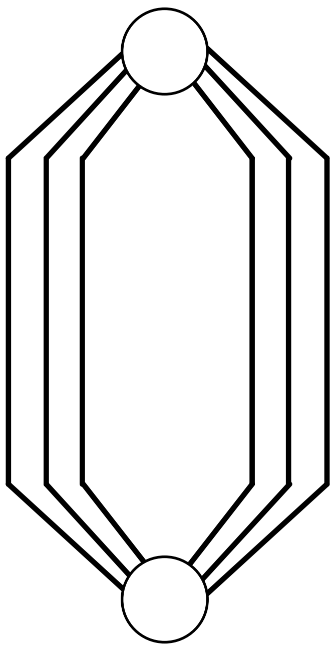
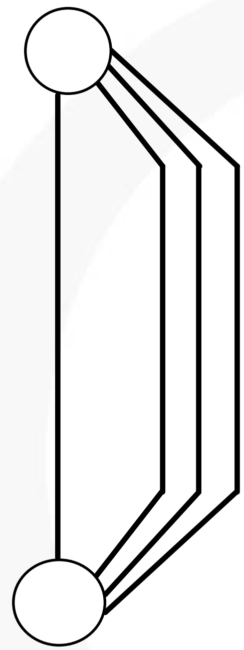
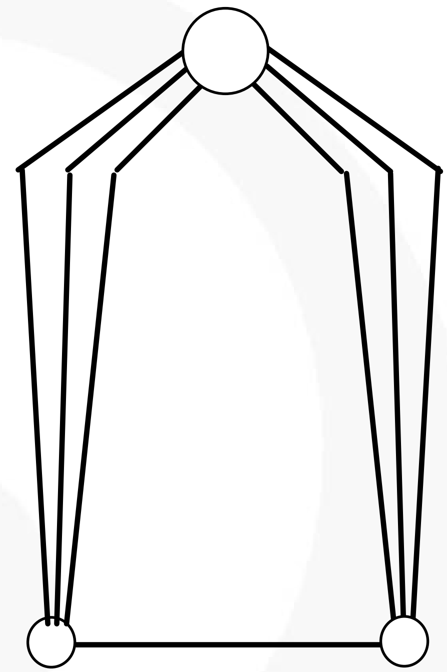
Different Designs



‘O’ Type



‘D’ Type



‘A’ Type

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Applications

- Medium - High Pressures (>120 psig)
- Power Generation
- High Outputs (>10,000 kg/hr)
- High Efficiency

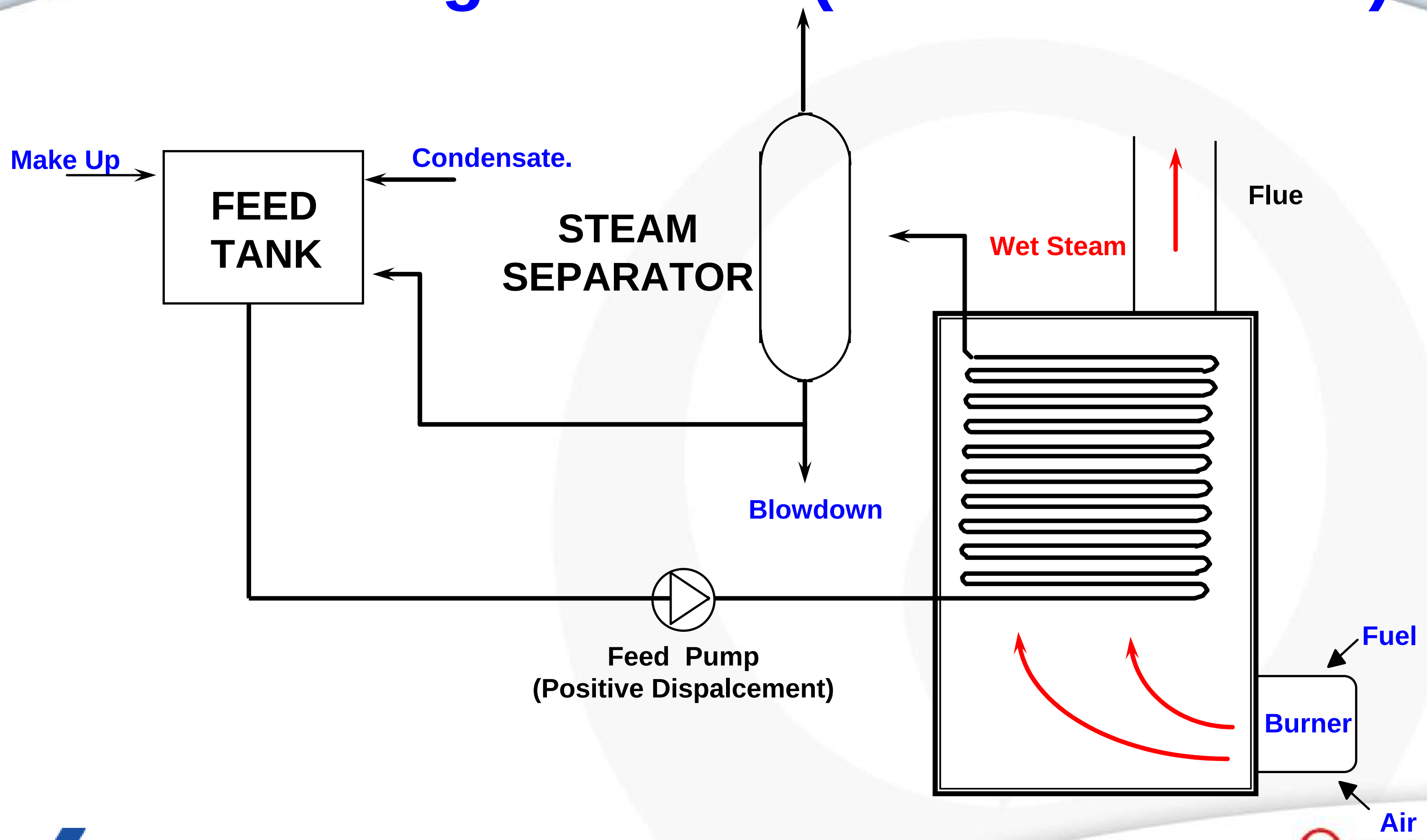
Special Designs

1 Once-Through Boilers

2 Electrode Boilers

3 Electric boilers

Once-Through Boilers (Coil Generators)



Problem Areas

Overview

1 Scale

2 Corrosion

3 Deposition/Fouling

4 Carryover

5 Where problems occur

Scale formation

Reaction

Scale

$$Ca(HCO_3)_2 \quad \boxed{CaCO_3 \Downarrow} + H_2O + CO_2$$

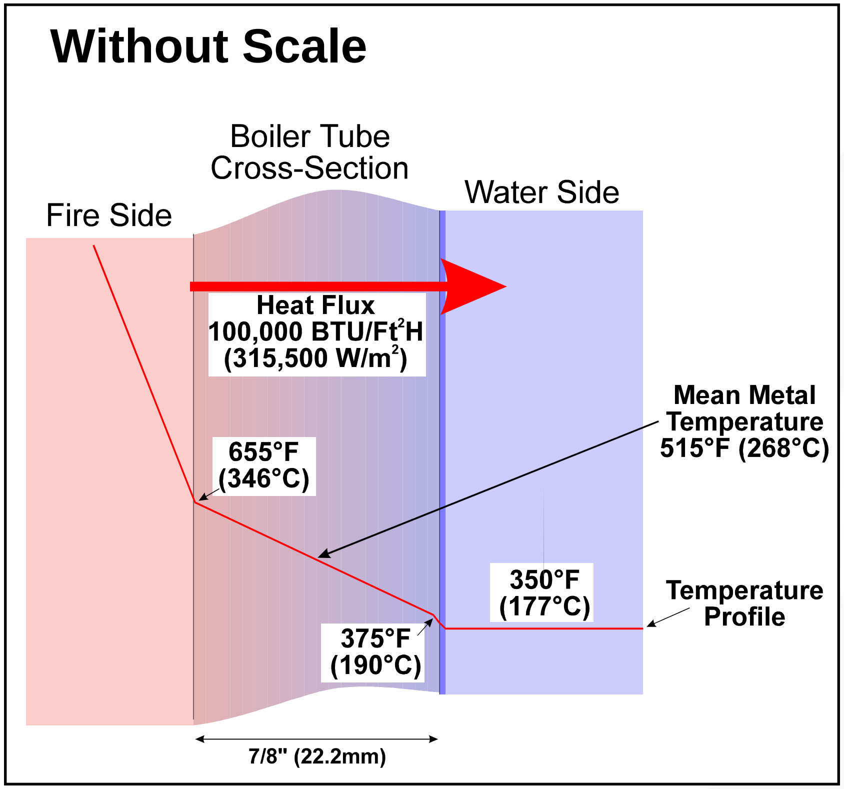
HEAT ⇨

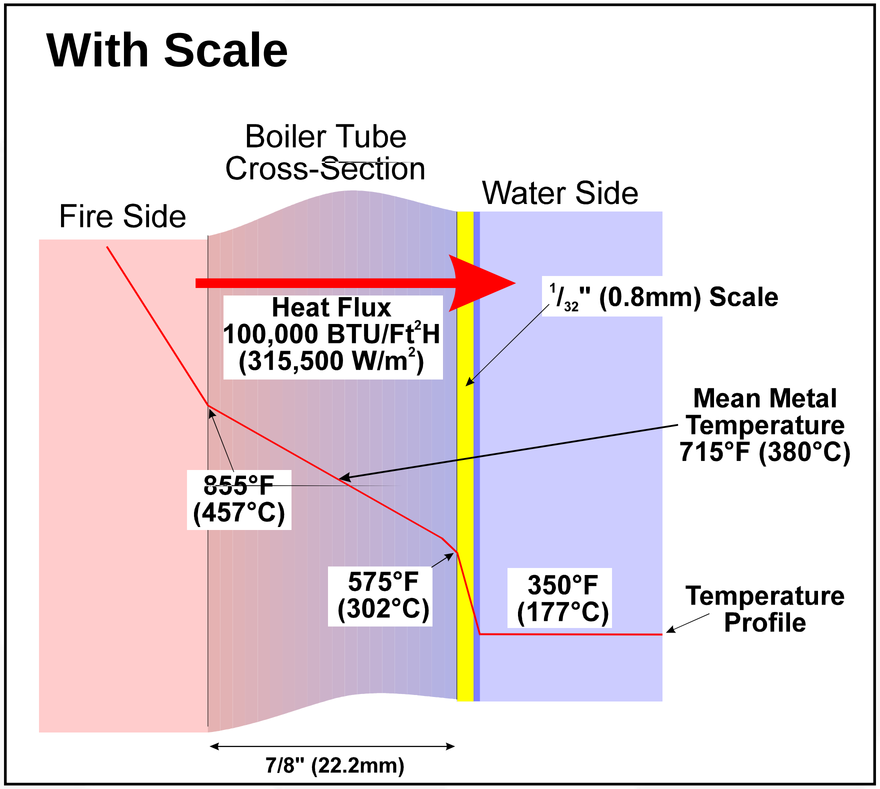
HIGH pH ⇨

⇦ **LOW pH**

CO_2 REMOVAL (Degassing) ⇨

Temperature Gradients





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Scale can lead to:

- ☹ Loss of efficiency
- ☹ Higher fuel consumption
- ☹ Blockages
- ☹ Tube failure
- ☠ In severe cases, explosions!

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Causes

- High Temperatures & Pressures
- Bare metal surfaces
- Under-deposit corrosion
- Oxygen and/or CO_2
- Low pH excursions
- High pressure systems - caustic embrittlement

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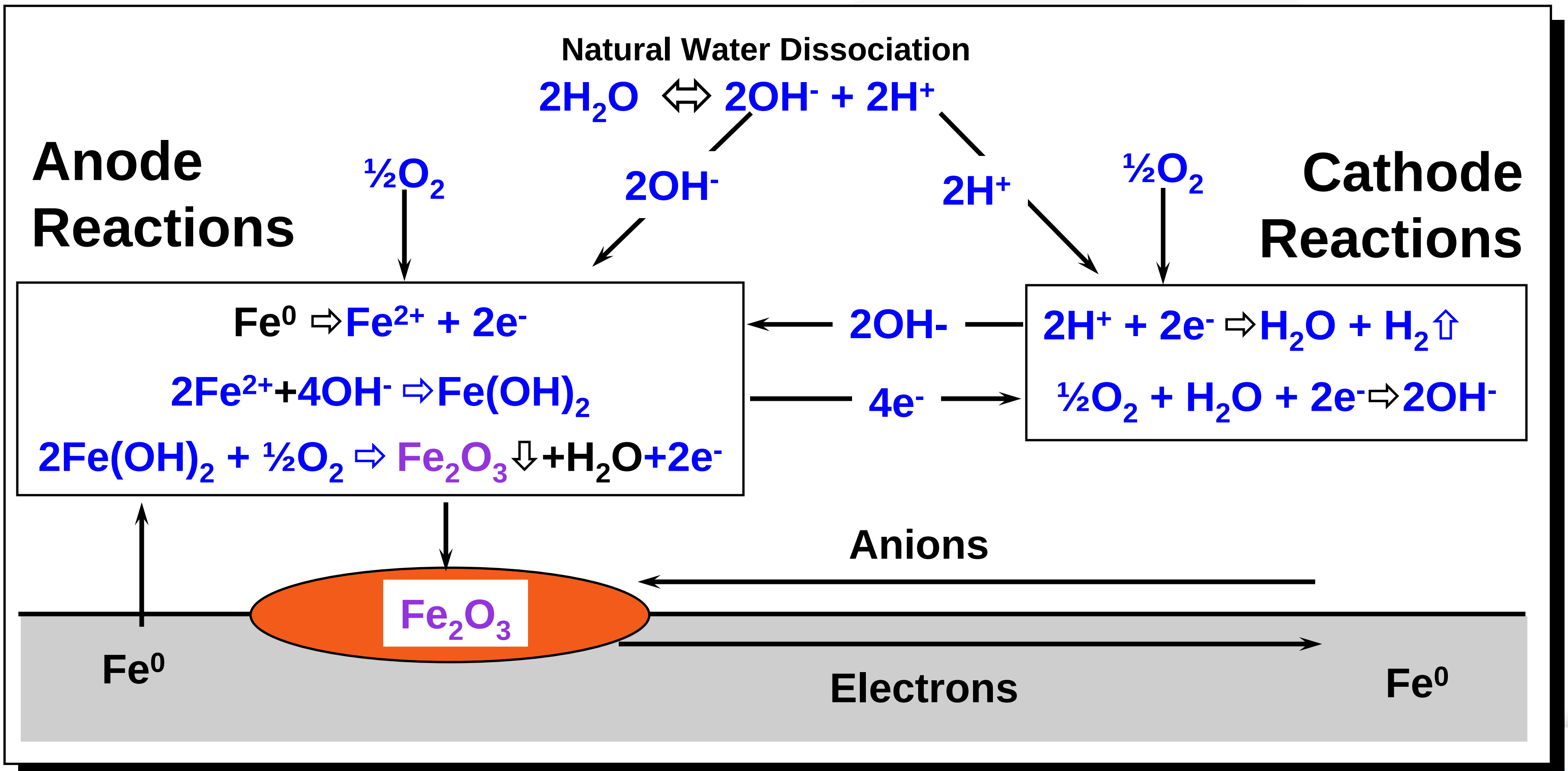
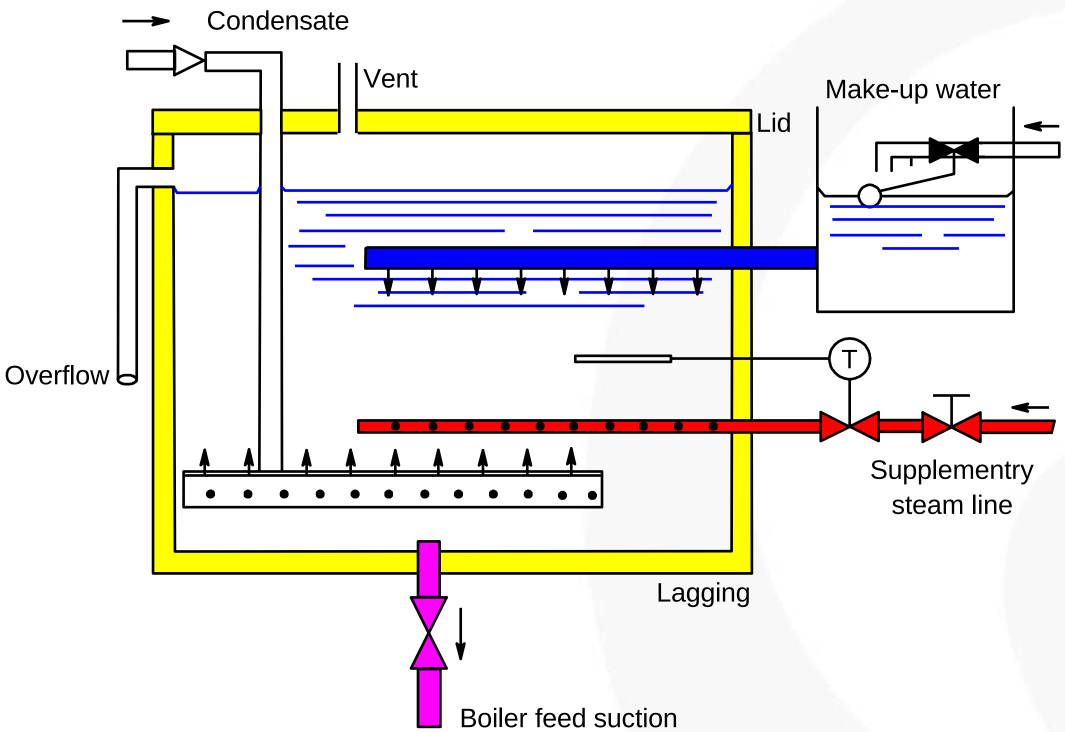
Problems Caused by Water Impurities

Corrosion

Corrosion cell



Feed Temperature



°C	°F	Oxygen for saturation ppm
0	32	14.16
5	41	12.37
10	50	10.92
15	59	9.76
20	68	8.84
25	77	8.11
30	86	7.83
35	95	7.04
40	104	6.59
50	122	5.57
60	140	4.76
70	158	3.89
80	176	2.89
90	194	1.63
100	212	0

Generation of Carbon Dioxide

Hard makeup water

$$Ca(HCO_3)_2 \Rightarrow CaCO_3\Downarrow + H_2O + CO_2\Uparrow$$

Calcium Bicarbonate — Calcium Carbonate (Scale) — Carbon Dioxide

$$CO_2 + H_2O \Leftrightarrow H_2CO_3$$

Carbon Dioxide — Carbonic Acid

Softened makeup water

$$2NaHCO_3 \Rightarrow Na_2CO_3 + H_2O + CO_2\Uparrow$$

Sodium Carbonate — Carbon Dioxide

and/or

$$2NaHCO_3 \Rightarrow 2NaOH + 2CO_2\Uparrow$$

Sodium Bicarbonate — Sodium Hydroxide — Carbon Dioxide

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Condensate Corrosion

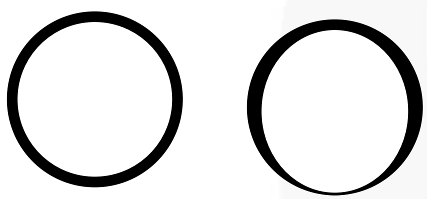
Causes of Condensate Corrosion

Carbon Dioxide

Reaction

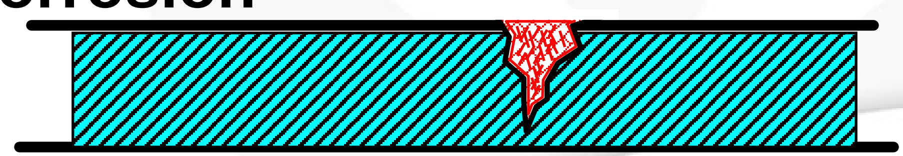
$CO_2 + H_2O \Rightarrow H_2CO_3$

Gouging Corrosion

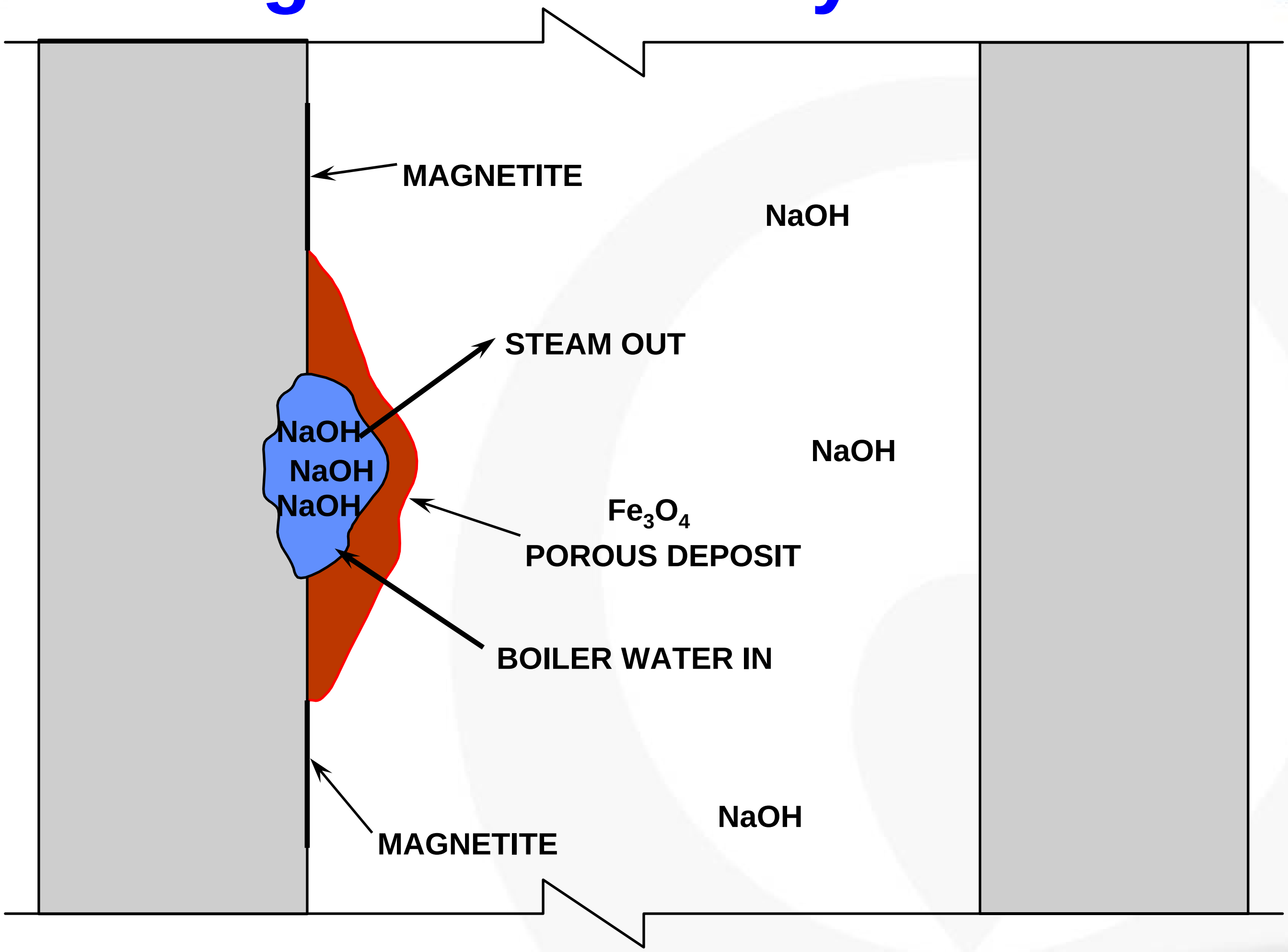


Oxygen

Pitting Corrosion



High Pressure Systems



Porous deposits provide conditions that cause high concentration of boiler water solids, such as sodium hydroxide (NaOH).

Fouling caused by :

- ☹ Scale deposits
- ☹ Metal oxide solubility
- ☹ Feed contamination
- ☹ Precipitation Treatment & no dispersant

Causes

1 Priming - Mechanical

2 Foaming - Chemical

Priming

Priming Caused by :

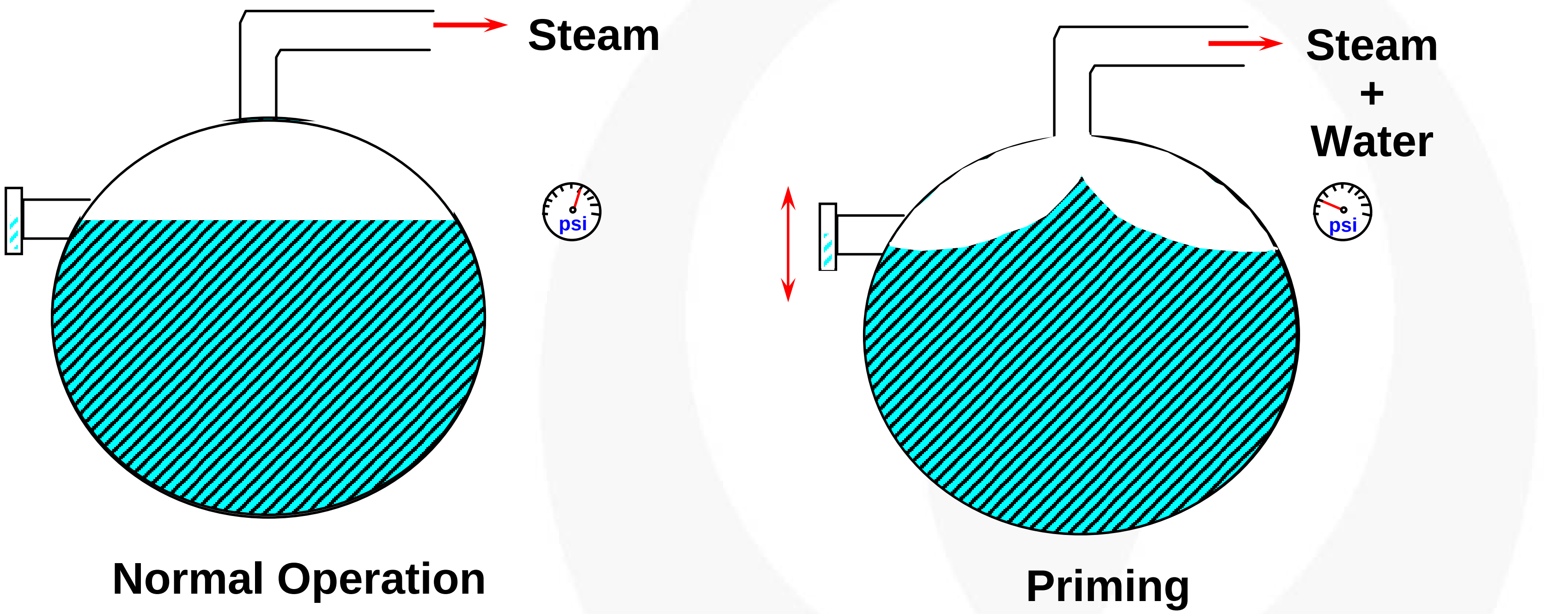
- **Rapid drop in boiler pressure**
- **Rapid increase in Steam load**

Both lead to :

- **Increase in specific volume of steam**
- **Increase in steam velocity.**

Boiler Water in ‘ Sucked out’ of the boiler.

Priming



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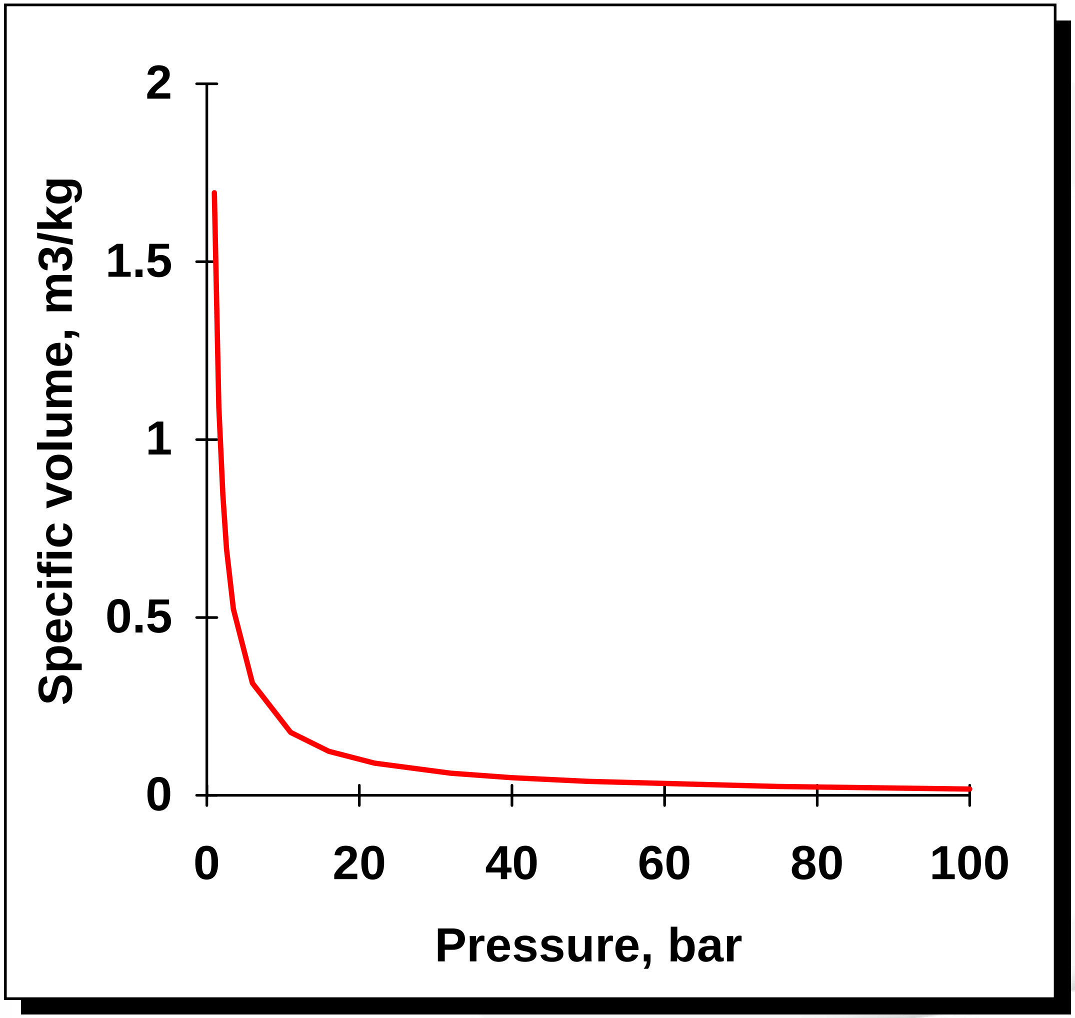
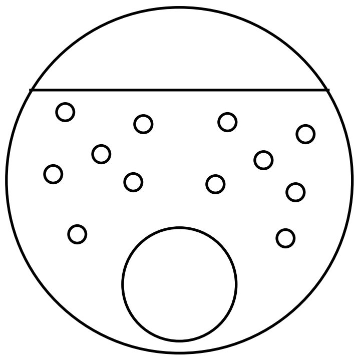
Boiler Water Carryover

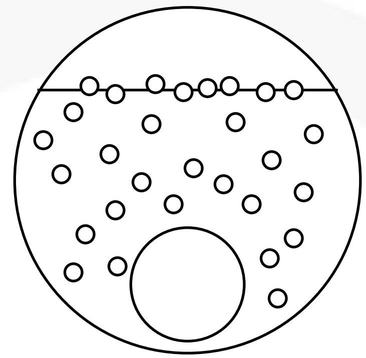
Priming



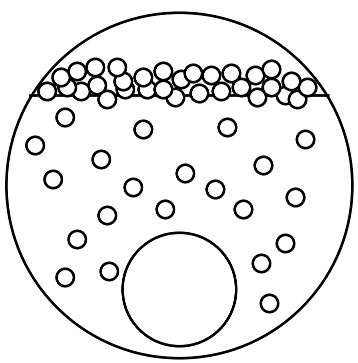
Foaming



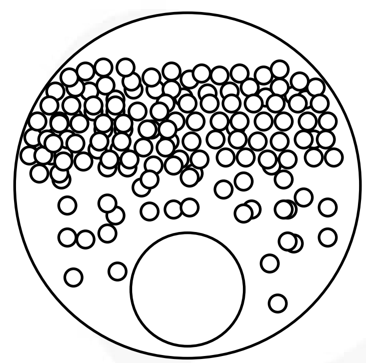
Normal Operation



Slight Foaming



Severe Foaming



DANGER!

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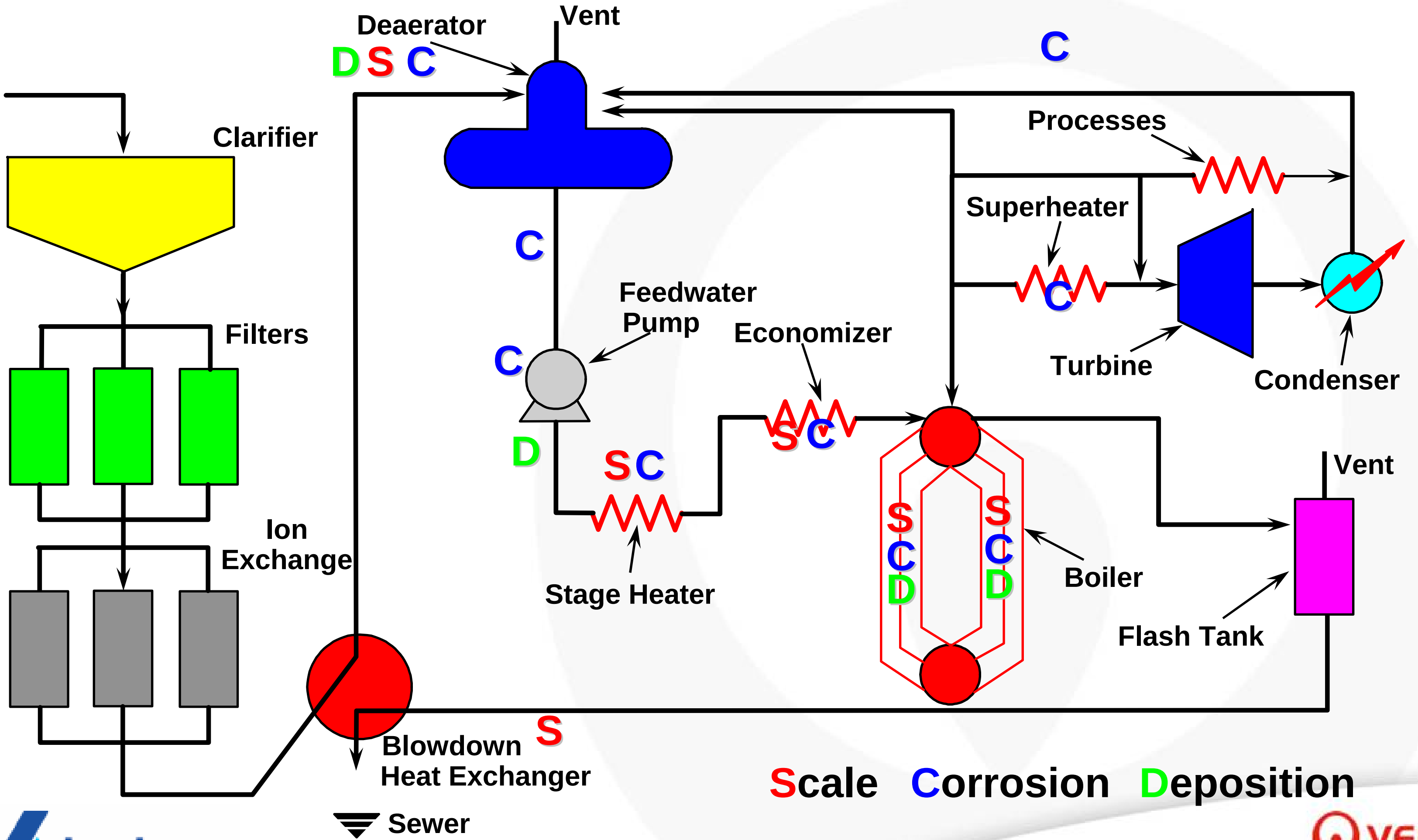
Causes of foaming

- High TDS/Alkalinity
- High Suspended Solids
- Contaminated feedwater - organics, etc.

Priming/foaming can lead to:

- ☹ Contaminated Steam/Condensate
- ☹ Extremely high boiler TDS levels
- ☹ Uncovered tubes
- ☠ In extreme cases tube failure/explosions

Where problems occur in steam system



Scale Corrosion Deposition

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Principles of Boiler Water Treatment

Overview

1 Scale Control

2 Corrosion Control

3 Suspended Solids Control

4 Alkalinity Builders

5 Special Applications

6 Integrated Approach

7 Programming

Treatment Methods

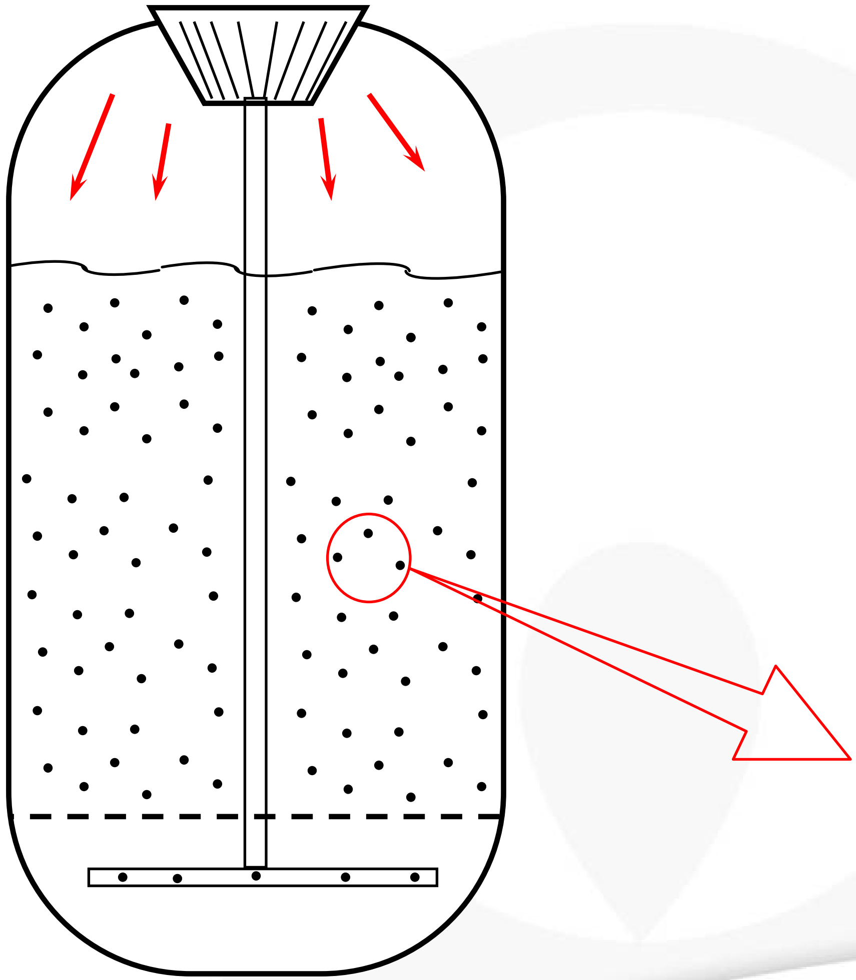
External Methods - Applied outside boiler

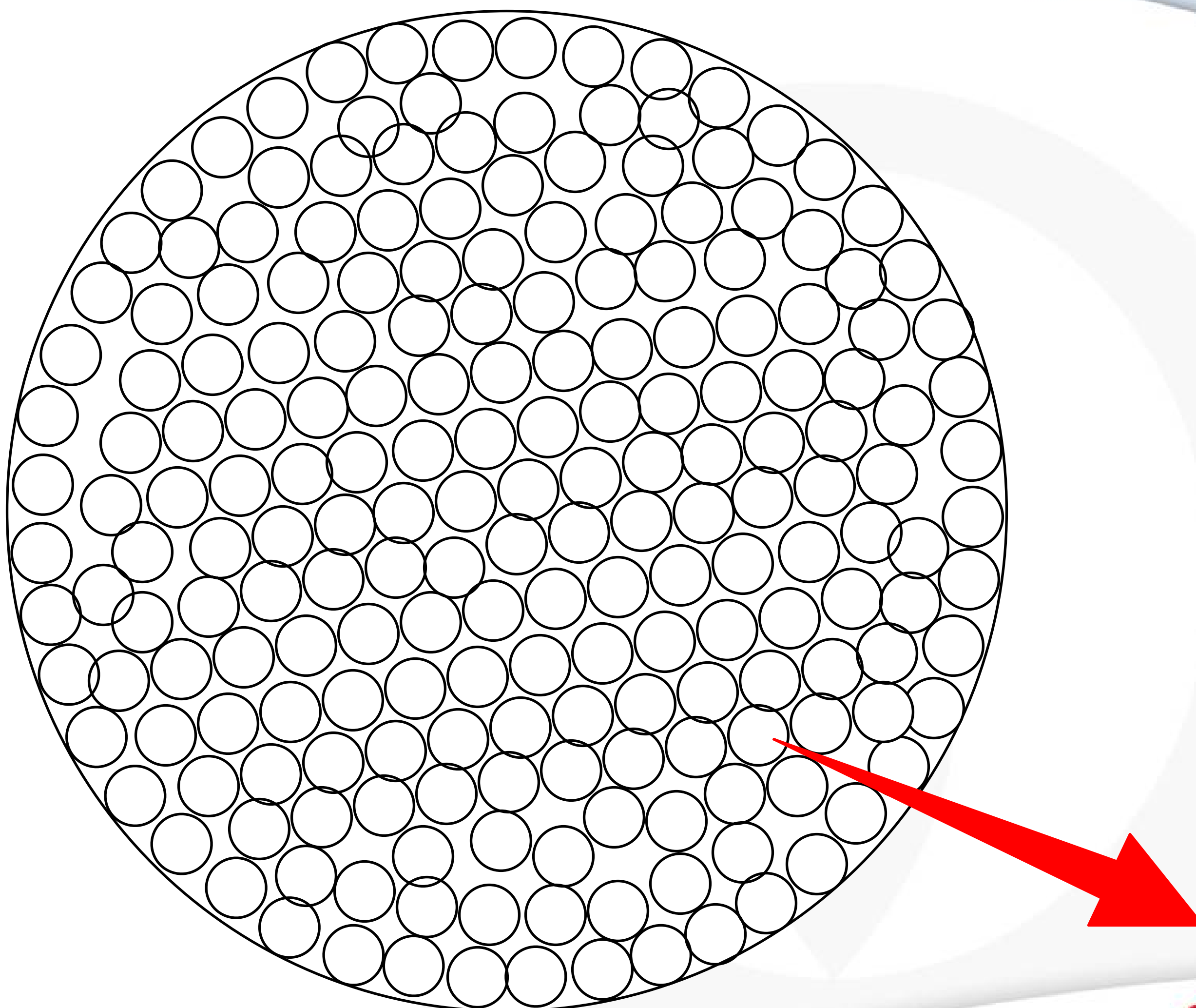
Internal Methods - Applied inside boiler

External Methods

- Precipitation Softening (Lime-Soda)
- Base Exchange Softening
- Reverse Osmosis
- De-Alkalisation
- De-Mineralisation

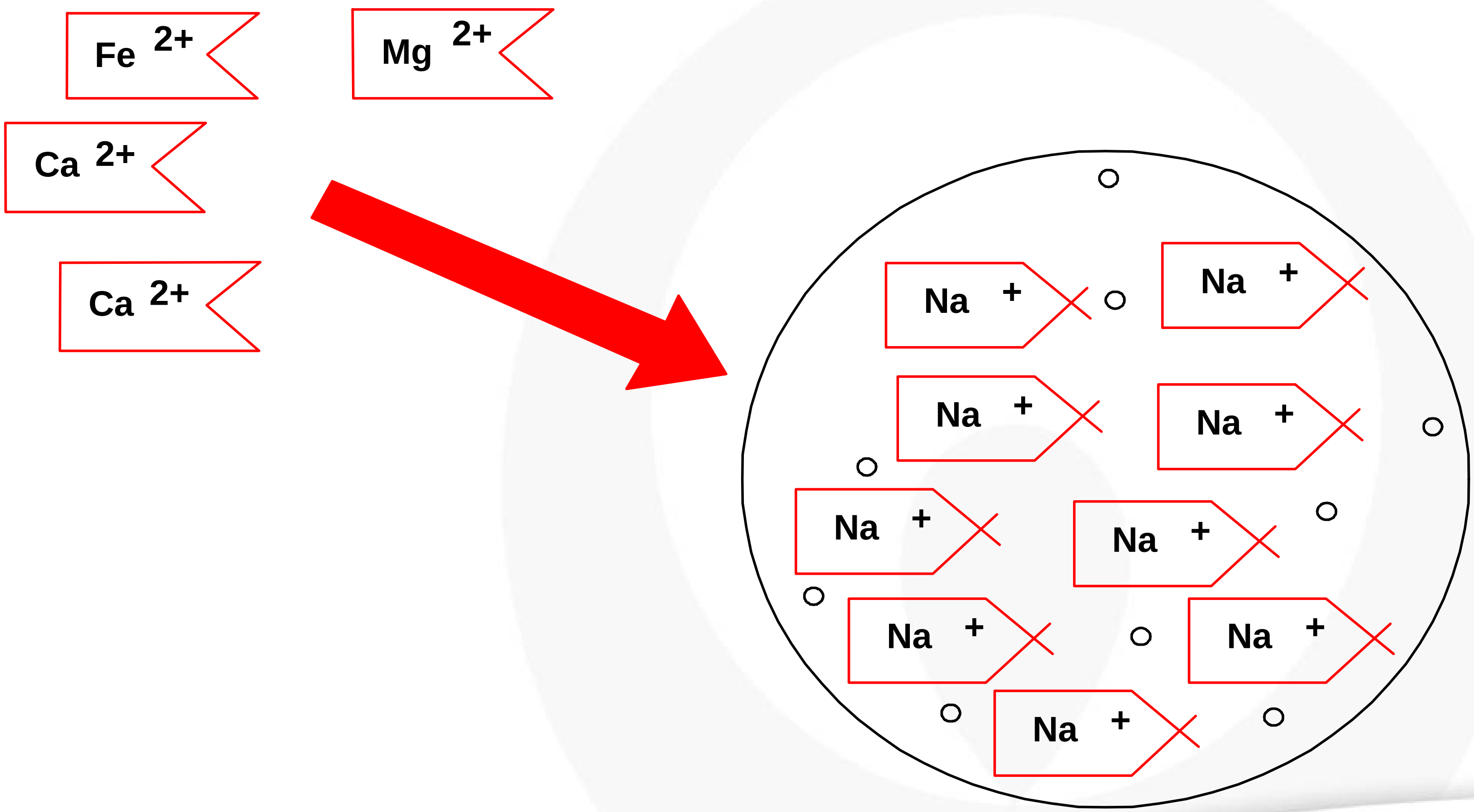
1) Principles of Ion Exchange



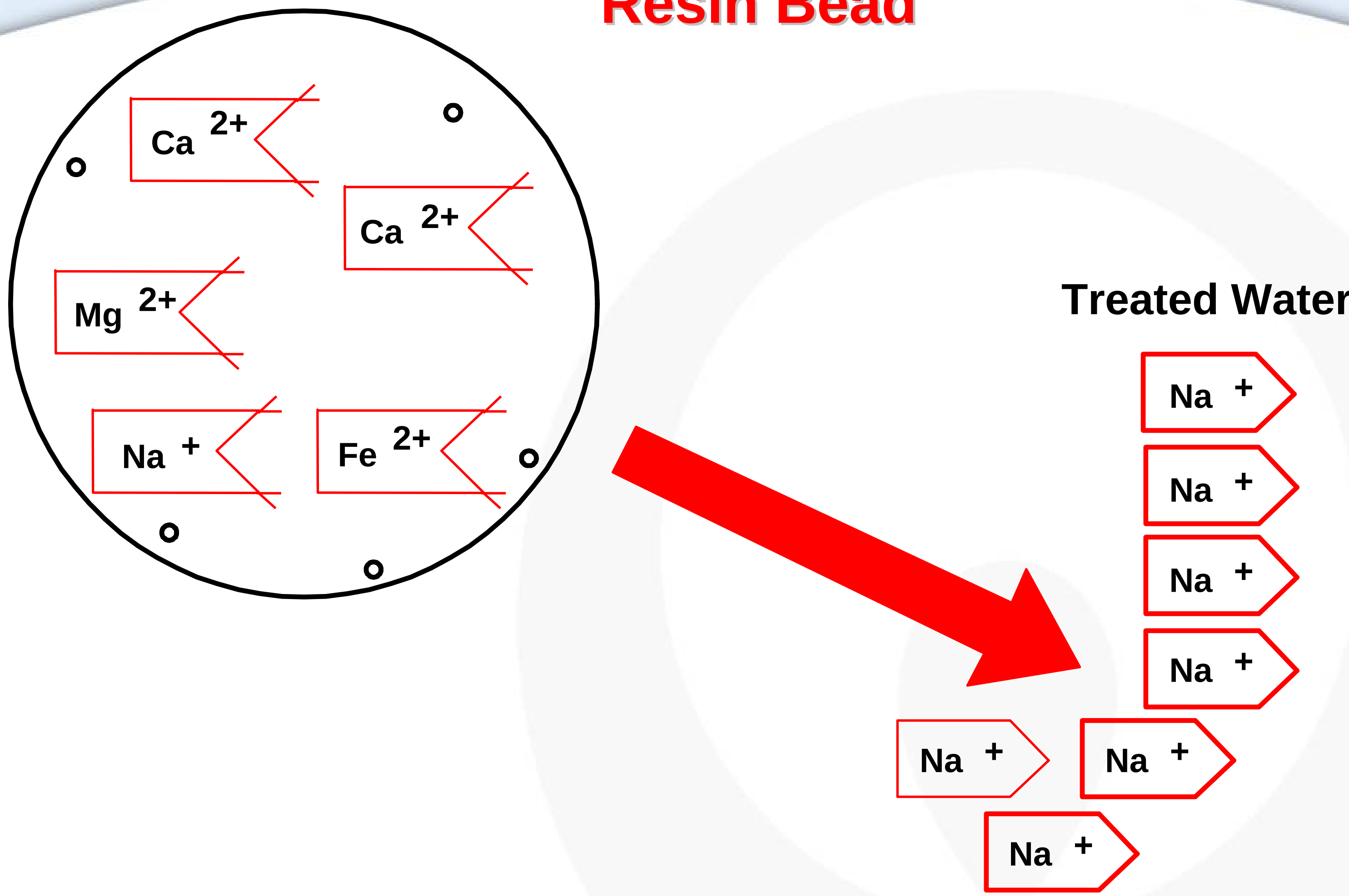


Resin Bead

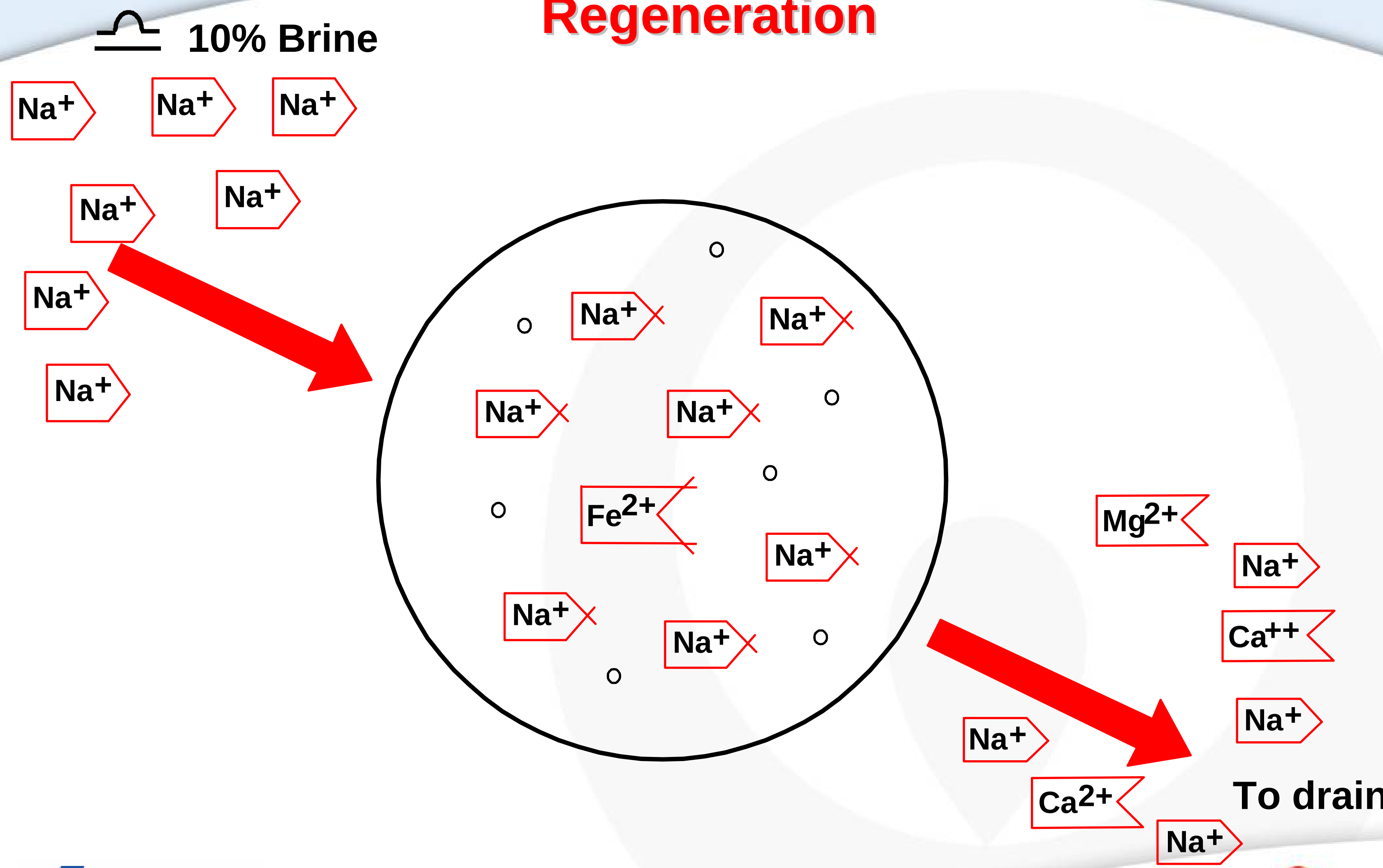
Incoming / untreated water



Resin Bead



Regeneration



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Regeneration Cycle

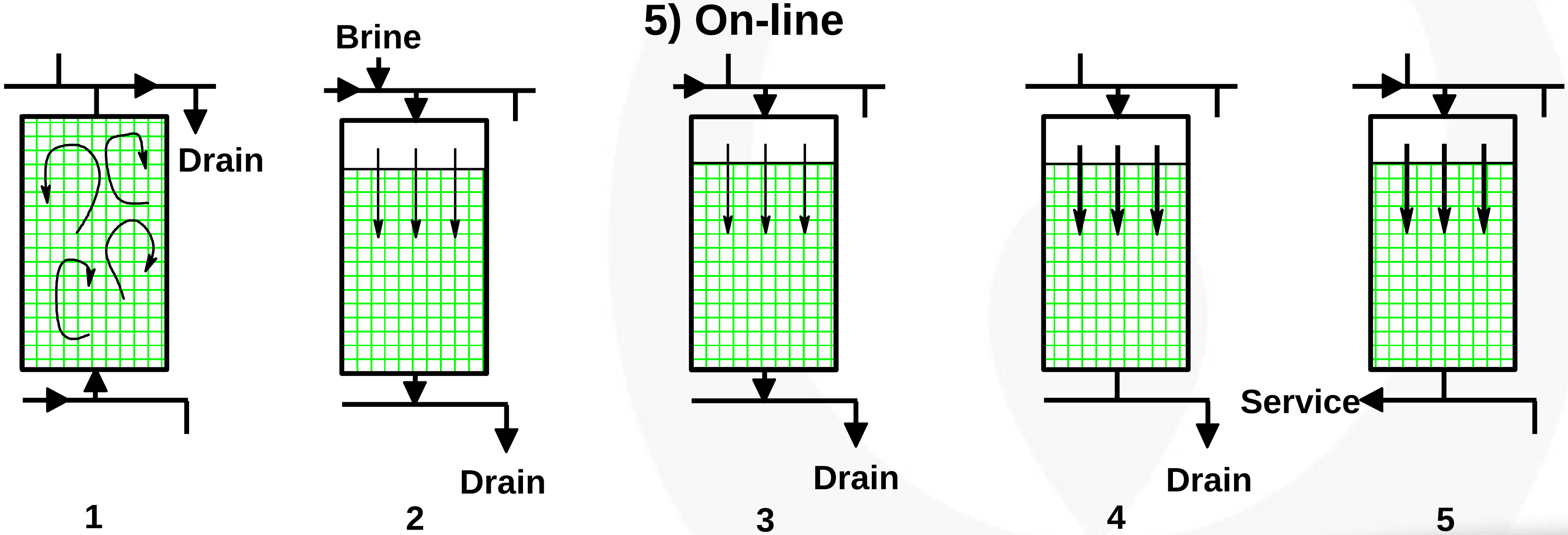
1) Backwash

2) Brine draw

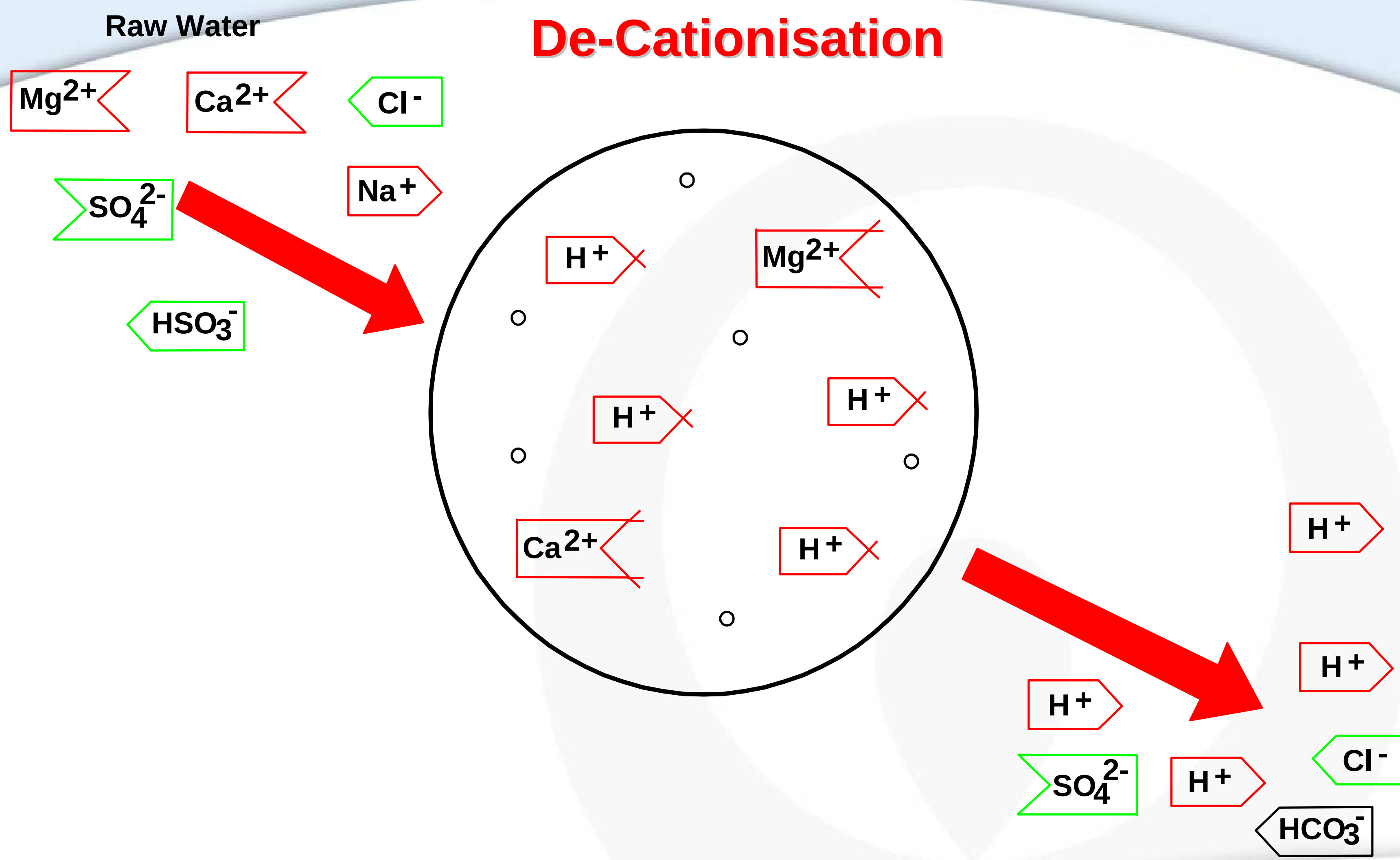
3) Slow rinse

4) Fast rinse

5) On-line

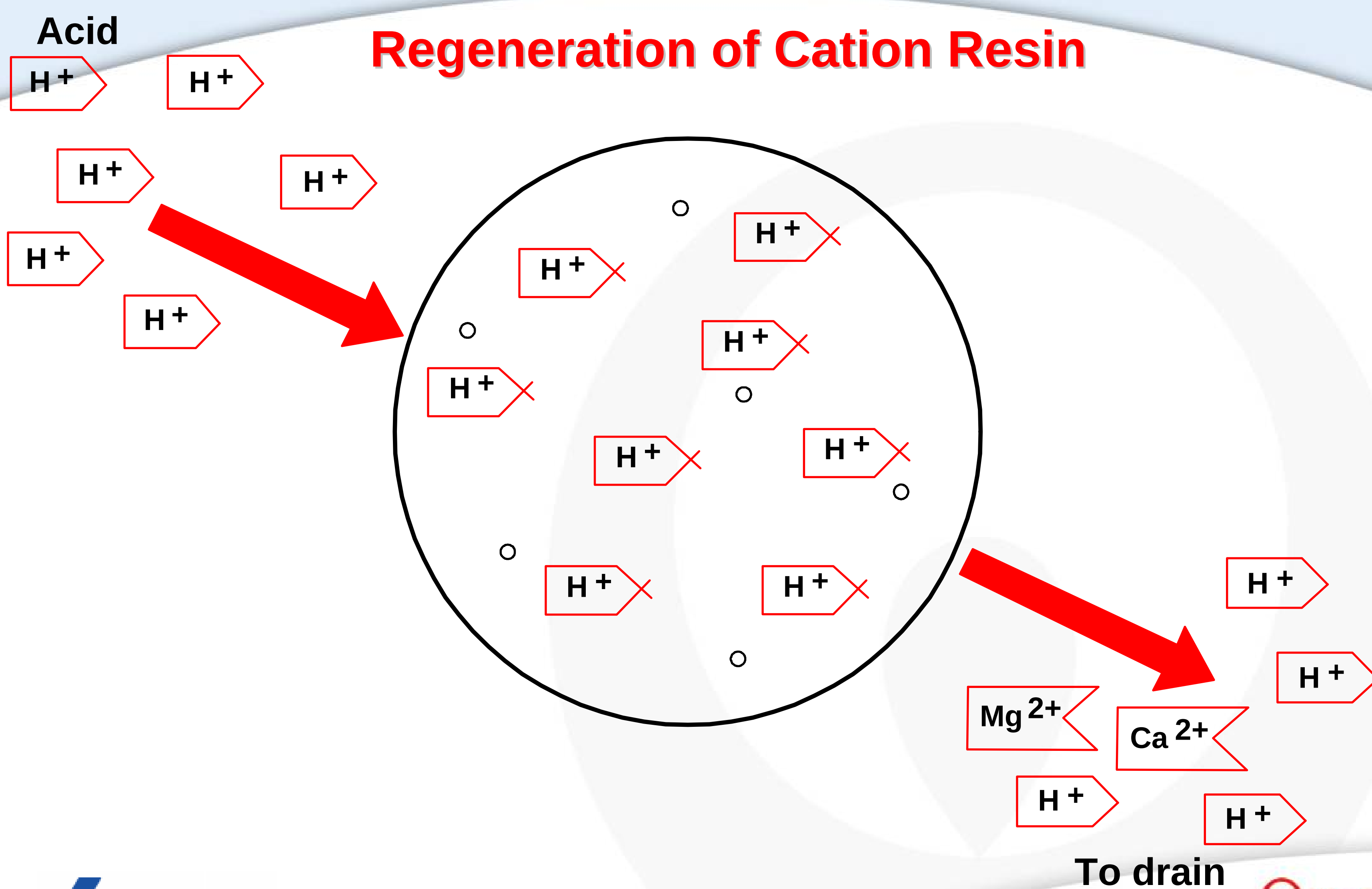


De-Cationisation



Treated Water

Regeneration of Cation Resin



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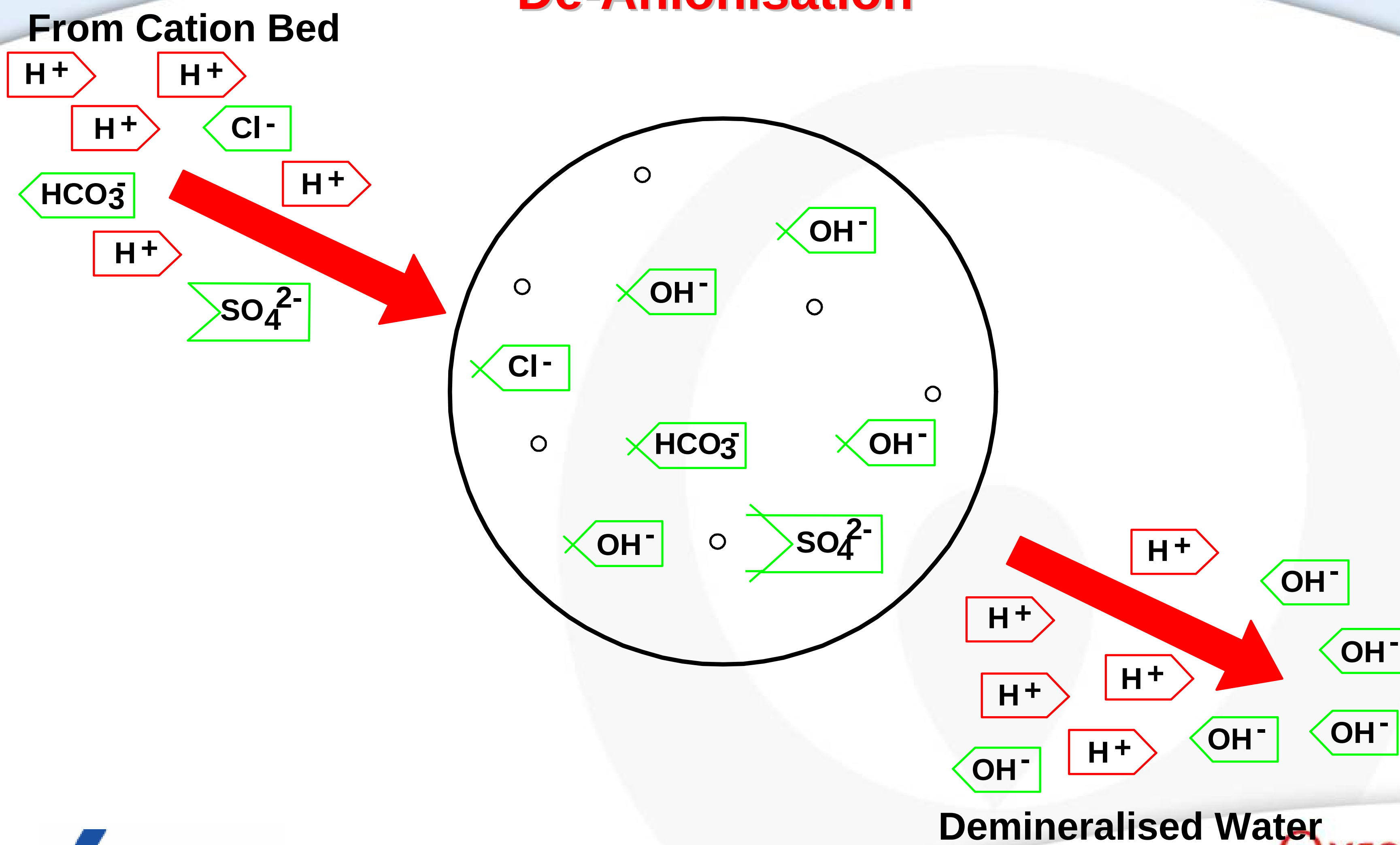
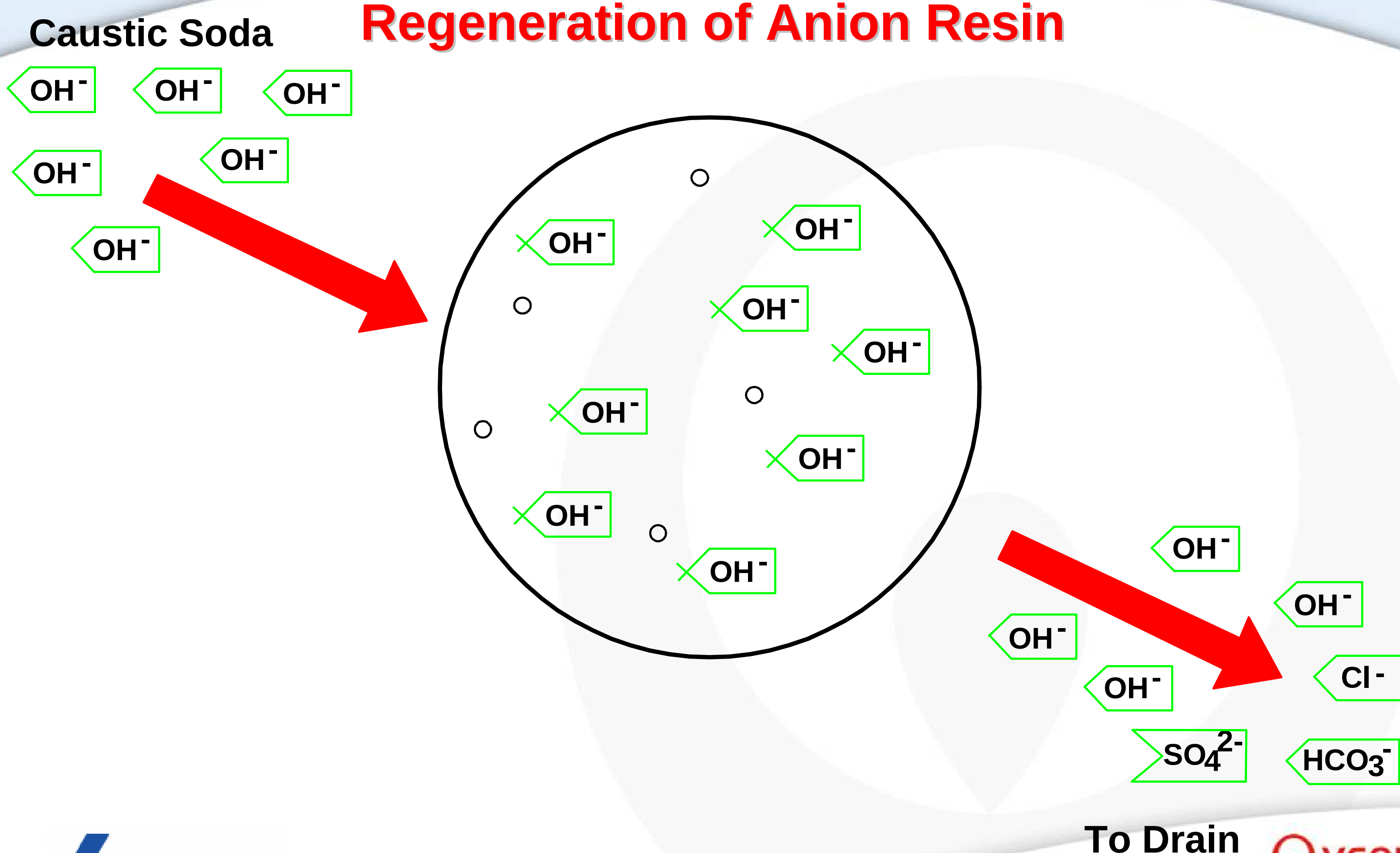
De-Anionisation



Regeneration of Anion Resin



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Internal Methods

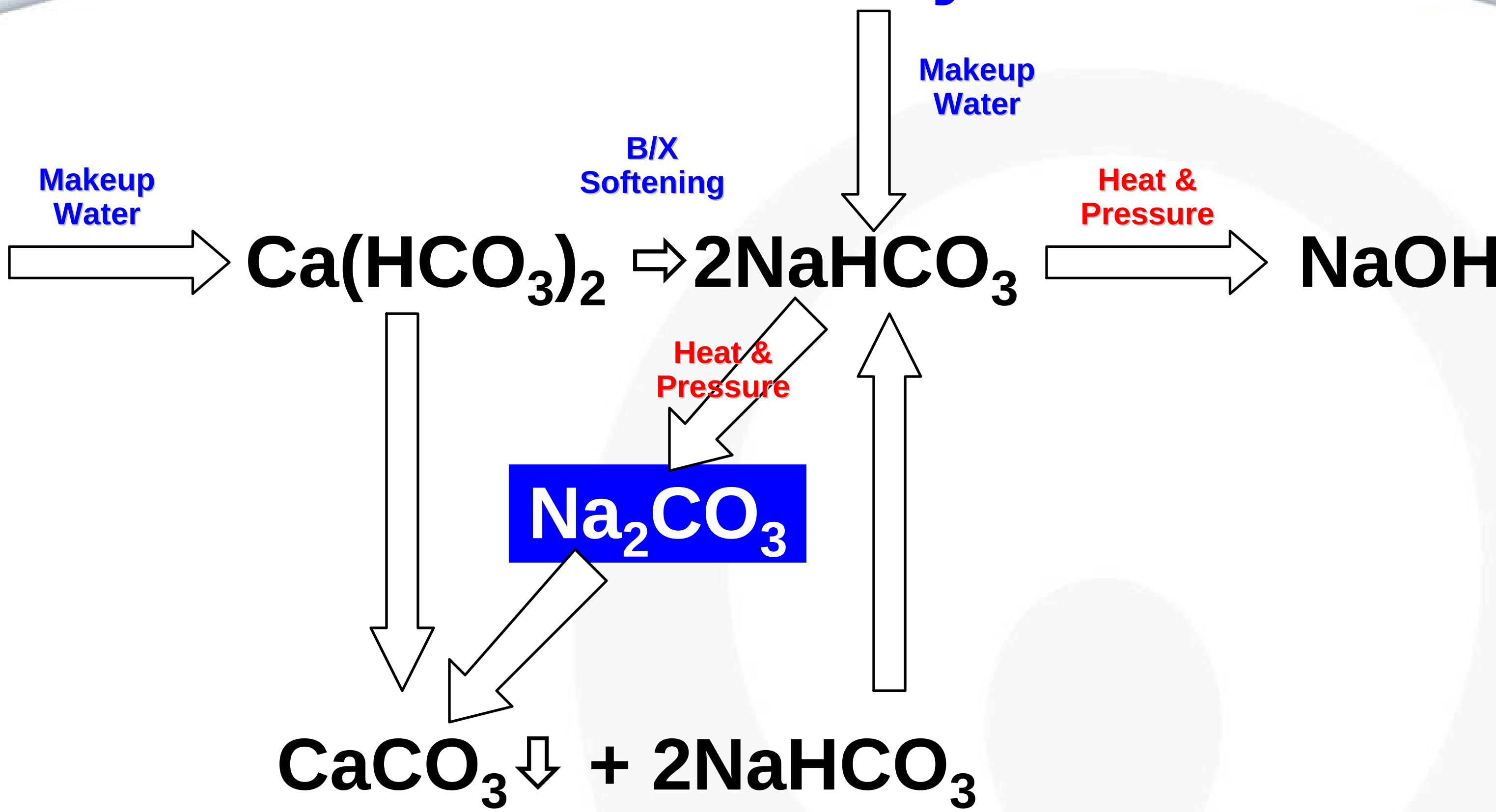
1 Carbonate Cycle (precipitation)

2 Phosphate (precipitation)

3 Chelant (solublisation)

4 Phosphate/Chelant (Combination)

Carbonate Cycle



Boiler Water Sodium Carbonate Alkalinity (2(M-P)) must be >250 ppm and boiler pressure must be <150 psig. REQUIRES DISPERSANTS for Calcium Carbonate conditioning.

Phosphate Programme

$$3Ca^{++} + 2PO_4^{3-} \Rightarrow Ca_3(PO_4)_2 \Downarrow$$

Phosphate reserve of 30-50 ppm PO_4 (as PO_4) must be maintained in boiler water, equivalent to 50-80 ppm as Na_3PO_4

Phosphate precipitate forms in the boiler water and is removed by bottom blowdown (not continuous blowdown)

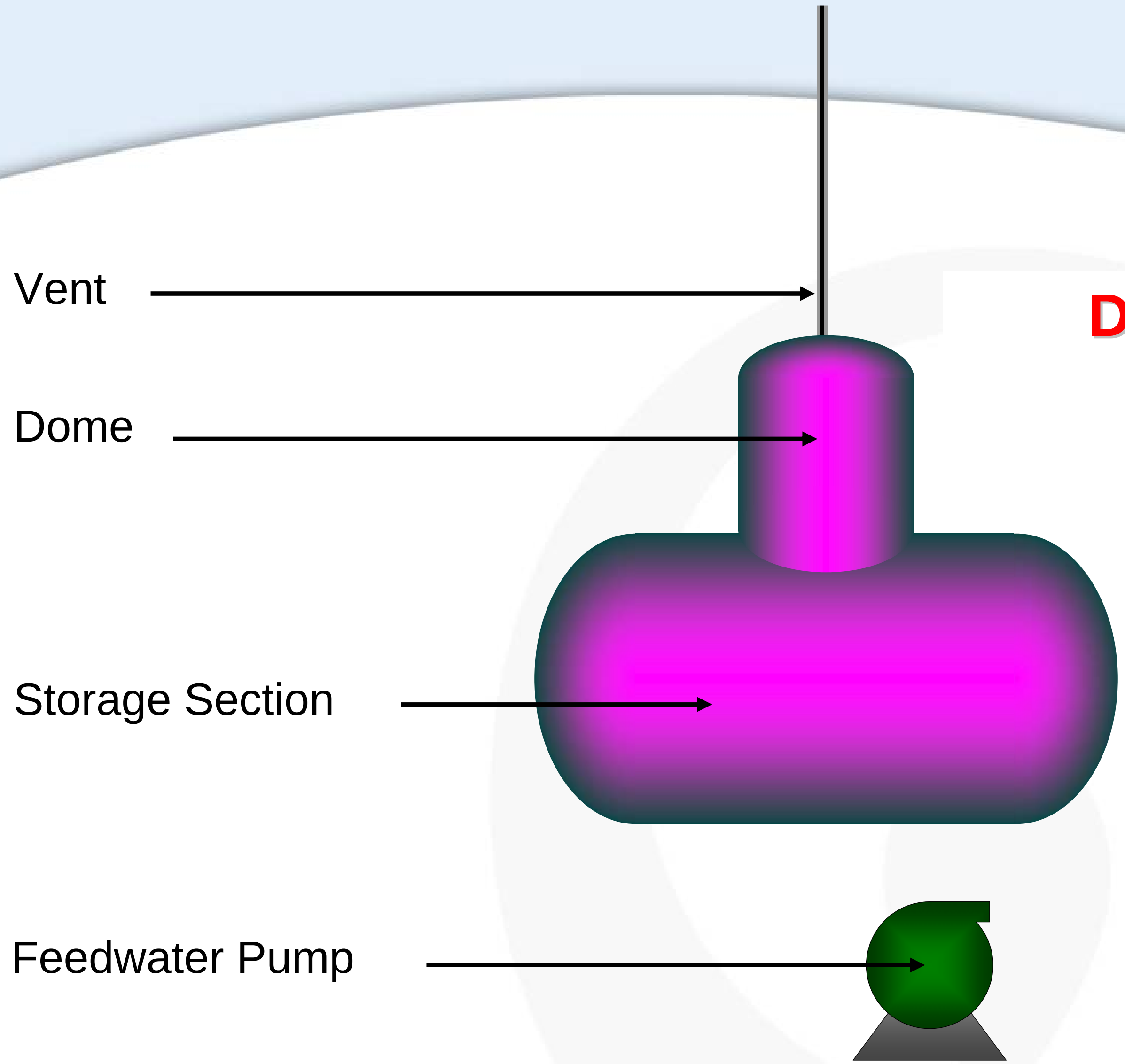
Dispersant (known as sludge conditioner) required for Calcium Phosphate, which otherwise will form a sticky deposit.

External Methods

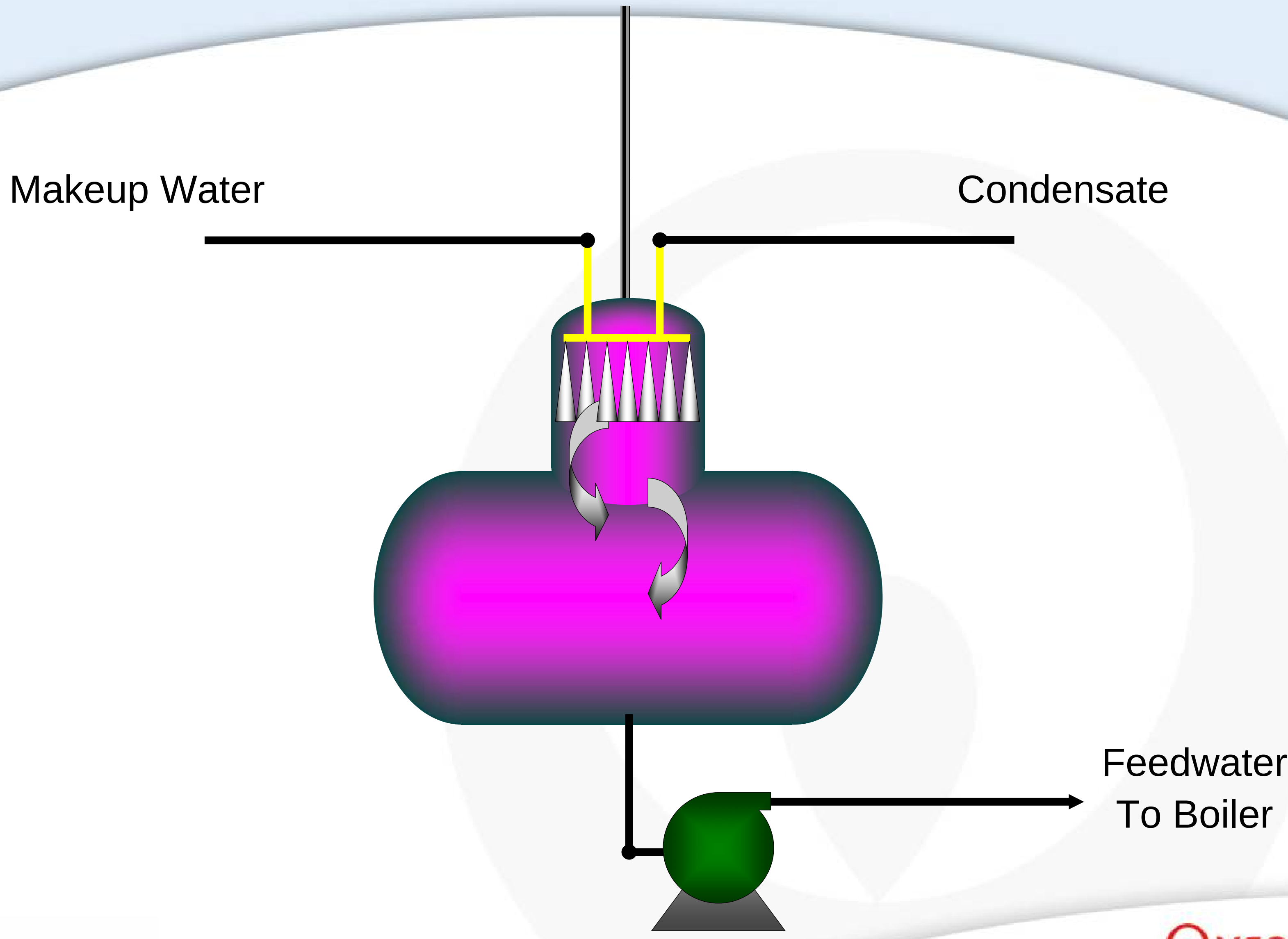
- De-Aeration
- De-Alkalisation (De-Mineralisation)
- Oxygen Scavengers

A deaerator heats boiler feedwater under slight pressure to force oxygen out. The vessel also breaks the water stream into small droplets to provide increased surface area allowing the oxygen to escape more easily.

Deaerator



Deaerator



Oxygen Scavengers

Sulphite

$$Na_2SO_3 + {}^1/_2O_2 \Rightarrow Na_2SO_4$$

Bisulphite

$$NaHSO_3 + NaOH \Rightarrow Na_2SO_3 + H_2O$$

Metabisulphite

$$Na_2S_2O_5 + H_2O \Rightarrow 2NaHSO_3$$

Less bisulphites are required than sulphite, per ppm of oxygen in the water (5.9 for Metabisulphite, 6.5 for Bisulphite and 7.88 for Sulphite).

Bisulphites must be used where free hydroxide is present for sulphite to be produced.

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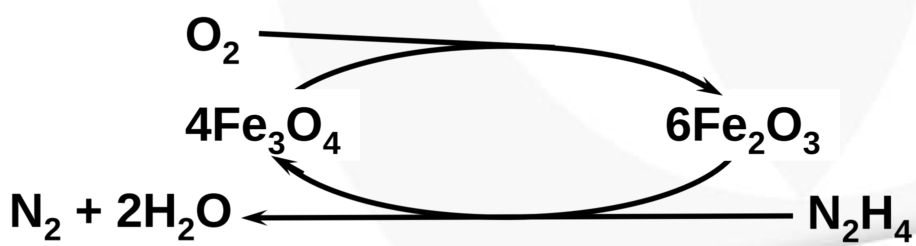
Oxygen Scavengers

Hydrazine

$$N_2H_4 + O_2 \Rightarrow N_2 + H_2O$$

- As oxygen scavenger, dose rate 1:1
- Usually dose an excess; 1.5-2:1
- Normally use catalysed hydrazine for BWT
- Feedwater pH >9.5
- Suitable for up to 2,500 psig
- Passivates metal surface:



Hydrazine Substitutes

	Carbodihydrazide	Ascorbic Acid	DEHA	MEKO
Feedrate	1.41:1	11:01	1.24:1	5.45:1
Reaction	Same or slower than hydrazine	Faster than hydrazine	V. slow @ low temp. Faster than hydrazine	Slow. Requires large excess
Advantages	Safer to handle than hydrazine. Volatile treatment - no solids.	No inorganic solids Ver safe to handle (GRAS). Performs well at low pH	No inorganic solids, volatile, safe to handle, volatile, attemporation acceptable, residual test	No inorganic solids, volatile, safe to handle, volatile, attemporation acceptable, residual test
Disadvantages	More expensive than hydrazine, poor performance at low tem not FDA approved, decomposes to produce ammonia.	Expensive, unacceptabl for superheater layup if flush/drain not possible	Decomposes to produce ammonia, not FDA approved, expensive.	Poor performance, not FDA approved

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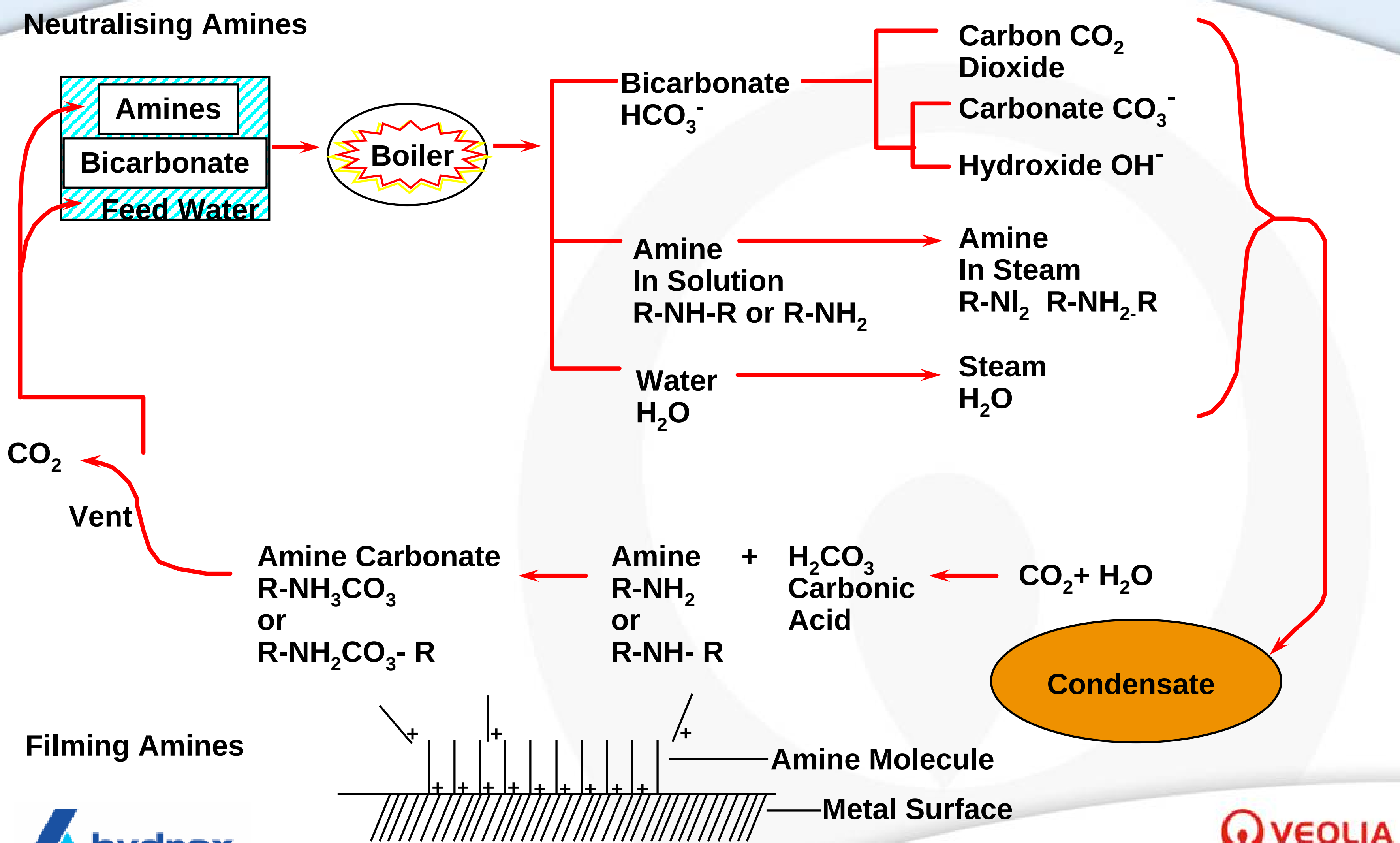
Condensate Protection

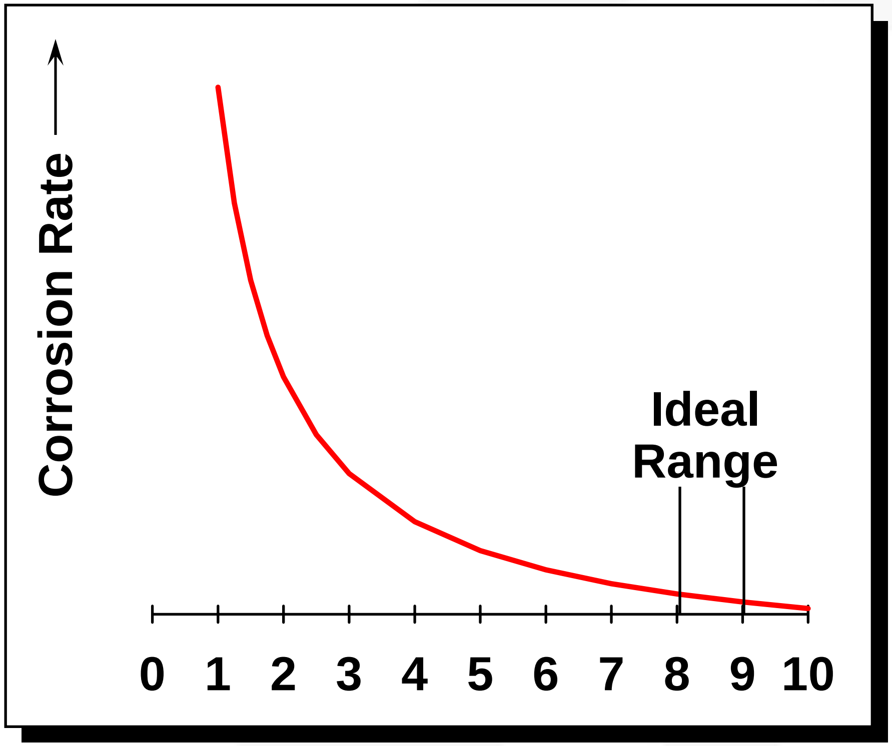
- **Neutralising Amines**
- **Filming Amines**
- **Combination and Blends.**

Condensate Protection



Condensate Protection

Corrosion vs. pH



Dispercants

Scale Control

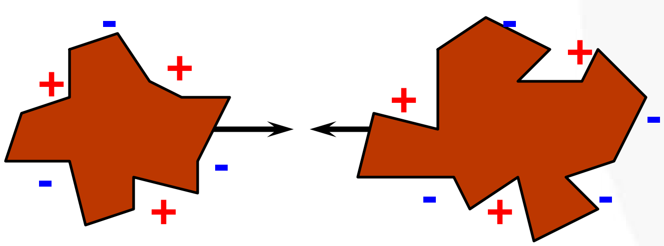
- Remove scale-forming salts

Corrosion (condensate) control

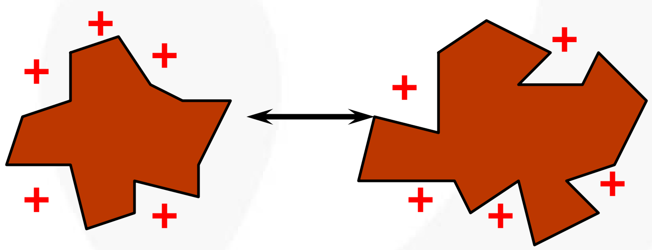
- Dissolved iron in condensateðBoilerðInsoluble Iron

Treatment

Dispersants



No Dispersant



With Dispersant

Why do we need them?

pH Control

Silica Control

$SiO_2 + 3NaOH \Rightarrow NaSiO_3 + H_2O$

OH Alk must be 1.7 × Silica Conc.

Magnesium Scale Control

$MgCl_2 + 2NaOH \Rightarrow Mg(OH)_2 + 2NaCl$

$MgCl_2 + SiO_2 \Rightarrow MgSiO_3 + 2NaCl + H_2O$

Two products form insoluble complex of magnesium hydroxysilicate.

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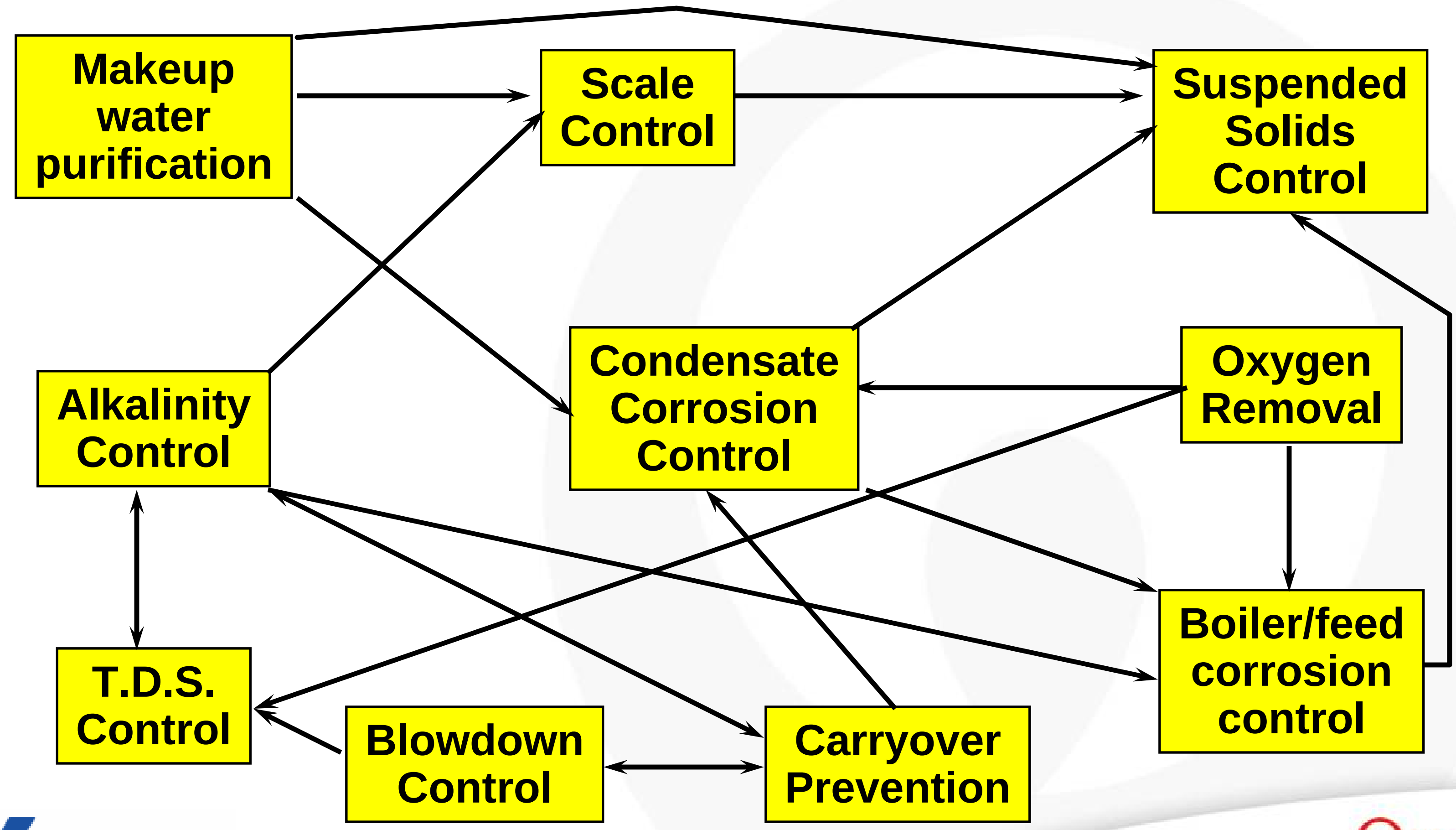
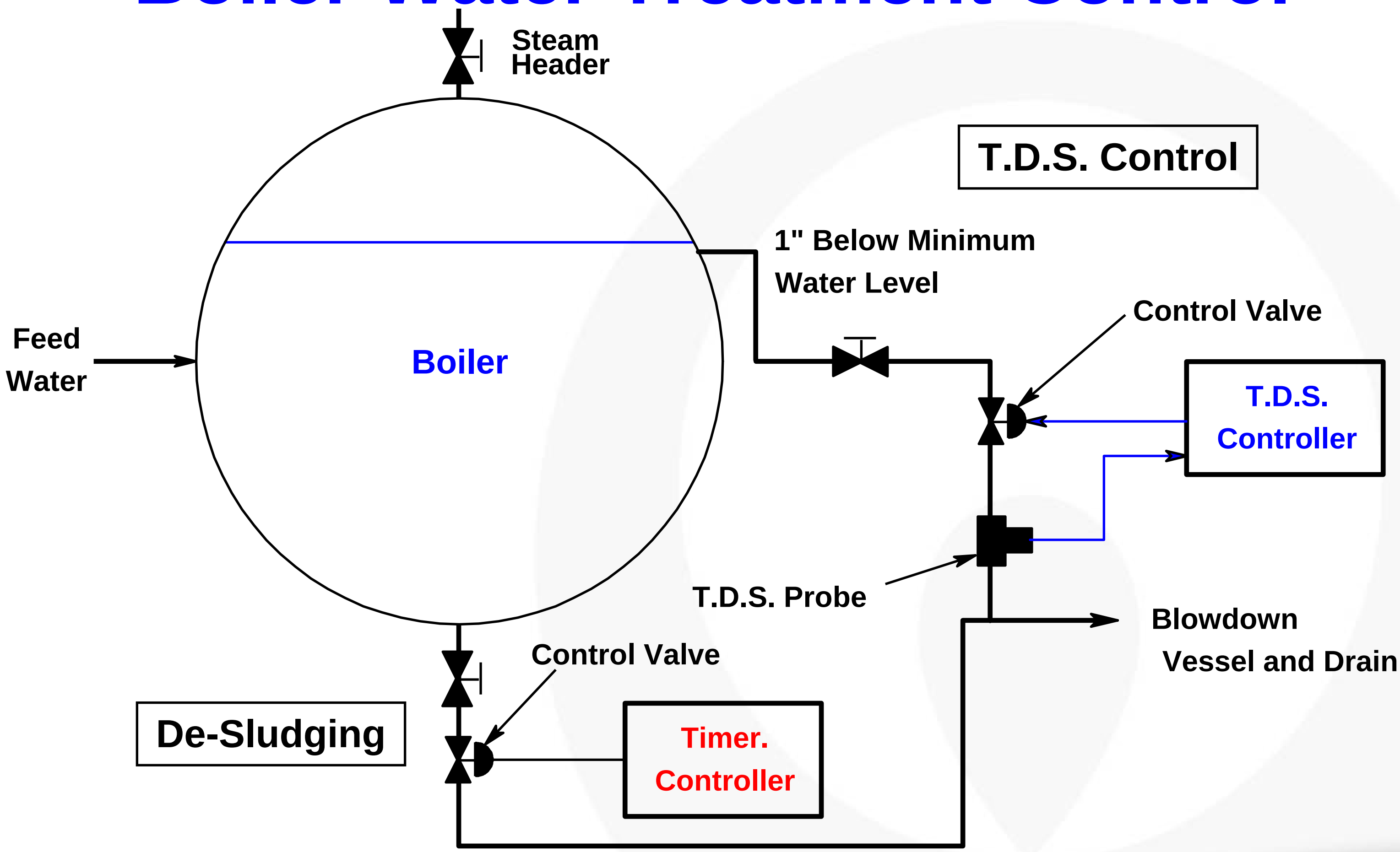
Integrated approach to BWT



Boiler Water Treatment Control



Solids or Water Balance

In = Out

F = E+B

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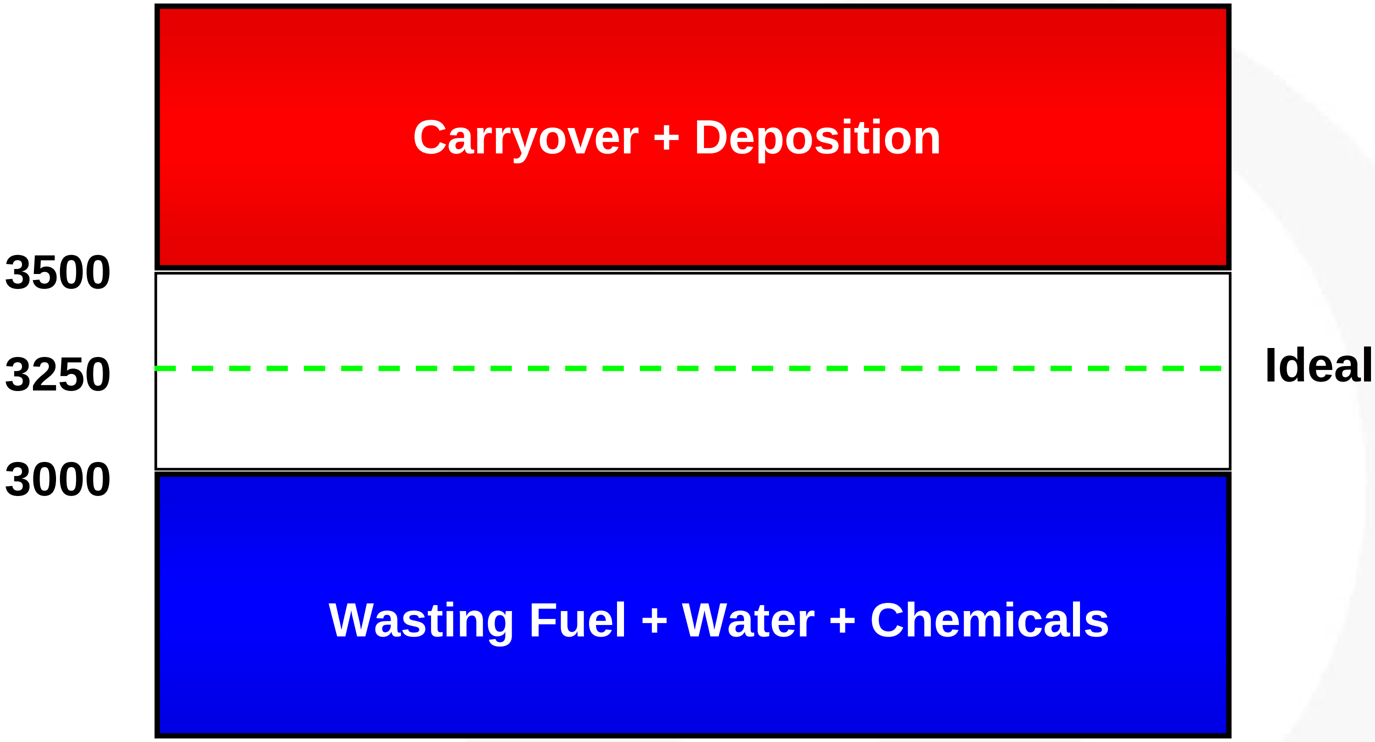
Typical Boiler T.D.S. Control Limits



Boiler Alkalinity

Wasted Chemical

High Boiler T.D.S. → High Blowdown

High Boiler Alkalinity → Carryover

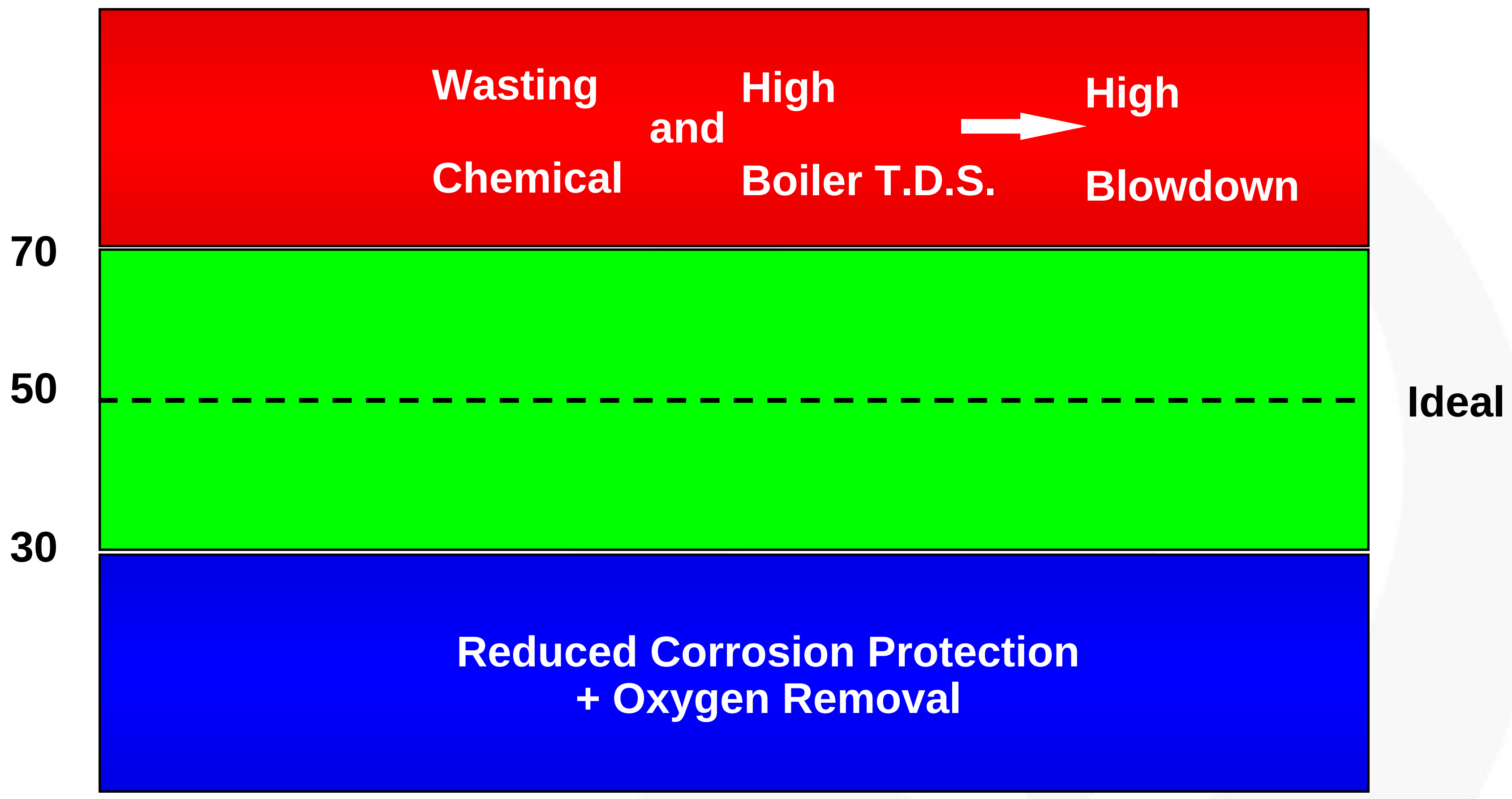
M = 1200

Ideal

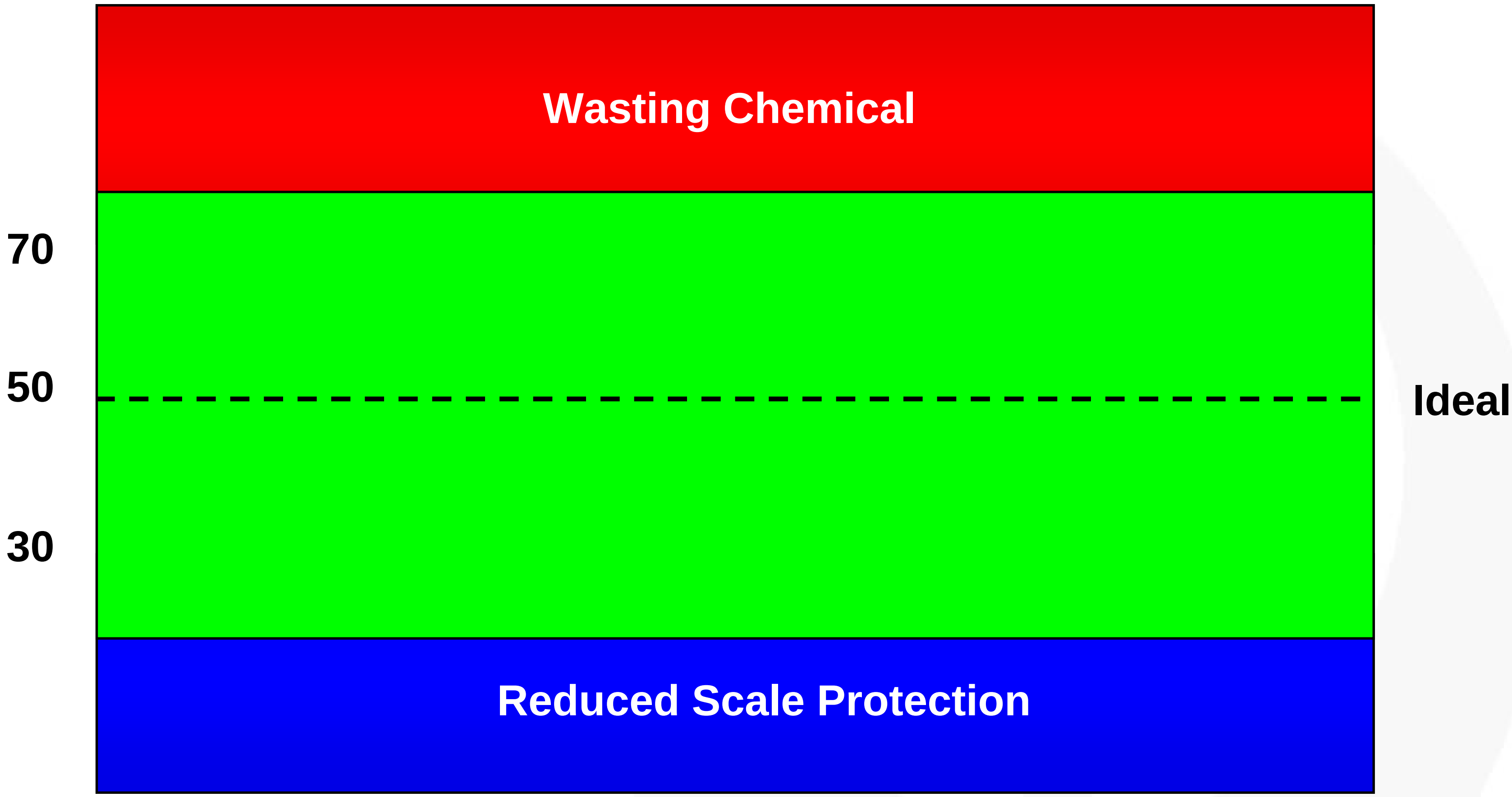
OH = 350

Reduced Protection Against Silica and Magnesium Carbonate Scale Formation

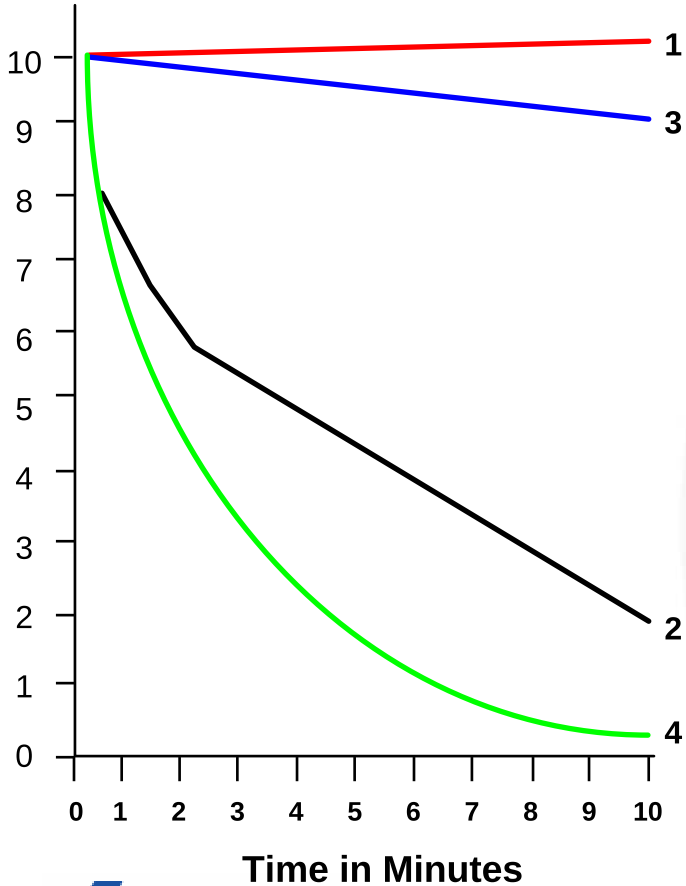
Sulphite Reserve



Phosphate Reserve



Dissolve Oxygen,
Solubilities & Reaction Times



mg/l Uncatalysed and Catalysed Hydrazine = 25

mg/l Uncatalysed and Catalysed Sodium Sulphite = 100

Temperature = 20^0C

pH = 10

Water : Deionised

Curve 1 : Uncatalysed Hydrazine

Curve 2 : Catalysed Hydrazine

Curve 3 : Uncatalysed Sodium Sulphite

Curve 4 : Catalysed Sodium Sulphite

°C	°F	Oxygen for Saturation ppm
0	32	14.16
5	41	12.37
10	50	10.92
15	59	9.76
20	68	8.84
25	77	8.11
30	86	7.83
35	95	7.04
40	104	6.59
50	122	5.57
60	140	4.76
70	158	3.89
80	176	2.89
90	194	1.63
100	212	0

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TREATMENT

1. SURVEY
2. WATER ANALYSIS
3. PRODUCTS SELECTION
4. CALCULATIONS

1 - SUVERY

1. Site name:
2. No. Of boilers
3. Steaming capacity (kg/hr)
4. Operation hours (day/week0
5. Boiler pressure (Psi)
6. Feed Temp (^{0}C)
7. Condensate return (%)
8. Use of steam
9. Softener size (cu ft)
10. Deateator size
11. Dosing system
12. Blow down system
13. Current treatment

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2-WATER ANALYSIS

Sample	Total hardness	Ca Hardness	Alkalinity			Cl^-	TDS	pH	Fe Total	SO_3	PO_4
			P	M	OH						
Raw											
Soft											
Feed											
Cond.											
Boiler											

3 CALCULATIONS (SHELL BOILER)

Determine C_{max} and limiting factor

Max TDS	**:**	**3500 ppm**
Max M.alk	**:**	**1200 ppm**
Max S.S	**:**	**50**
Max Silica	**:**	**133**

$$C_{TDS} = \frac{3500}{\text{Feed TDS} + (O_2 \times 8)}$$

$$C_{Alk} = \frac{1200}{\text{Feed M.Alk} - \text{Feed T. Hardness}}$$

$$C_{S.S} = \frac{50}{\text{Feed T. Hardness} + \text{Feed T. Fe}}$$

C max IS LOWEST ONE

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$$\text{Blow down \%} = \frac{100}{C}$$

$$\text{Feed} = \text{Steam} + \text{Blow down}$$

Testing & Monitoring Boiler Sampling & Analysis

Boiler System Testing - What, Where & Why

Sample	Analysis	Reason
Main Water	T.D.S. Hardness pH	To Check variability of supply
Treated water at each stage	Hardness Alkalinity (P+M) T.D.S. Ph	To check treatment plant operation is satisfactory. Also used to check condensate return.
Feed Water	pH	Low → Corrosive
	Hardness	Contamination or poor treatment plant operation
	T.D.S.	Condensate return
	Alkalinity (P+M)	Condensate treatment Dosing neutralising Amine
	Temperature	For oxygen scavenger Dosing
Boiler Water	Oxygen scavenger reserve	Low → Corrosion / High → Waste
	Phosphate reserve	Low → Scale forming / High → Waster
	'M' Alkalinity	Low → Corrosion / High → Carryover
	'OH' Alkalinity	Low → Scaling / High → Carryover
	T.D.S.	Low → Waste / High → Carryover
	pH	Low → Corrosive
Condensate	pH	Low → Corrosive / High → Carryover
	T.D.S.	High → Carryover
	Iron	High → Corrosion

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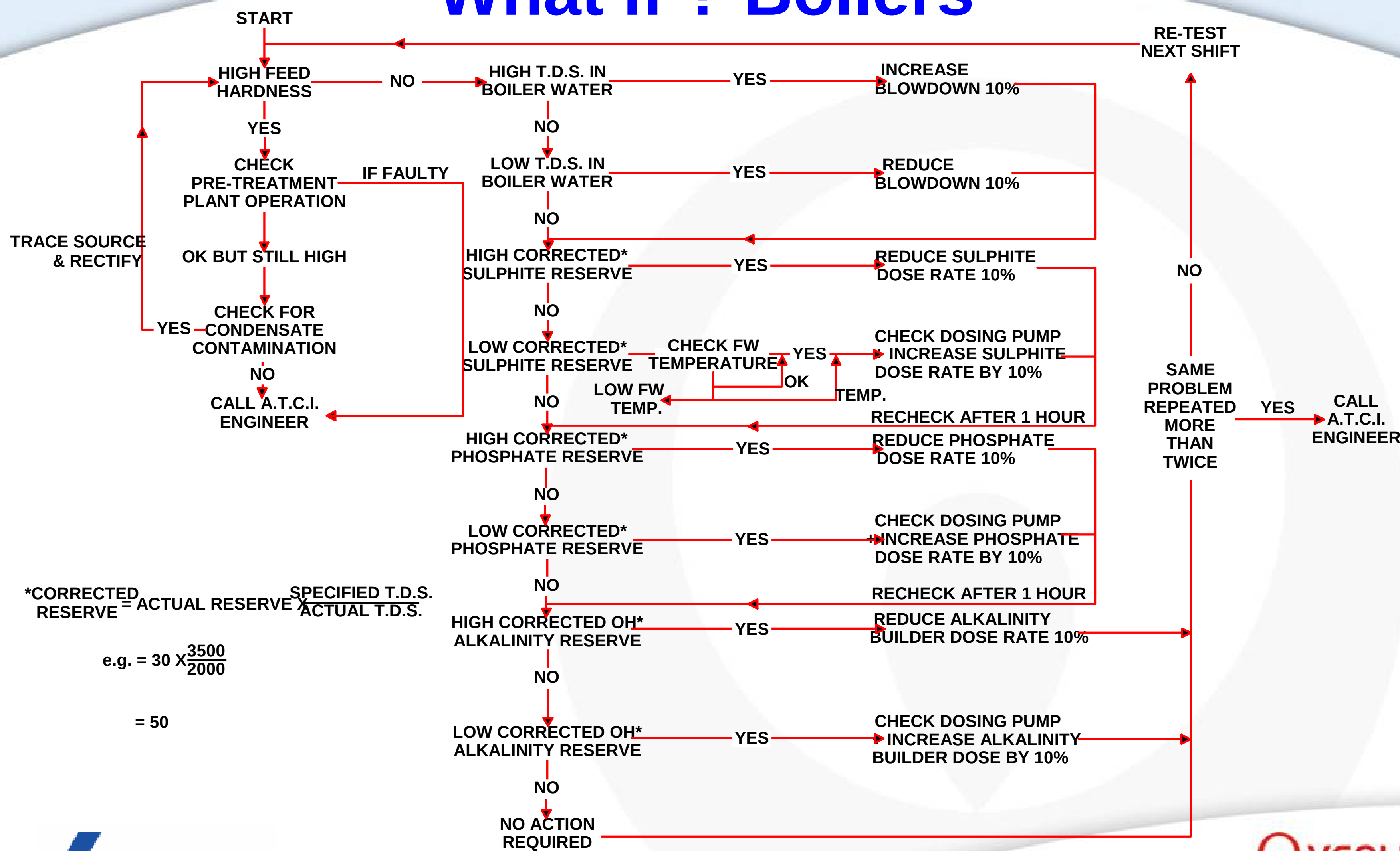
What if ? Boilers



$$\text{*CORRECTED RESERVE} = \text{ACTUAL RESERVE} \times \frac{\text{SPECIFIED T.D.S.}}{\text{ACTUAL T.D.S.}}$$

$$\text{e.g.} = 30 \times \frac{3500}{2000}$$

$$= 50$$

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