By: MOTAZ_95

Boiler – Fundamentals and Best Practices

Boiler - Fundamentals

Steam production and steam uses

Steam purity and steam quality

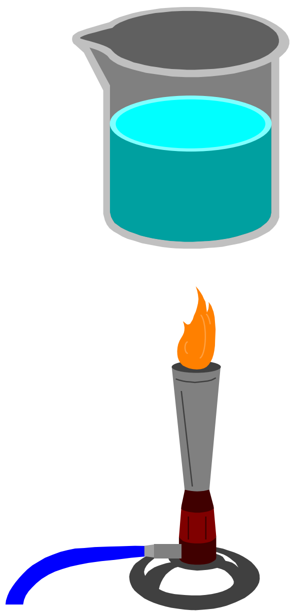
Types of boilers

Basic boiler principles

Basic boiler calculations

Steam Production
and
Steam Uses

Steam Production



When heat is added to water, its temperature rises at a rate of 0.56°C (1°F) for each heat input of 2.095 kJ/kg (1 Btu/lb)

If we take water at 0°C (32°F) and we add 419 kJ/kg (180 Btu/lb) then we will increase the temperature of the water by 100°C (180°F)

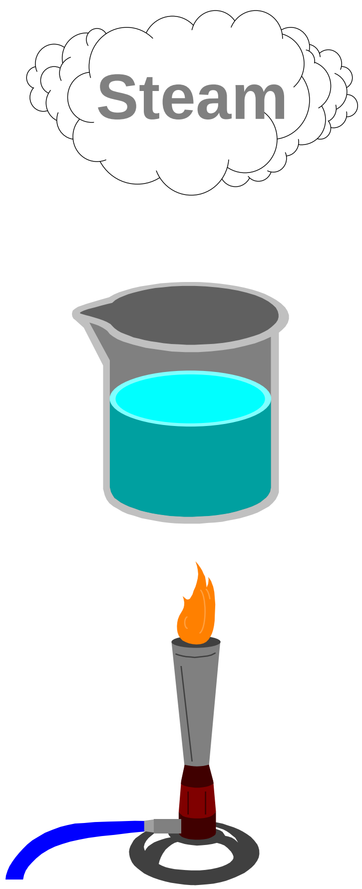
This rise in temperature can be detected and is called Sensible Heat (Specific Enthalpy - Water)

Steam Tables

Pressure psig	Temperature °F	Sensible Heat Btu/lb	Latent Heat Btu/lb	Total Heat Btu/lb	Volume Dry Saturated ft^3/lb
0	212	180	971	1151	26.80
15	250	218	946	1164	13.90
31	275	244	929	1173	9.30
51	299	268	912	1180	6.60
100	338	309	882	1190	3.89
150	366	339	858	1997	2.76
200	388	362	838	1200	2.14

Pressure barg	Temperature °C	Water kJ/kg	Evaporation kJ/kg	Steam kJ/kg	Specific Volume Steam m^3/kg
0	100.00	419.04	2257.00	2676.00	1.673
1	120.42	505.60	2201.10	2706.70	0.881
2	133.69	562.20	2163.30	2725.50	0.603
4	151.96	640.70	2108.10	2748.80	0.374
6	165.04	697.50	2066.00	2763.50	0.272
10	184.13	781.60	2000.10	2781.70	0.177
14	198.35	845.10	1947.10	2792.20	0.132

Steam Production

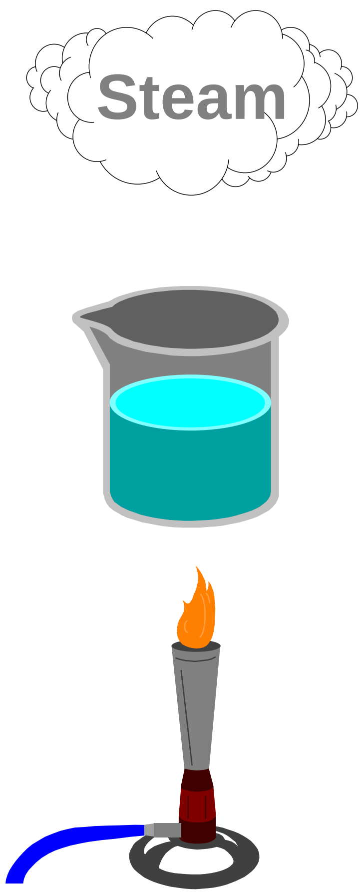


At normal atmospheric pressure, any further addition of heat to water at 100°C will not increase the temperature but will convert some of the water into steam

In order to convert water into steam 2,257 kJ/kg (971Btu/lb) of additional heat must be added

This cannot be detected as a rise in temperature and is called the Latent Heat of Vaporisation (Specific Enthalpy - Evaporation)

Steam Production



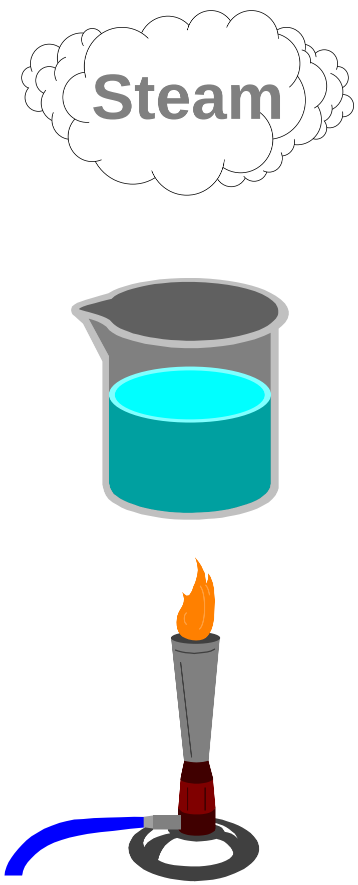
Total Heat of Steam = Sensible Heat + Latent Heat of Vaporisation

Specific Enthalpy :
Steam = Water + Evaporation

Thus the Total Heat of Steam (Specific Enthalpy - Steam) is 2,676 kJ/kg (1151 Btu/lb)

This data is found in Steam Tables

Steam Production



From steam tables we can see that the total heat of steam does not vary a great deal as the boiler pressure increase

The boiling point (b.p.) increases as the pressure increases

Thus the sensible heat increases as the pressure increases, and the latent heat decreases

Boiler pressures are expressed in psia, psig, bar, kg/cm^2, kpa

Steam Uses

Space heating

Drying - paper mill

Process heating

Sterilisation

Humidification

Power generation

Steam Purity
and
Steam Quality

Steam Purity

Steam purity is an expression of the quantity of non water components in the steam

Components can be dissolved in the steam, dissolved in water droplets entrained in the steam or carried as discrete solid particles in the steam

Steam impurities are normally expresses as a quantity in parts per million (ppm) or parts per billion

Steam Quality

Steam quality relates to the quantity of moisture present in the steam

100% quality specifying no moisture content

0% quality specifying all liquid

Liquid droplets entrained in the steam leaving a boiler contain dissolved solids

Types of Boilers

Types of Boilers

- **Fire Tube**
- **Water Tube**
- **Waste Heat**

Types of Boilers

Fire Tube Boilers

Low Pressure Systems

Water Tube Boilers

Medium to High Pressure Systems

Waste Heat Boilers

Process applications
HRSG

Fire Tube Boilers

Also referred to as smoke tube boilers, shell boilers, package boilers

Multiple gas paths - 2, 3 and 4 pass

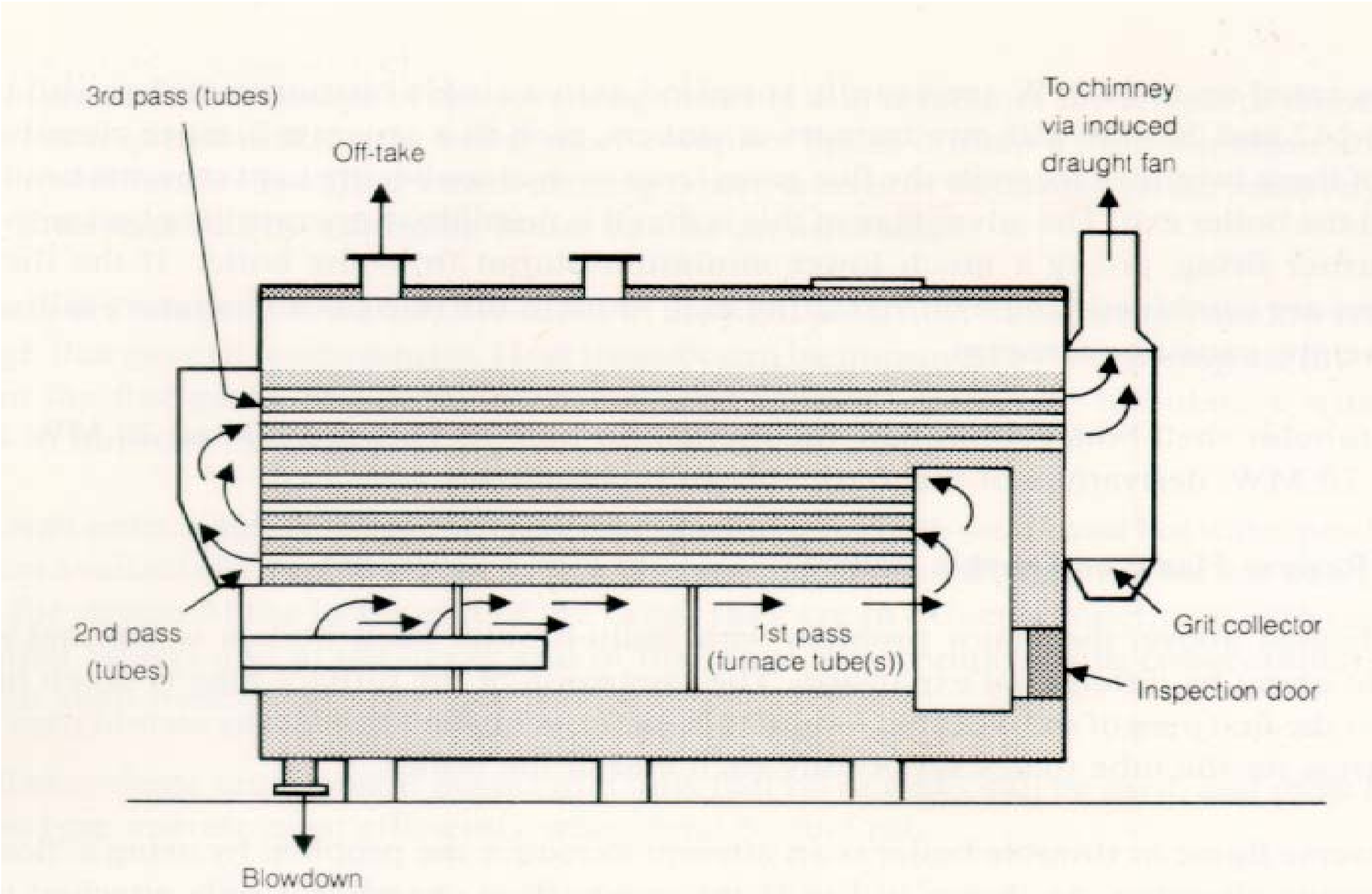
Internal furnace or fire box as the 1st pass

Dry back or wet back design

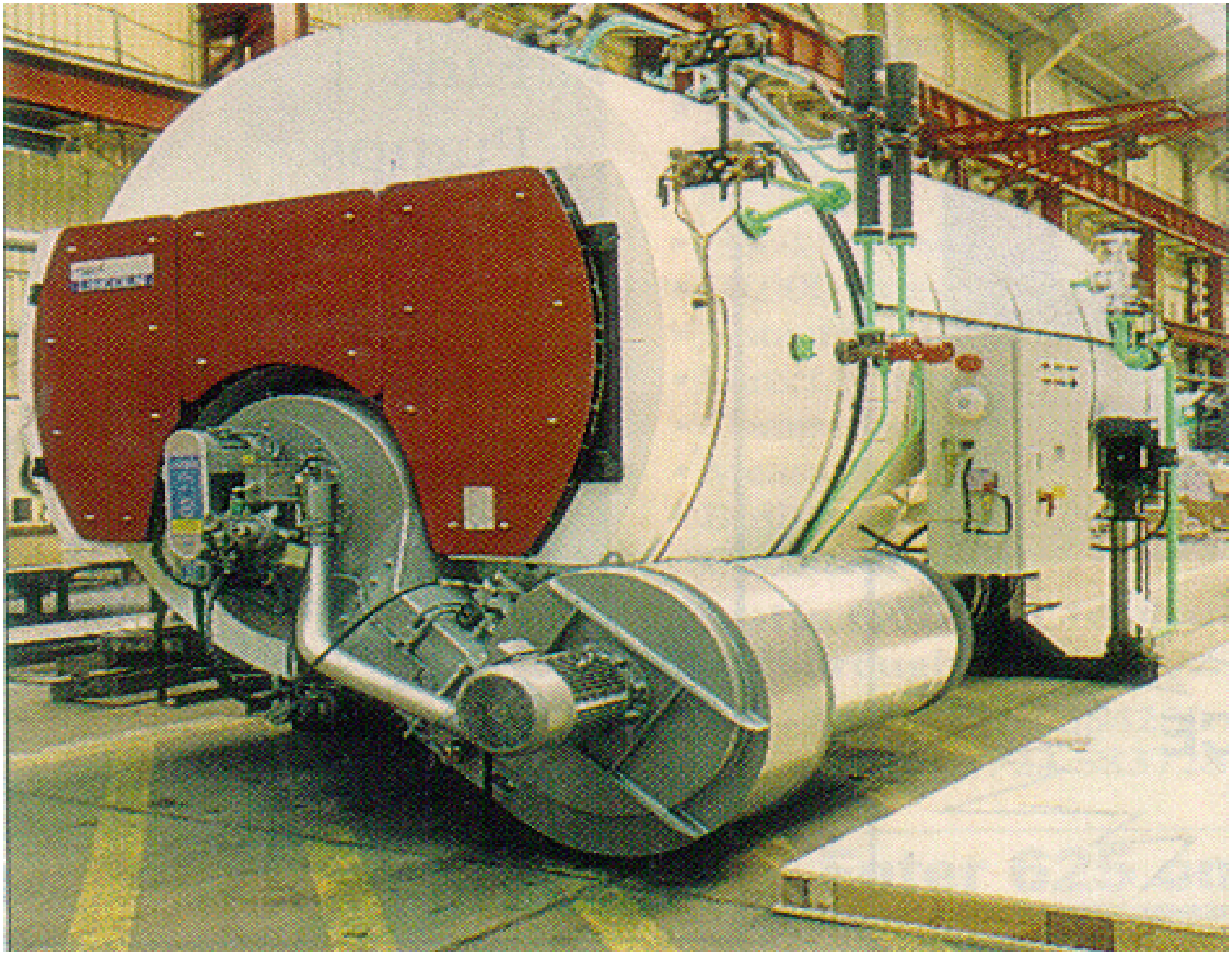
Single fuel or dual fuel design

Little or no steam separation equipment

Fire Tube Boilers



Fire Tube Boilers



Fire Tube Boilers

Typical designs are O, D and A type boilers

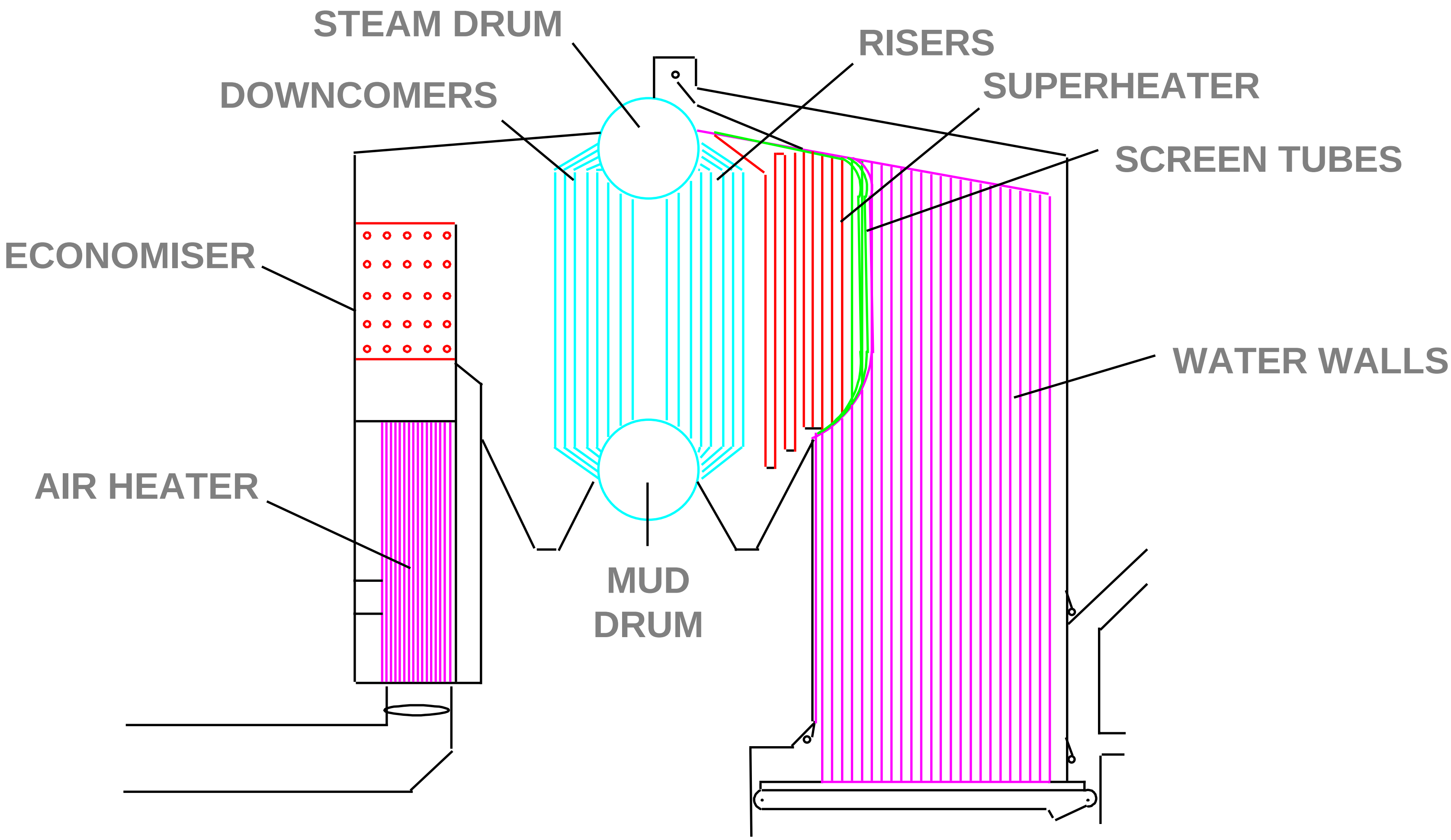
Steam separation equipment - drum furniture

- Cyclone separators
- Demister pads
- Baffle plates

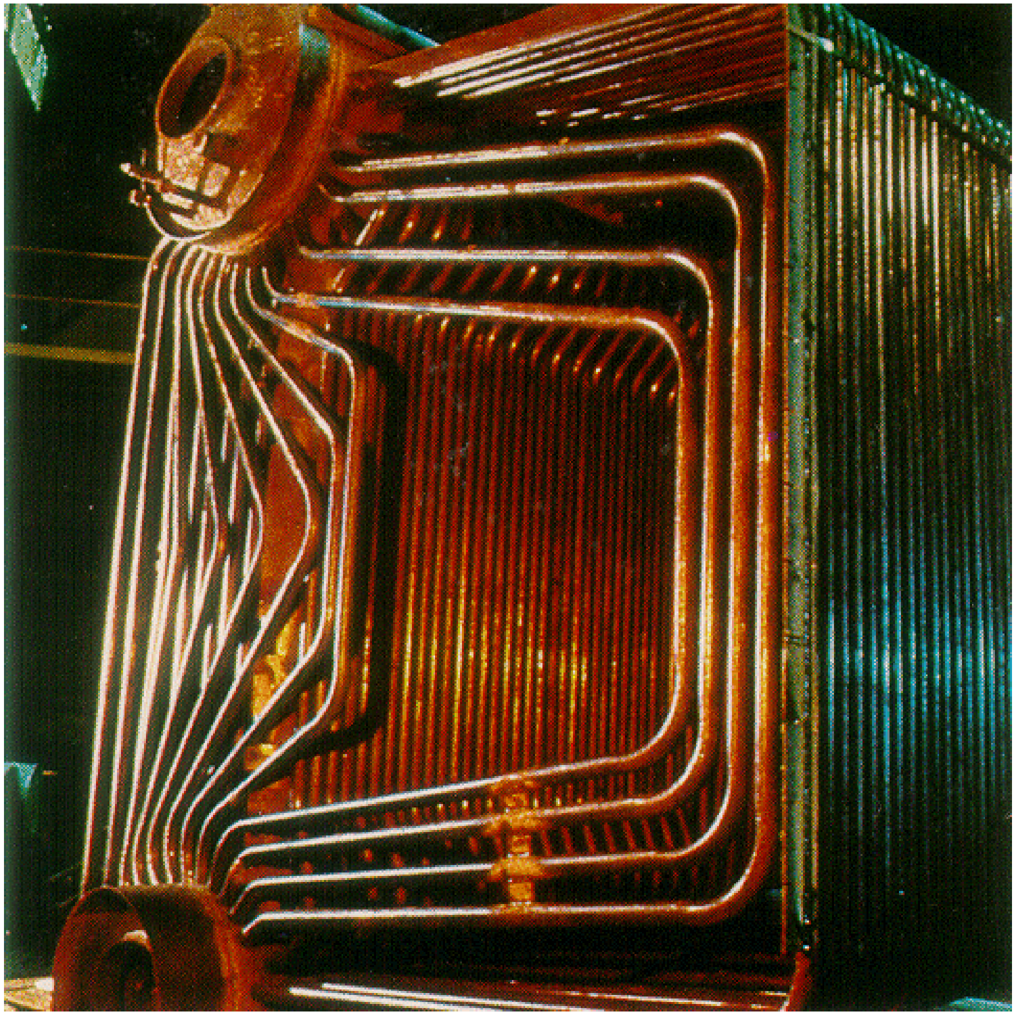
Have economisers and superheaters

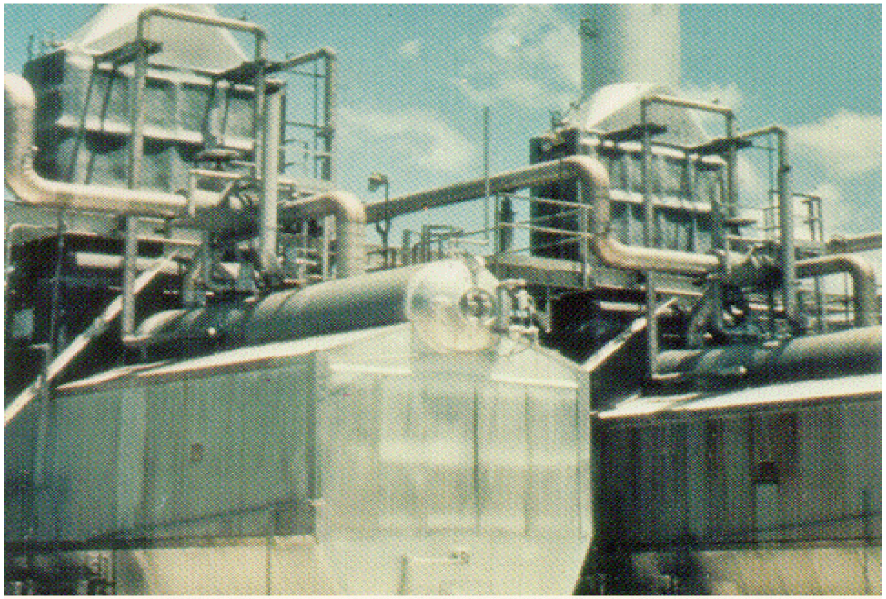
Large water tube boilers are field erected and may be unique design

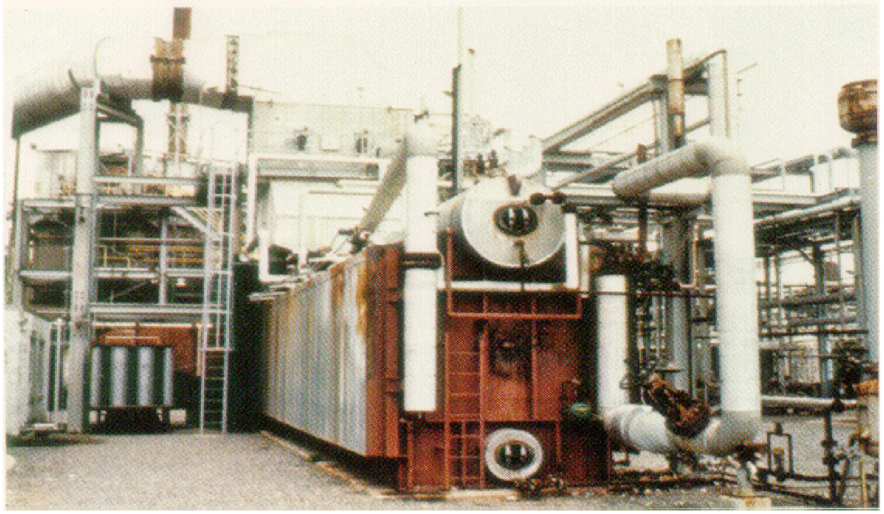
Fire Tube Boilers



Fire Tube Boilers







Waste Heat Boilers

Various types and designs

Shell and tube exchanger

Linked to process

Ammonia plant

Waste Heat Boiler

Ammonia Plant

Heat Recovery Steam Generators (HRSG)

Various types and designs

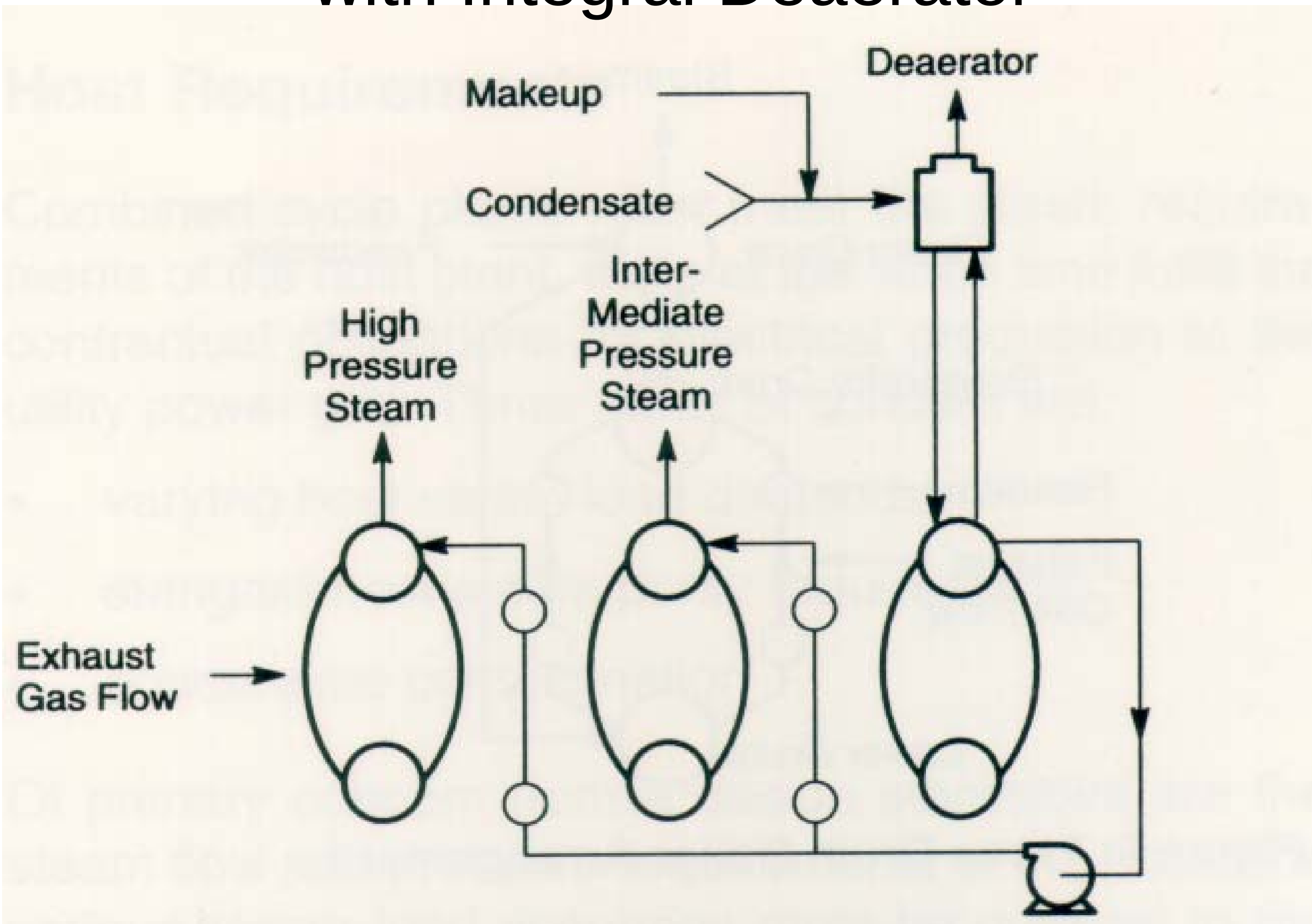
Shell and tube exchanger

Water tube boiler

Multiple drum system

- low pressure (LP)
- medium pressure (MP)
- high pressure (HP)

Multi Pressure Boiler System with Integral Deaerator



Steam Generators

Coil designs, vertical or horizontal

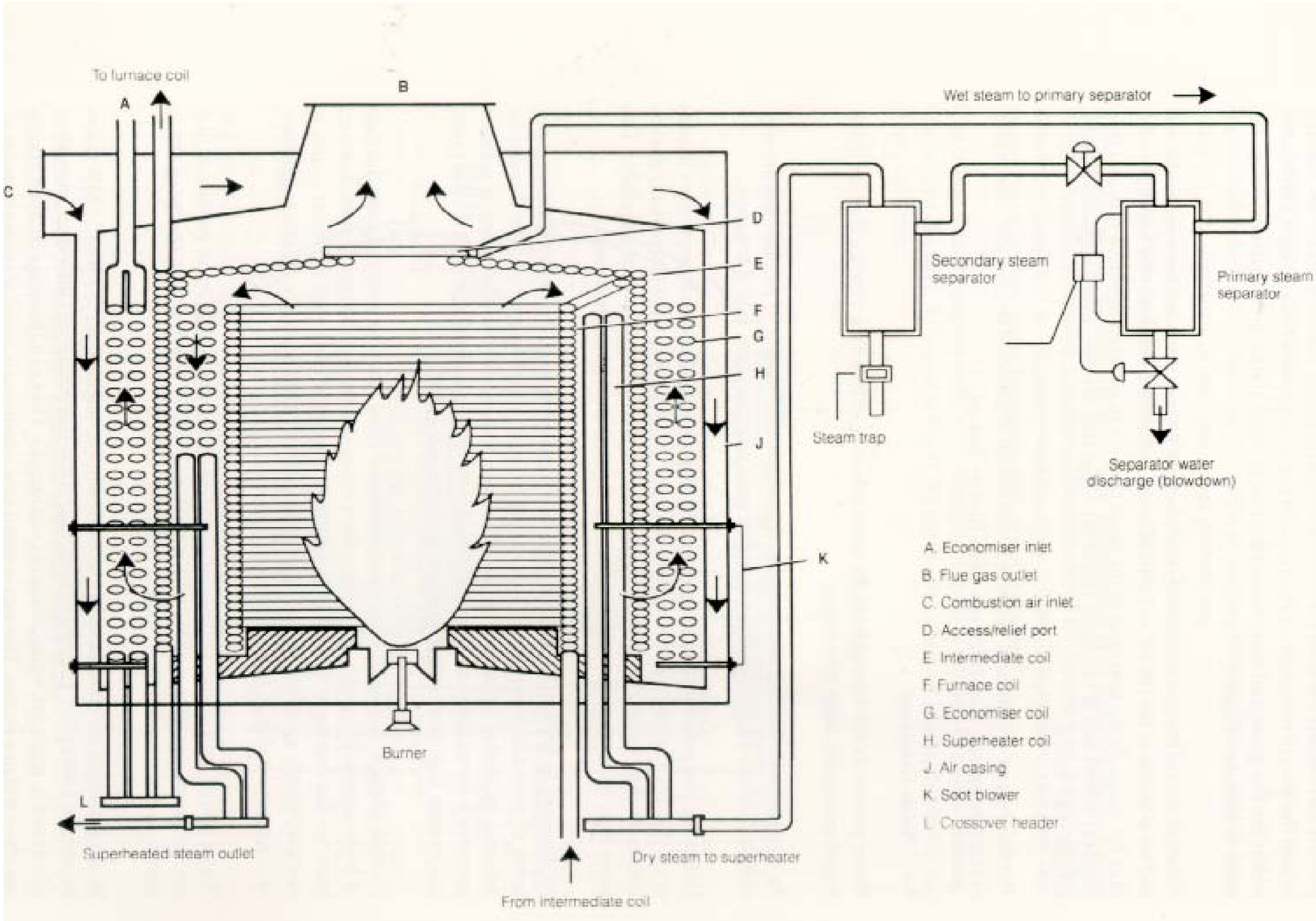
Bucket types

Steam water separator

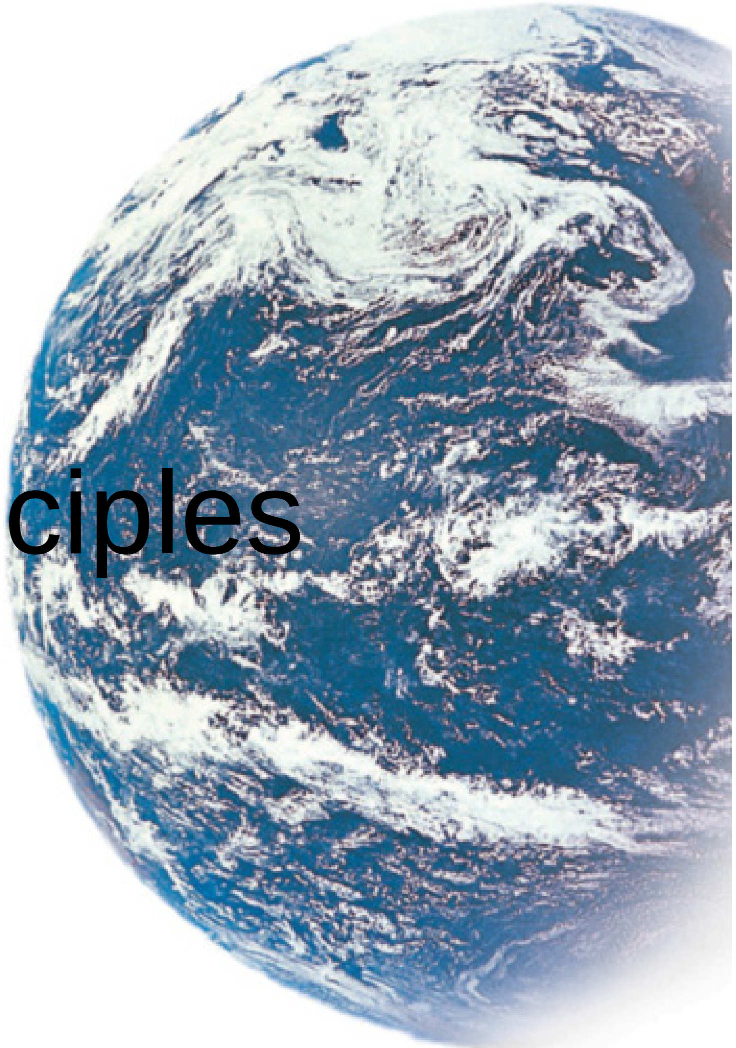
Boiler water returned to feed tank

May include economiser and superheater

Steam Generator - Coil



Basic Boiler Principles



Basic Boiler Principles

EXTERNAL TREATMENT

MAKE UP

WATER
AND
SOLIDS

HOT WELL
DEAERATOR

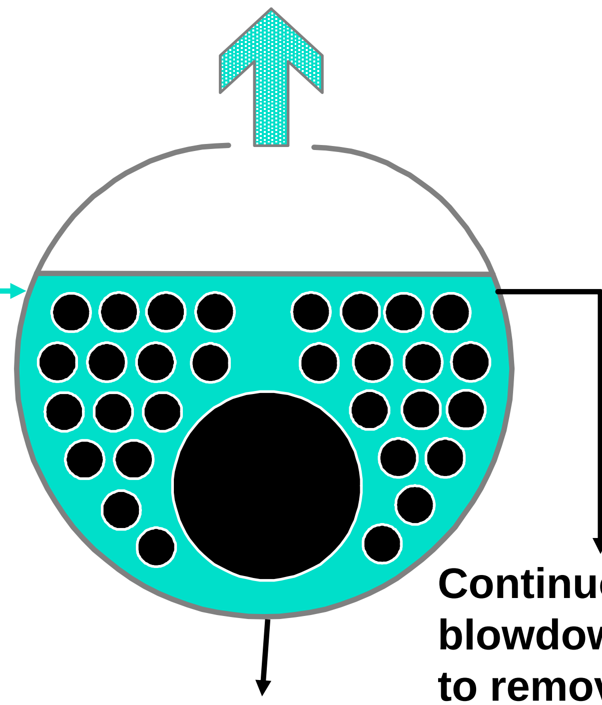
RETURNED CONDENSATE

WATER AND HEAT

FEEDWATER

WATER
AND
SOLIDS

SATURATED STEAM
EVAPORATED WATER



Continuous blowdown to remove dissolved solids in boiler water

Intermittent blowdown to remove suspended solids in boiler water

Blowdown - Removes boiler water with a high concentration of solids which is replaced by feedwater containing a low concentration of solids

Basic Boiler Principles

Water and solids enter the boiler

Water leaves the boiler as steam

Solids concentrate in the boiler

Therefore the boiler water will contain more solids than the feedwater

This Concentrating effect is called

The Cycles of Concentration or The Cycles

Basic Boiler Principles

A boiler can only tolerate a specific number of cycles of concentration

This will vary depending on

Type and pressure of the boiler

Type of external treatment

Percentage condensate return

Basic Boiler Principles

The chemical factors which limit the boiler water cycles of concentration are

Suspended solids (Total Hardness)

Dissolved solids

Total alkalinity (M Alkalinity)

Silica

Basic Boiler Principles

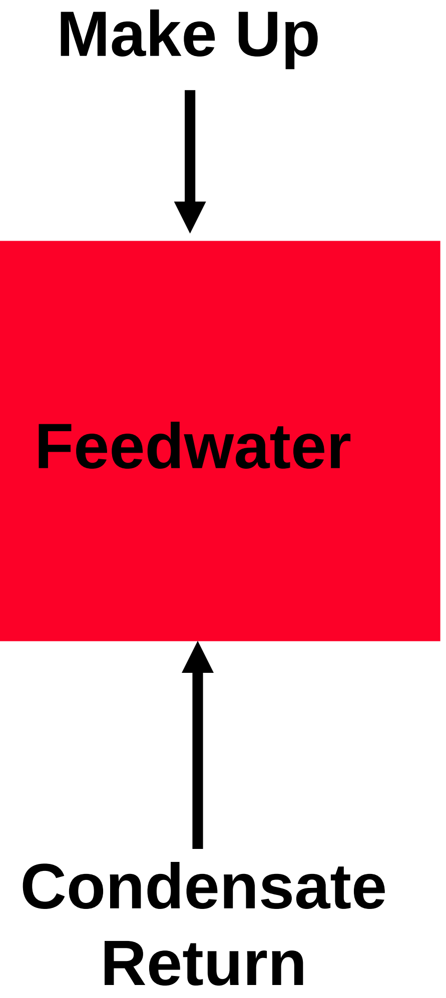
How do we determine the chemical control limits that we apply to an operating boiler ?

- British Standard BS2486:1997
- ASME Guidelines* 1994

★ Consensus on operating practices for the control of feedwater and boiler water chemistry in modern industrial boilers

Basic Boiler Calculations

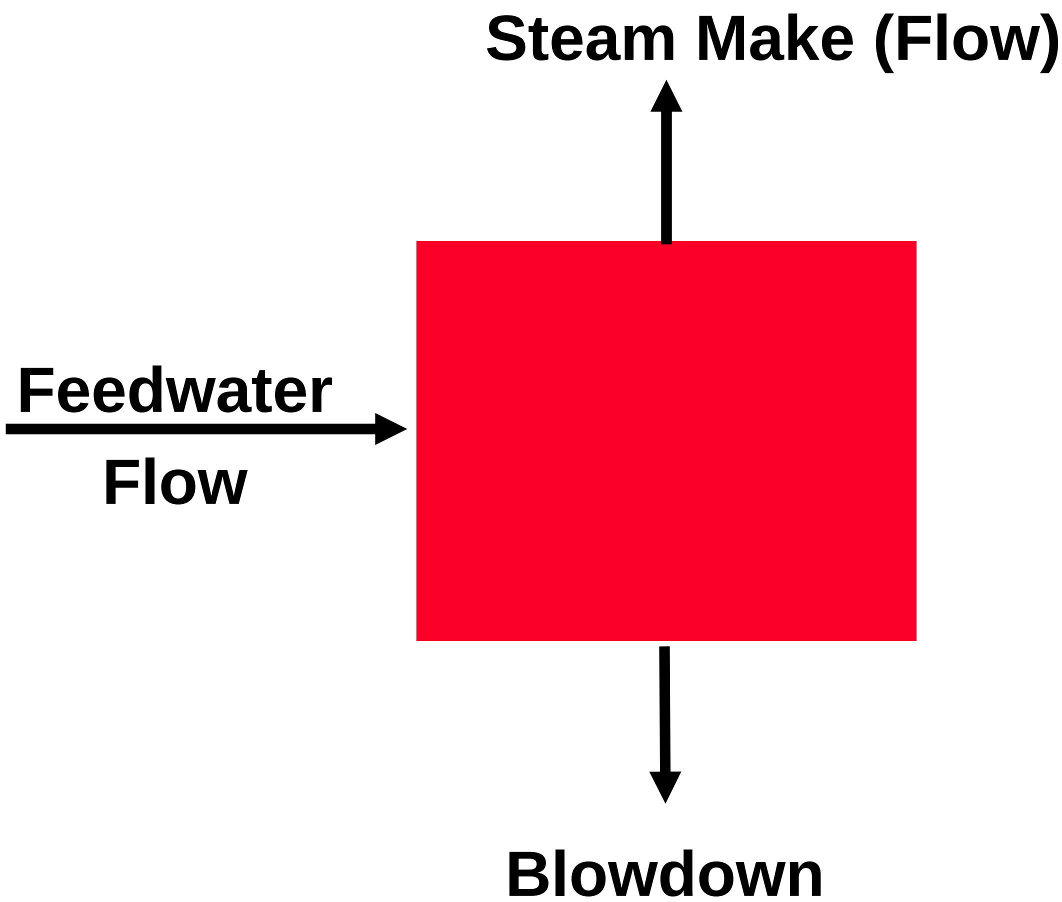
Basic Boiler Calculations



Basic Boiler Calculations

- Feedwater = Make up + Condensate Return

Basic Boiler Calculations



Basic Boiler Calculations

- Feedwater = Make up + Condensate Return
- Feedwater Flow (FWF) = Steam Make + Blowdown

Basic Boiler Calculations

- Feedwater = Make up + Condensate Return
- Feedwater Flow (FWF) = Steam Make + Blowdown(BD)
- Feedwater Flow (FWF) = Steam Make + Steam Make
- Cycles - 1

Basic Boiler Calculations

- Feedwater = Make up + Condensate Return
- Feedwater Flow (FWF) = Steam Make + Blowdown(BD)
- Feedwater Flow (FWF) = Steam Make + Steam Make
- Cycles -1
- Blowdown = Steam make or = FWF
- Cycles –1 Cycles
- % Blowdown = 1 as a % of FWF
- Cycles

Basic Boiler Calculations

Condensate Return is also expressed as % of FWF

If Condensate Return = 60% Make up = 40%

% Condensate + % Make up = 100% = FWF

As the boiler water cycles of concentration increase then the feedwater flow and the steam make approach the same number

Basic Boiler Calculations

Calculate the feedwater composition (impurities) from make up and condensate analysis below

	Make-Up	Condensate	Feedwater
Total Hardness	2	0	
M Alkalinity	200	10	
TDS	350	15	
Silica	6	0	
% Condensate		50	

Basic Boiler Calculations

Calculate the feedwater composition (impurities) from make up and condensate analysis below

	Make up	Condensate	Feed water
Total Hardness	**2**	**0**	**1**
M Alkalinity	**200**	**10**	**105**
TDS	**350**	**15**	**182.5**
Silica	**6**	**0**	**3**
% Condensate		**50**	

Boiler Water Best Practises

Boiler Water

Internal Treatment

Technology

Why is Effective Internal Boiler Water Treatment Necessary ?

Effective Internal Boiler Water Treatment

Controls

- Deposition
- Corrosion
- Carryover

and

Enhances System Reliability and Efficiency

- Avoids unscheduled shutdowns
- Helps ensure uninterrupted production
- Reduces maintenance costs
- Reduces operating costs

What Operating Costs are Associated with Boiler Operation ?

Boiler Operating Costs

- Fuel - Gas, Oil, Coal
- Water - Influent and Effluent
- Regenerants - Salt, Acid, Caustic
- Water Treatment

Boiler Operating Costs

- Fuel - Gas, Oil, Coal
- Water - Influent and Effluent
- Regenerants - Salt, Acid, Caustic

- Water Treatment

Boiler Operating Costs

- Need to minimise all operating costs

  Reducing boiler water blowdown gives water, energy and chemical savings

- Need to maximise efficiency

  Maintain clean heat transfer surfaces

  Heat recovery systems

Effective Internal Boiler Water Treatment

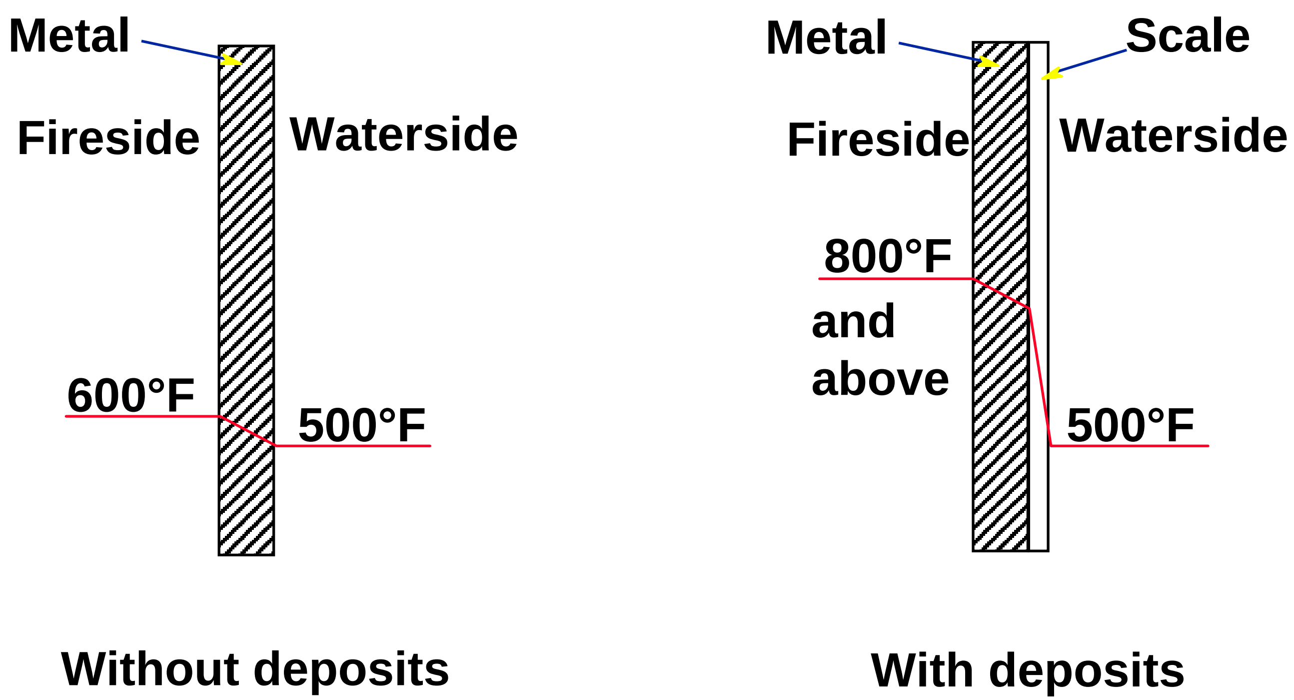
Controls

- Deposition

Boiler Water Deposit Control

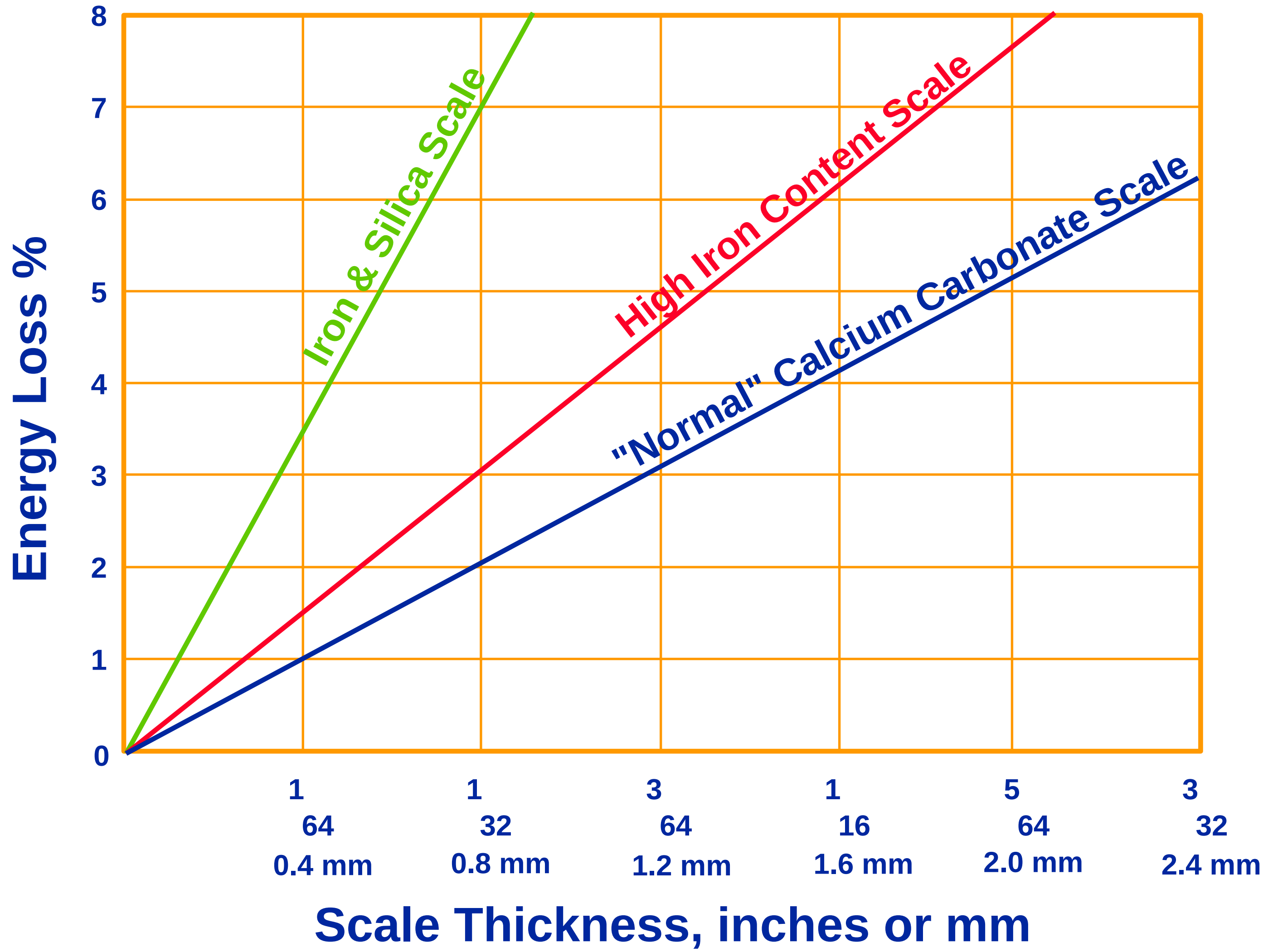
- Hardness salts
  - Calcium
  - Magnesium
- Metal oxides
  - Iron
  - Copper

Comparison of Heat Transfer Surfaces With and Without Deposits



Energy Loss from Scale Deposits

(from Energy Conservation Programme Guide for Industry & Commerce)



Long Term Overheating

Boiler Water Deposit Control

- Removal of impurities
  - Pretreatment plant
- Chemical treatment
- Controlled blowdown

Effective Internal Boiler Water Treatment

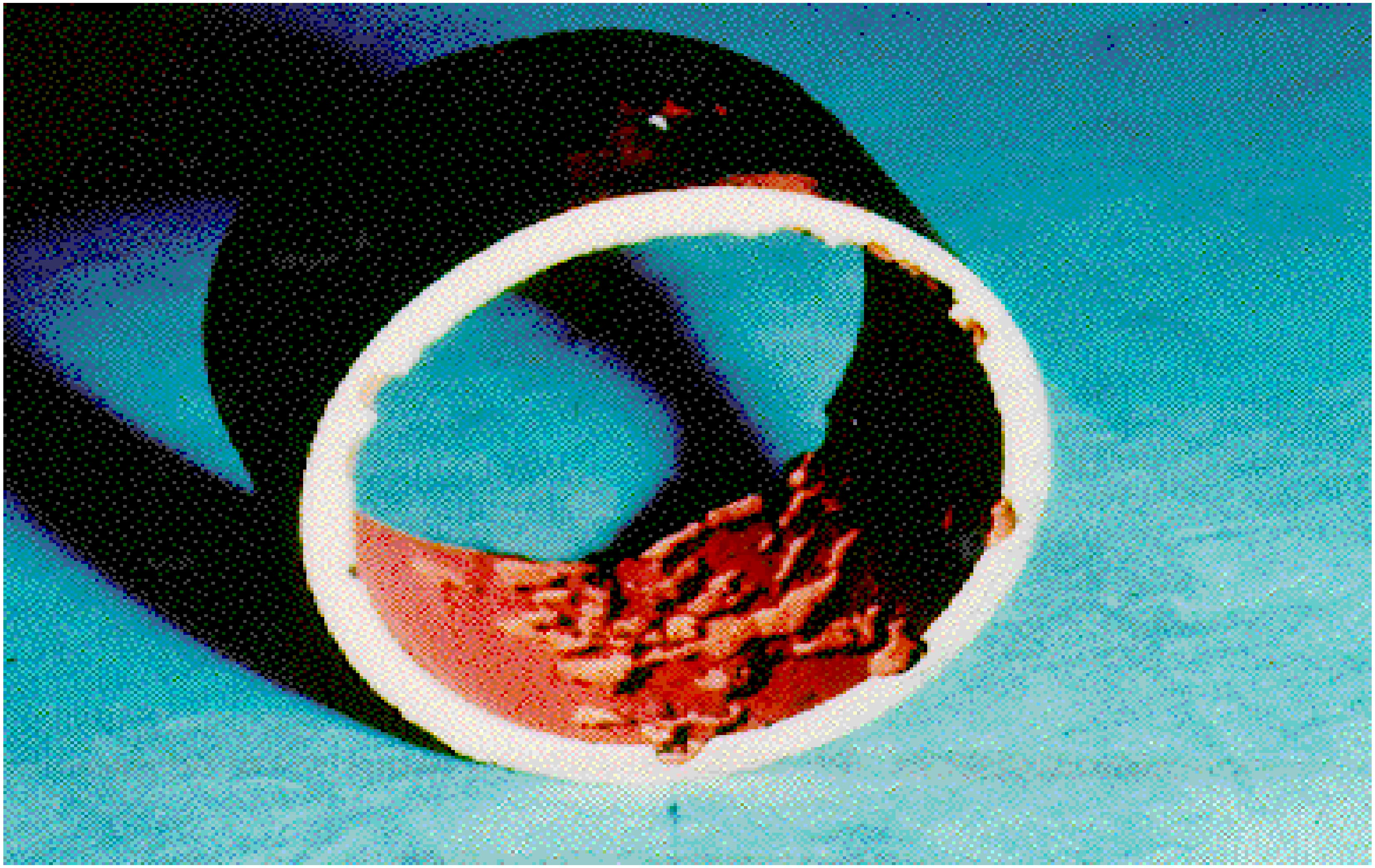
Controls

- Deposition
- Corrosion

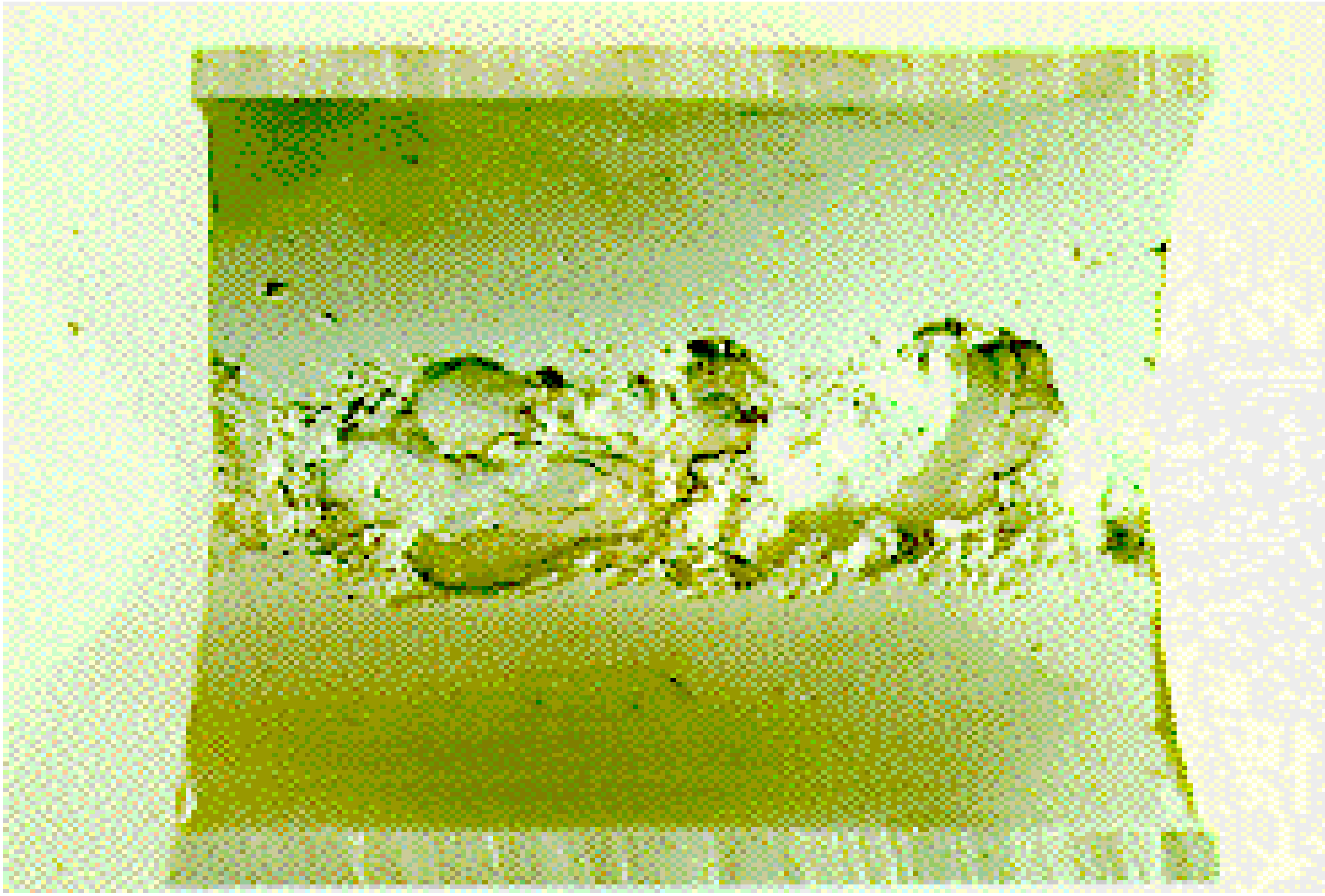
Boiler Water Corrosion Control

- Oxygen pitting
- Caustic corrosion
  - Embrittlement or gouging
- Acidic attack

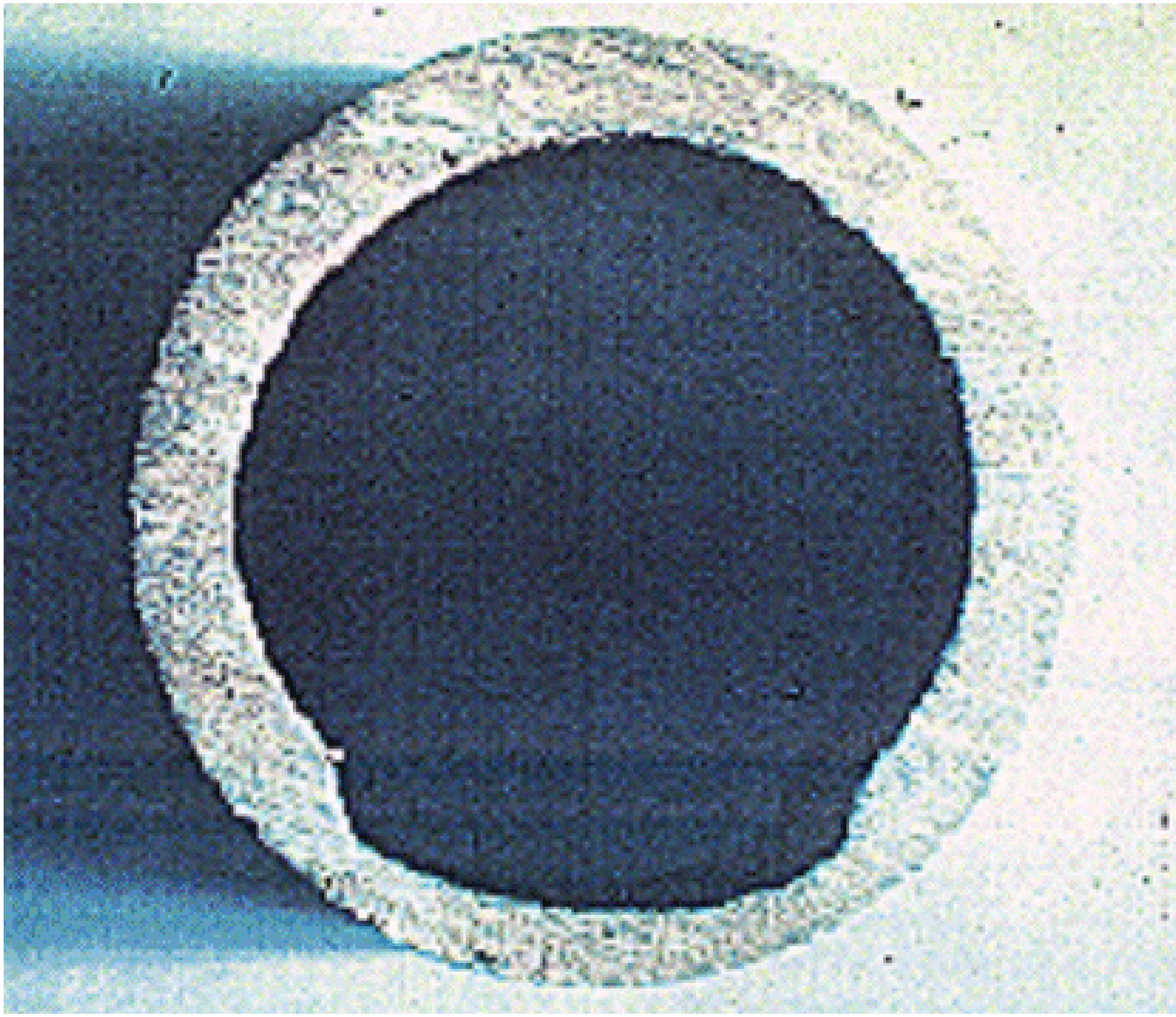
Oxygen Corrosion - Pitting



Caustic Gouging



Acid Corrosion



Effective Internal Boiler Water Treatment

Controls

- Deposition
- Corrosion
- Carryover

Control of Boiler Water Carryover

- Effective mechanical steam separation
- Proper control of boiler water chemistry
- Antifoam, as needed
- Avoid major contaminant ingress
- Proper boiler operating practices

What Types of Internal Boiler Water Treatments are Available ?

Internal Treatment Programmes

General Classifications

- Precipitating
- Solubilising
- Combination

Internal Treatment Programmes

- Phosphate/Polymer
- Phosphonate/Polymer
- Chelant/Polymer
- Phosphate/Chelant/Polymer
- All Polymer
- Coordinated pH/Phosphate/Polymer
- All Volatile Treatment (AVT)

Boiler Water Polymers

are Crucial to the

Success of any

Internal Treatment Programme

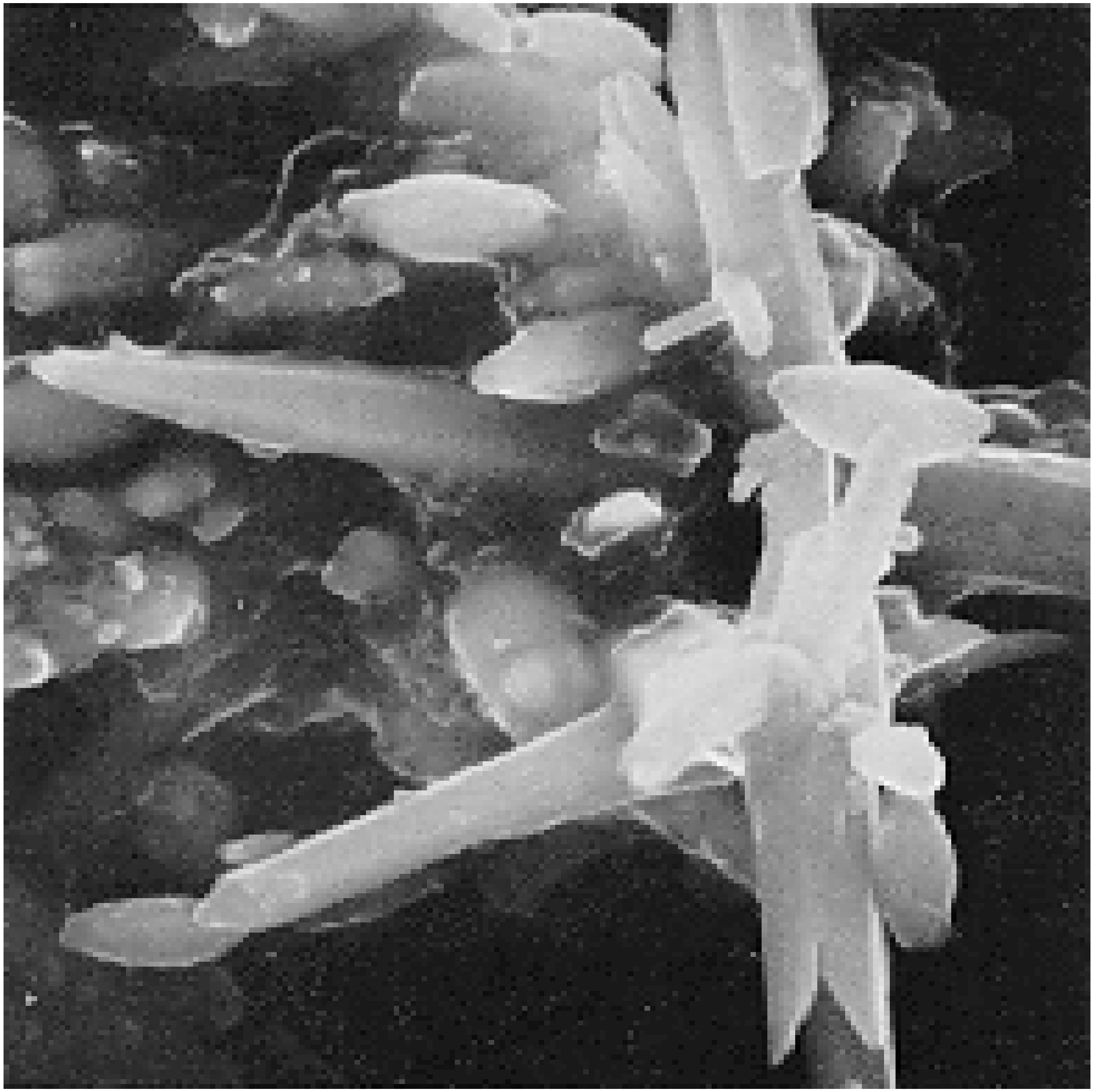
How do Boiler Water Polymers Function ?

Boiler Water Polymers

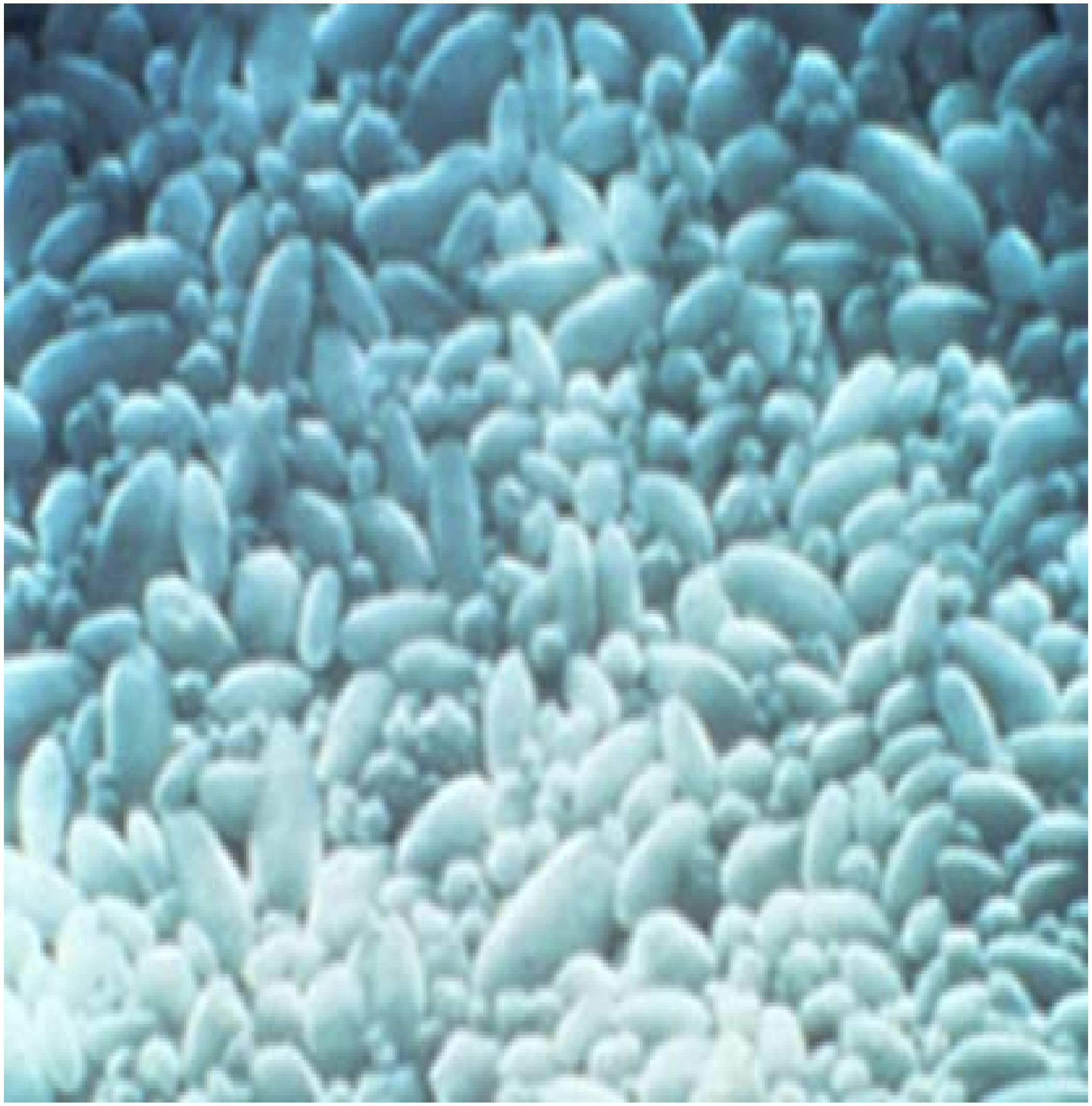
The mechanisms by which boiler water polymers function are

- Complexation / Solubilisation
- Crystal modification
- Dispersion

Calcium phosphate, magnesium silicate crystals formed in boiler water without dispersant



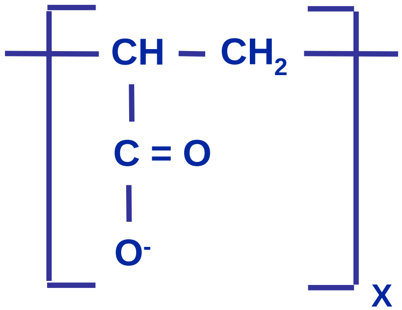
Calcium phosphate, magnesium silicate crystals formed in boiler water in the presence of a sulphonated polymer



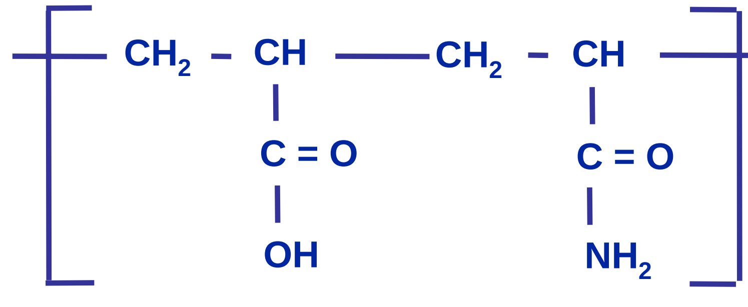
Variables Affecting Polymer Performance

- Functional group
  - carboxylated (SCP/SCCP)
  - sulfonated (SSP)
  - phosphorylated (HTP)
- Polymer backbone
- Molecular weight

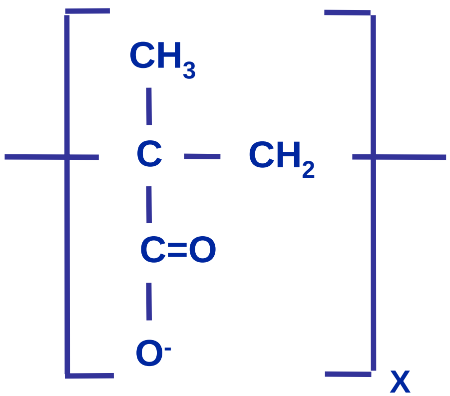
Typical Polymer Structures



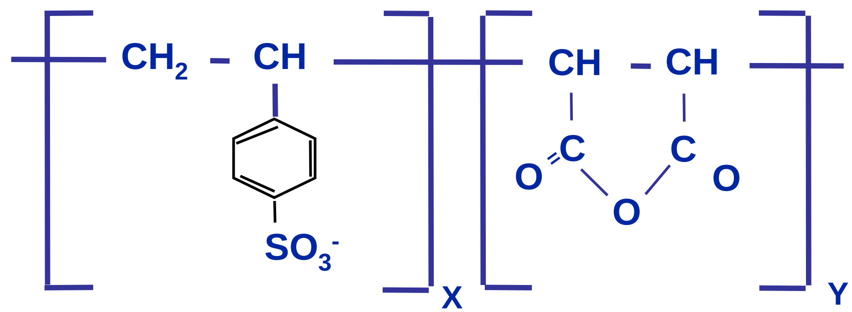
Polyacrylate



Acrylate-Acrylamide Copolymer

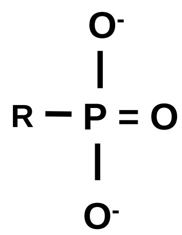


Polymethacrylate

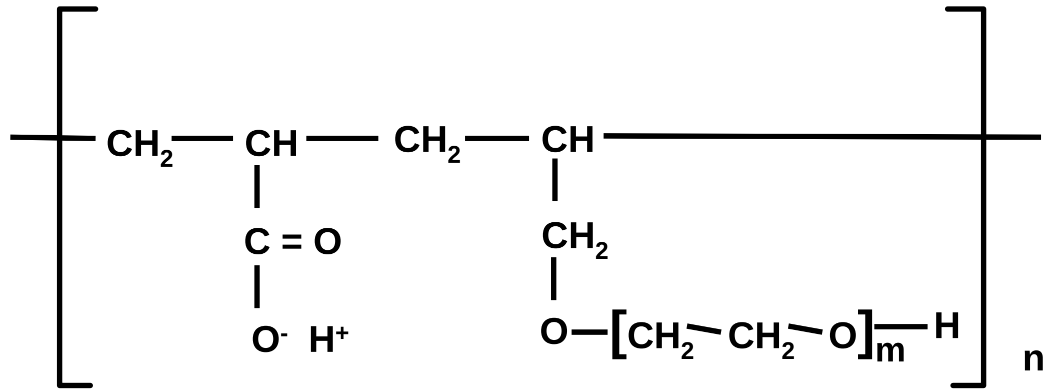


Sulfonated Styrene-Maleic Anhydride Copolymer

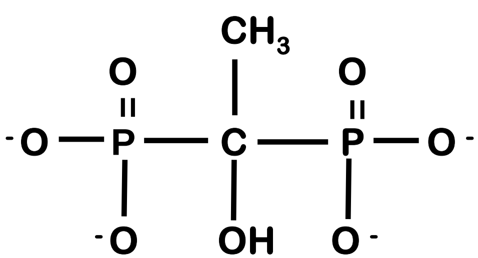
Typical Polymer Structures



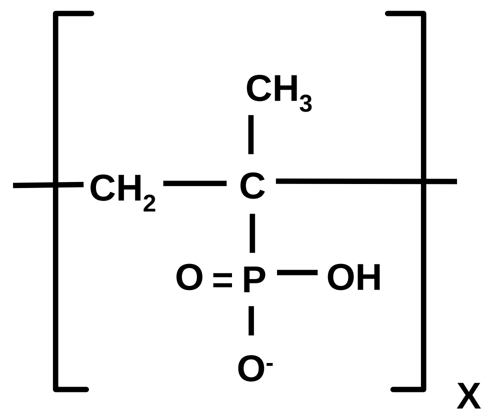
Phosphonate



Polyethylene glycol allyl ether **(PEGAE)**



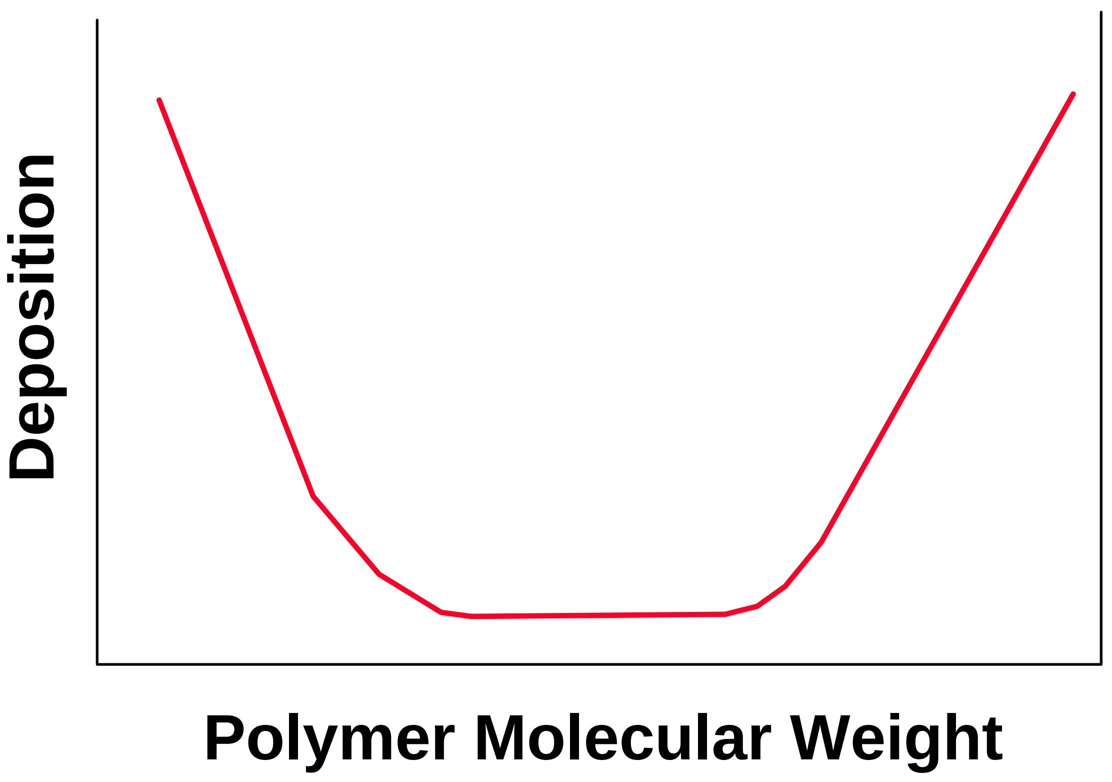
HEDP



Poly (isopropenyl phosphonic acid)

PIPPA

Polymer Performance
vs
Molecular Weight



Programme Selection Considerations

- Boiler pressure, design
- Pre-treatment plant type
- Feedwater quality
- Hot well, deaerator type
- Steam turbine
- Control capabilities

Chemical Factors

- Total Dissolved Solids (TDS)
- Alkalinity
- Silica
- Suspended Solids

ASME Boiler Feedwater Quality Guidelines for Modern Industrial Water-Tube Boilers

Drum Pressure (kg/cm^2)	Iron (ppm Fe)	Copper (ppm Cu)	Hardness (ppm $CaCO_3$)
0 - 21	0.10	0.05	0.30
22 - 31	0.05	0.025	0.30
32 - 42	0.03	0.02	0.20
43 - 52	0.025	0.02	0.20
53 - 63	0.02	0.015	0.10
64 - 70	0.02	0.015	0.05
71 - 105	0.01	0.01	0.0

Internal Treatment Programmes

- Phosphate/Polymer

Phosphate/Polymer Treatment

- **Reactions:**
- Ca + PO_4 + OH → $Ca(OH)PO_4$ ↓
- Calcium Phosphate Hydroxide Hydroxyapatite
-
- Mg + SiO_3 + OH → $Mg(OH)SiO_3$ ↓
- Magnesium Silica Hydroxide Serpentine

Phosphate/Polymer Treatment

Characteristics

- Hardness controlled by precipitation
- Polymers used to control hardness sludge and metal oxides
- Phosphate residual used for programme control
- Hydroxide alkalinity required (pH : 10.5 - 12)

Phosphate/Polymer Treatment

Boiler Control Parameters

- Phosphate residual as PO_4 depending on hardness in the feedwater
  - usually associated with boiler pressure
  - and environmental legislation
- M alkalinity of 700 ppm as $CaCO_3$ (25 % of TDS)
- Polymer : min 360 ppm as SP8100
- Still the most used method for treating low pressure boilers

Phosphate/Polymer Treatment

Advantages

- **Tolerates a wide range of feedwater hardness**
- **Non corrosive treatment**
- **Suitable for low to medium pressure systems**
- **Easy operator control**

- **Disadvantages**
- **Is a precipitation programme (some deposition is normal)**
- **Higher blowdown rates may be required**

Internal Treatment Programmes

- Phosphate/Polymer
- Phosphonate/Polymer

Phosphonate/Polymer

Characteristics

- Organic phosphor donors combined with three synergistic polymers
- Complexes hardness, iron and copper ions in BFW
- Disperses/solubilises contaminants in boiler minimising sludge formation

Phosphonate/Polymer

a) Solubilising

Boilerplate Control Parameters

- 200 - 300 ppm in blowdown
- (BFW hardness + tot Fe) max 1 ppm for 300 ppm in boiler
- filtered tot. PO_4 min 6 ppm in BD
- Other :
  - conductivity
  - SiO_2
  - M-alk

Phosphonate/Polymer

b) Precipitating

Boiler Control Parameters

- Phosphate residual as PO_4 depending on hardness in the feedwater
- M alkalinity of 700 ppm as $CaCO_3$ (25 % of TDS)

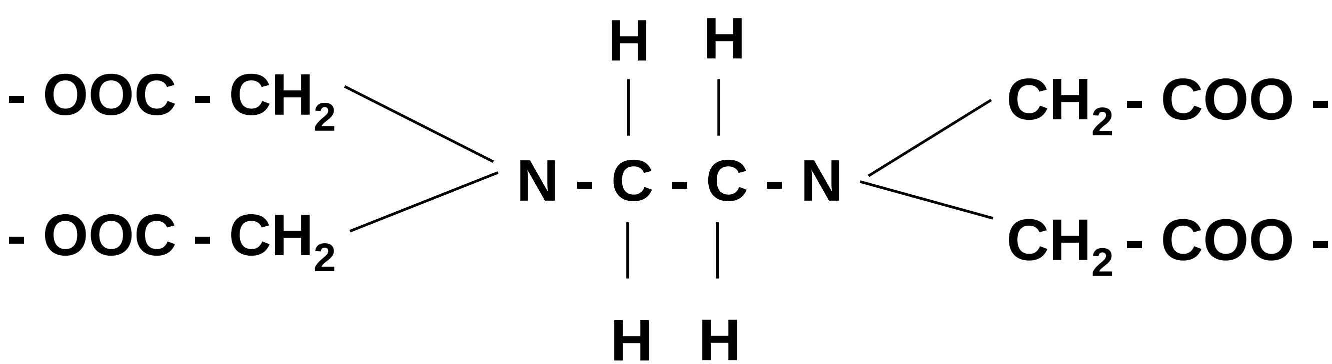
Internal Treatment Programmes

- Phosphate/Polymer
- Phosphonate/Polymer
- Chelant/Polymer

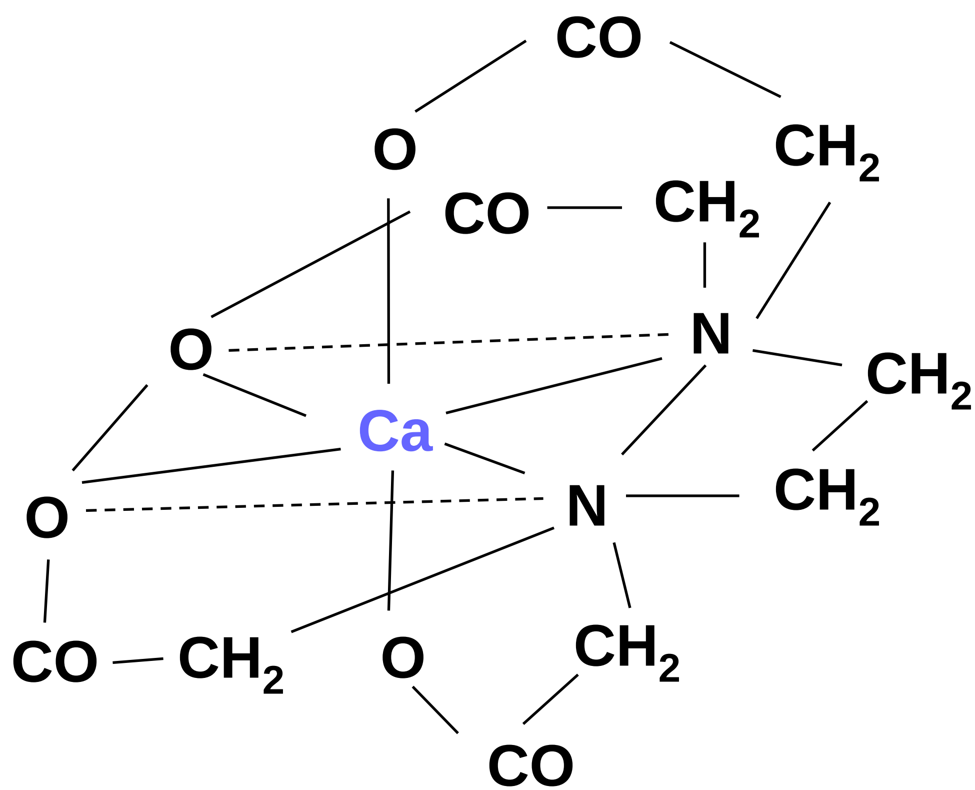
Chelant/Polymer Treatment

- Common Chelating Agents
  - EDTA
    - NTA

Chemical Structure of EDTA



EDTA/Calcium Complex



Chelant/Polymer Treatment

Characteristics

- Are solubilising treatments
- Chelant complexes hardness and soluble iron / copper
- Polymers used to enhance metal oxide control
- Must be fed to the feedwater line

Chelant/Polymer Treatment

Advantages

- **Solubilising treatment**
- **Effective on hardness and soluble iron**
- **Allow reduced blowdown**
- **Increased reliability and efficiency**
- **Suitable for low to medium pressure systems**

- **Disadvantages**

- **Requires intensive operator control**
- **Potentially corrosive if misapplied**

Internal Treatment Programmes

- Phosphate/Polymer
- Phosphonate/Polymer
- Chelant/Polymer
- Phosphate/Chelant/Polymer

Chelant/Phosphate/Polymer Treatment

Characteristics

- Utilises EDTA chelant (partial chelation)
- Primarily a solubilising programme
- Phosphate provides back-up upset protection
- Residual phosphate test used as programme control
- Polymers used to control metal oxides and other precipitates

Chelant/Phosphate/Polymer Treatment

Advantages

- **Primarily a solubilising treatment**
- **Effective on hardness and iron**
- **May allow reduced blowdown**
- **Increased reliability and efficiency**
- **Easy and accurate control test**
- **Tolerates a wide range of feedwater hardness**
- **Suitable for low to medium pressure systems**

- **Disadvantages**
- **Some precipitation is possible**
- **Potentially corrosive if misapplied**

Internal Treatment Programmes

- Phosphate/Polymer
- Chelant/Polymer
- Phosphate/Chelant/Polymer
- All Polymer

All Polymer Treatment

Characteristics

- Certain polymers can be effective complexing agents
- Principle mechanism is complexation of soluble impurities
- Secondary mechanism is dispersion of particulates
- Fed to the boiler feedwater

Limitations of Polyacrylate Based All Polymer Programmes

- Low tolerance to feedwater quality upsets
- Potential for calcium polyacrylate deposition
- Releases ammonia
- Economiser iron pick-up
- Precise testing for polymers is difficult

Internal Treatment Programmes

- Phosphate/Polymer
- Phosphonate/Polymer
- Chelant/Polymer
- Phosphate/Chelant/Polymer
- All Polymer/OptiSperse AP

What is OptiSperse AP ?

- A new, revolutionary programme using patented co-polymer technology

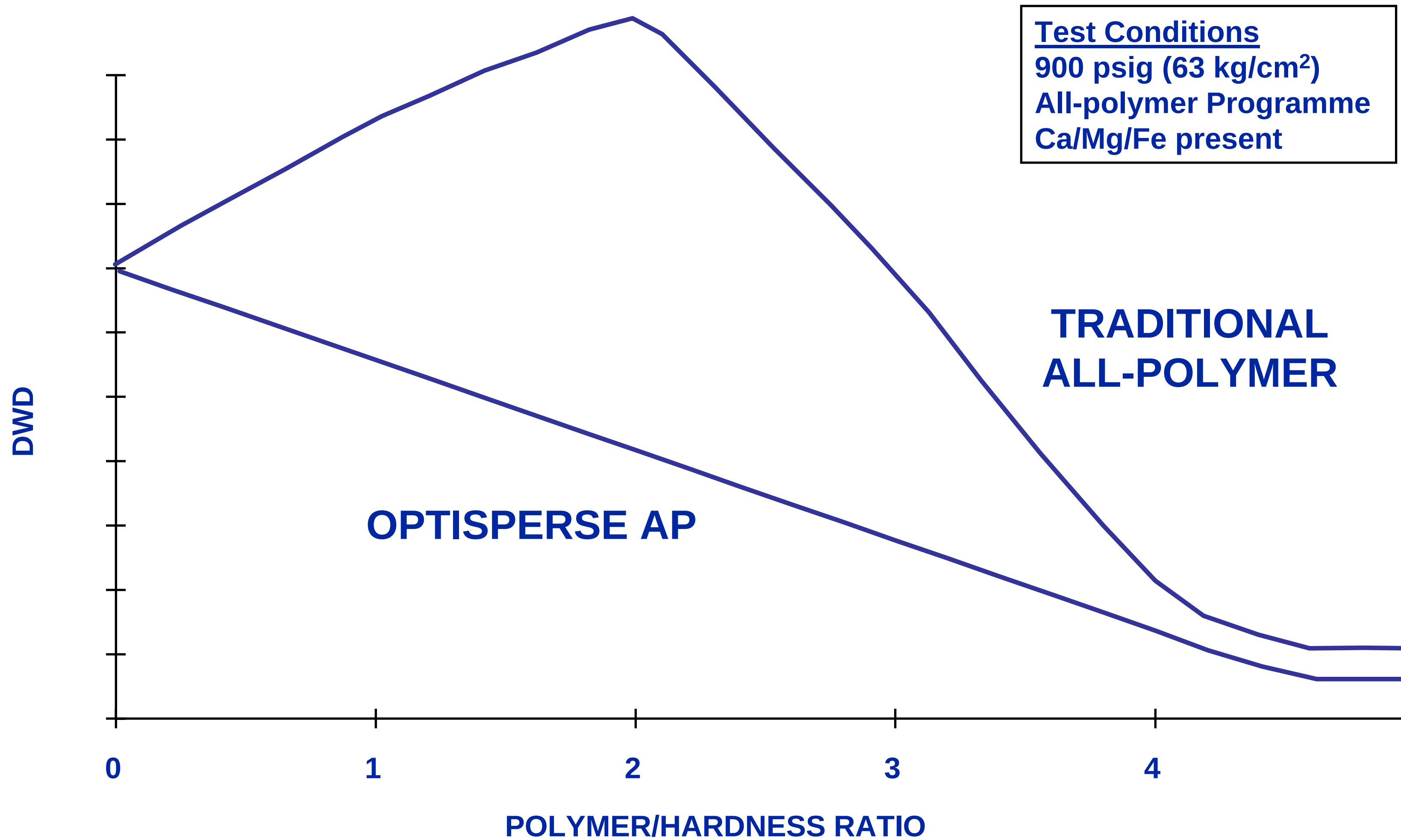
- A stand-alone all polymer / all organic boiler internal treatment programme which provides superior control over hardness and iron deposition

OptiSPerse AP Treatment vs. Traditional All Polymer

- Traditional All Polymer Programme
  - Generates ammonia
  - Forms calcium-polymer deposits with BFW hardness excursions or underfeed
  - Overfeed may cause foaming
  - Corrosive to economiser surfaces
  - Must be fed downstream of copper alloys

- OptiSperse AP Programme
  - No ammonia generated
  - No treatment related deposition
  - No steam purity problems
  - Not corrosive to preboiler circuit
  - May be fed ahead of copper alloys in BFW

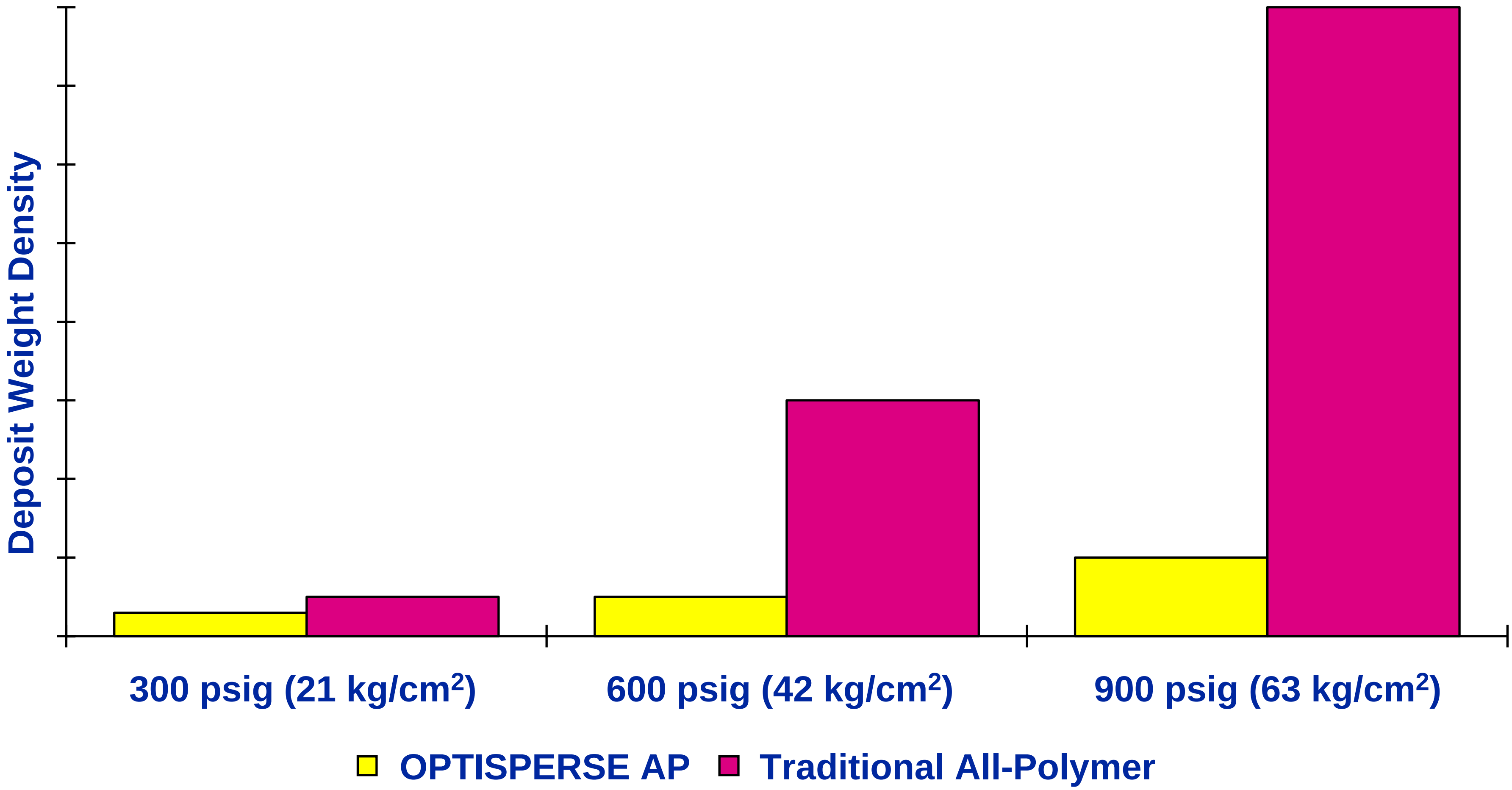
Research Boiler Studies Under Fouling Conditions



Research Boiler Studies

Under Potential Fouling Conditions

(Equal Polymer Actives)



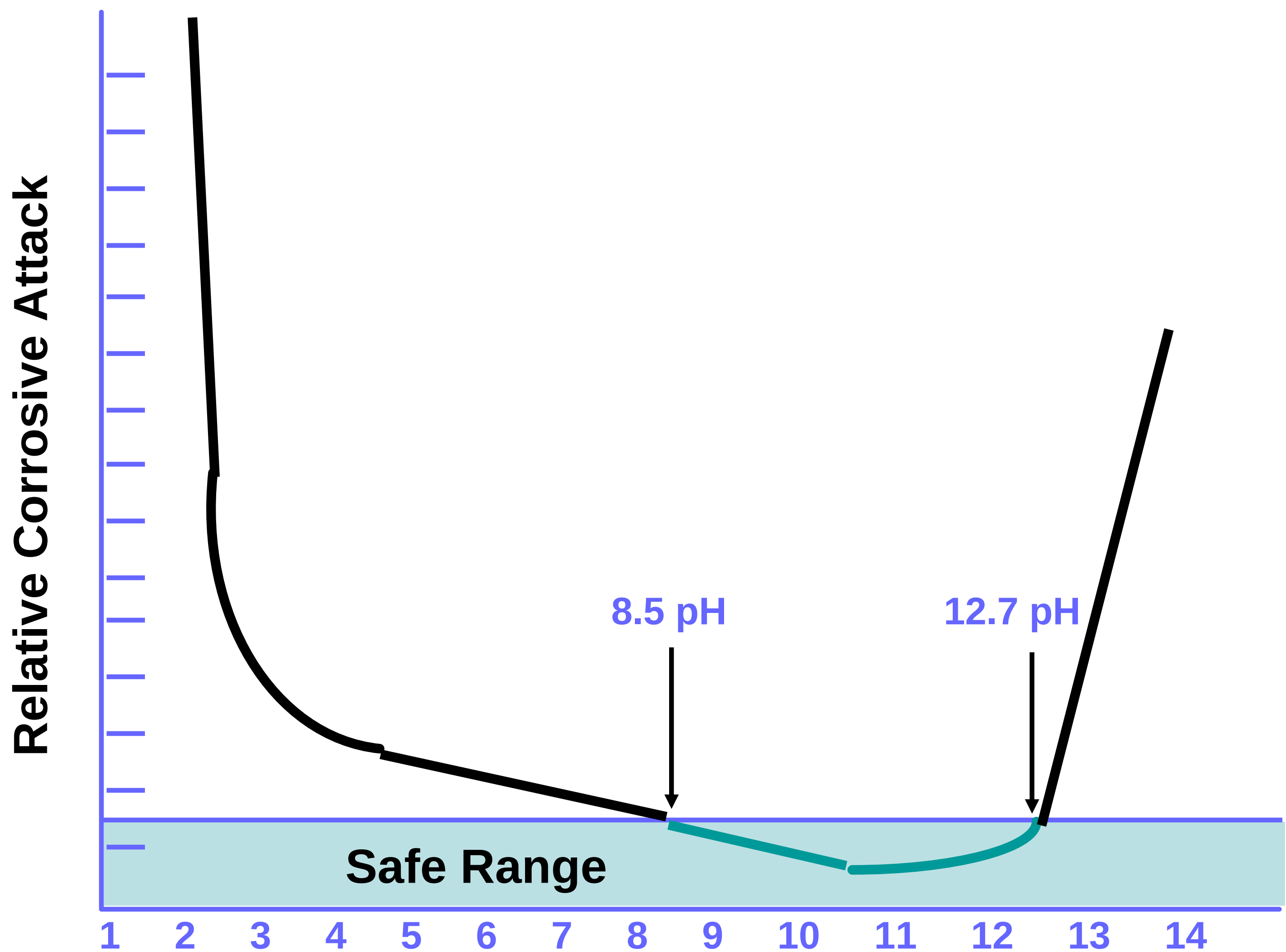
Internal Treatment Programmes

- Phosphate/Polymer
- Phosphonate/Polymer
- Chelant/Polymer
- Phosphate/Chelant/Polymer
- All Polymer
- Coordinated pH/Phosphate/Polymer

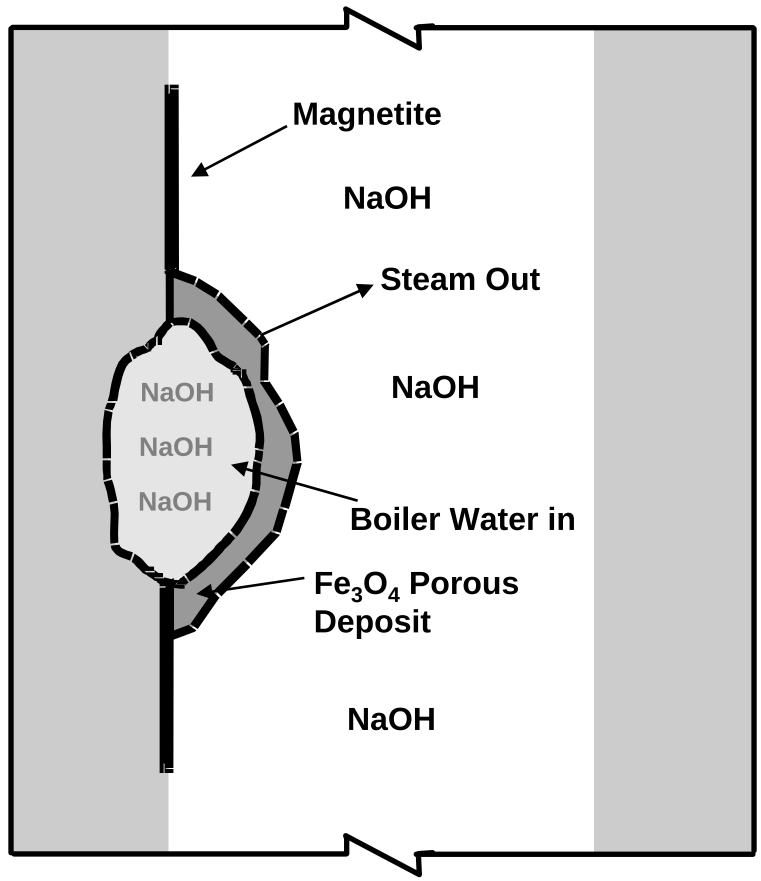
Coordinated pH/Phosphate Polymer Treatment
Characteristics

- Primarily for high purity/high pressure systems
- Mainly a corrosion control programme
- Phosphate used to control pH and neutralise excess caustic
- Polymers used to control deposition

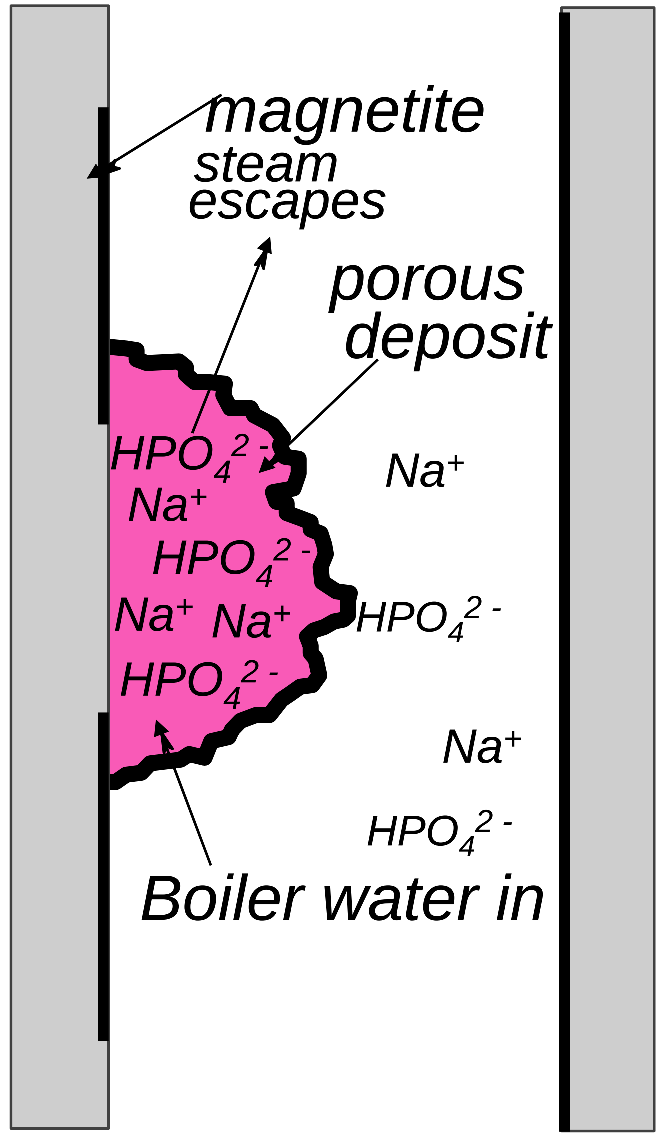
Corrosion of Mild Steel vs. pH



Caustic Concentration Mechanism



Prevention



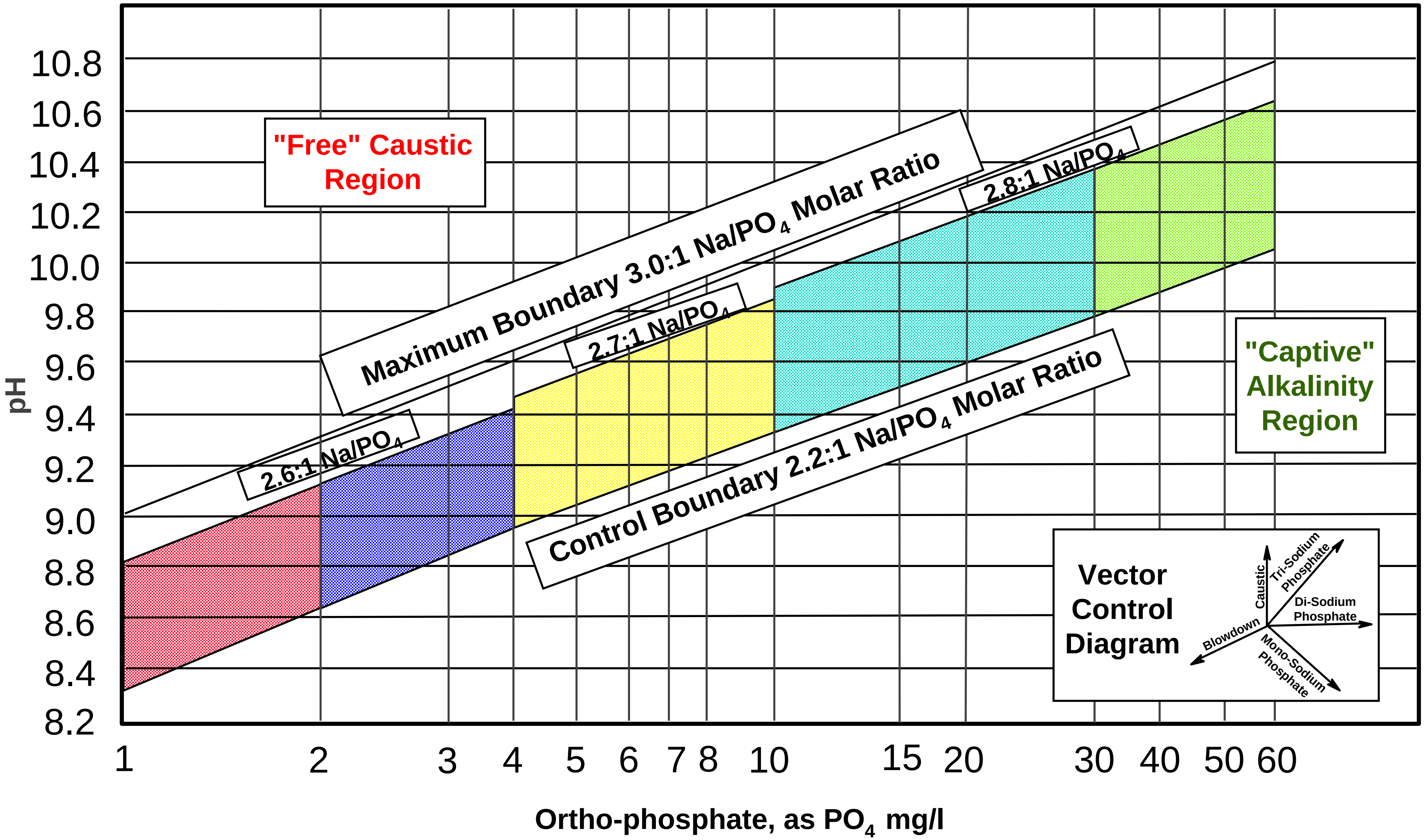
magnetite
steam
escapes
porous
deposit
HPO_4^{2-}
Na^+
HPO_4^{2-}
Na^+ Na^+
HPO_4^{2-}
Na^+
HPO_4^{2-}
Na^+
HPO_4^{2-}
Boiler water in

Minimising Caustic Concentration and Corrosion using Phosphate

$$NaOH + Na_2HPO_4 \longrightarrow Na_3PO_4 + H_2O$$

Caustic Soda	**Disodium Phosphate**	**Trisodium Phosphate**	**Water**

Co-ordinated Congruent Phosphate/pH Control Chart



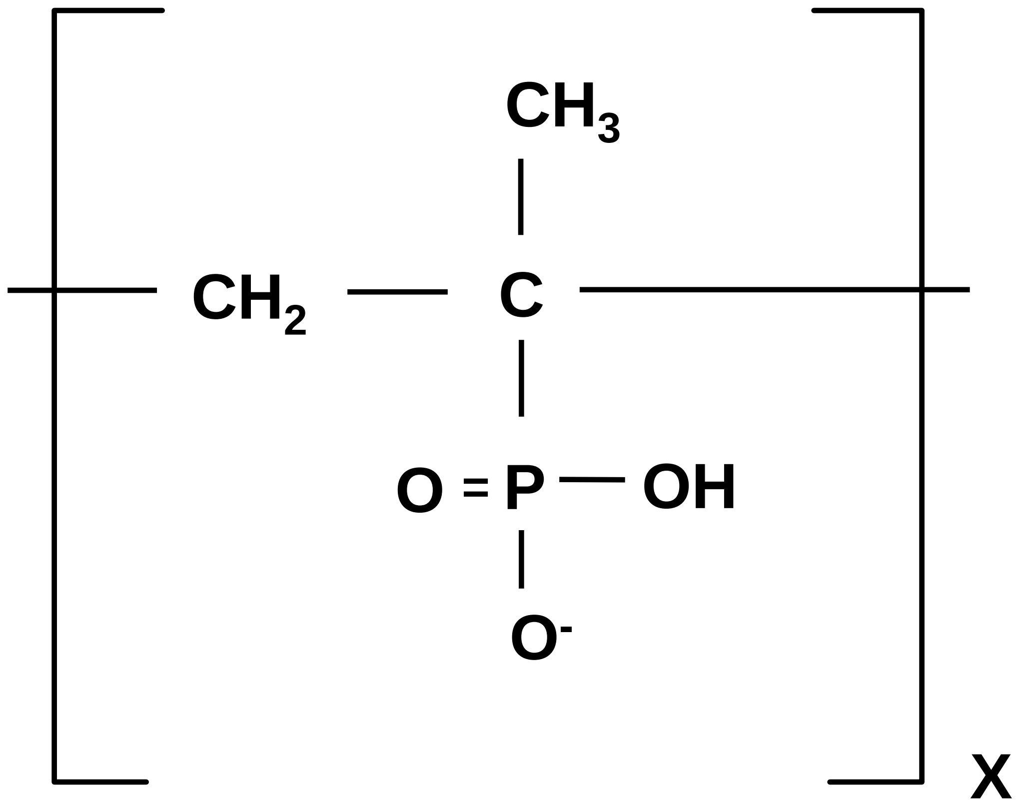
Internal Treatment Programmes

- Phosphate/Polymer
- Phosphonate/Polymer
- Chelant/Polymer
- Phosphate/Chelant/Polymer
- All Polymer
- Coordinated pH/Phosphate/Polymer OptiSperse HTP

Characteristics of HTP-2

- A unique new phosphorylated boiler polymer
- Particularly effective on iron
- Demonstrated clean-up ability
- Designed for high purity/high cycles systems
- Suitable for use up to 125 kg/cm^2

HTP-2 Polymer Structure



Poly (isopropenyl phosphonic acid) . . . PIPPA

Internal Treatment Programmes

- Phosphate/Polymer - OptiSperse PO, OptiGuard MCP
- Phosphonate/Polymer - OptiSperse PQ
- Chelant/Polymer - OptiSperse CL
- Phosphate/Chelant/Polymer - OptiSperse CP
- All Polymer - OptiSperse AP, OptiGuard MCA
- Coordinated pH/Phosphate/Polymer - OptiSperse HTP
- All Volatile Treatment (AVT)

COMPLETED

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