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

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
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<td>180</td>
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<td>388</td>
<td>362</td>
<td>838</td>
<td>1200</td>
<td>2.14</td>
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<table>
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<tr>
<th>Pressure barg</th>
<th>Temperature °C</th>
<th>Water kJ/kg</th>
<th>Evaporation kJ/kg</th>
<th>Steam kJ/kg</th>
<th>Specific Volume Steam m³/kg</th>
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</thead>
<tbody>
<tr>
<td>0</td>
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<td>419.04</td>
<td>2257.00</td>
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<td>1.673</td>
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<td>2</td>
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<td>562.20</td>
<td>2163.30</td>
<td>2725.50</td>
<td>0.603</td>
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<td>4</td>
<td>151.96</td>
<td>640.70</td>
<td>2108.10</td>
<td>2748.80</td>
<td>0.374</td>
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<td>6</td>
<td>165.04</td>
<td>697.50</td>
<td>2066.00</td>
<td>2763.50</td>
<td>0.272</td>
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<td>2000.10</td>
<td>2781.70</td>
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<td>14</td>
<td>198.35</td>
<td>845.10</td>
<td>1947.10</td>
<td>2792.20</td>
<td>0.132</td>
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</table>
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 (971 Btu/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 increases.

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/cm², 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

- Water Walls
- Superheater
- Screen Tubes
- Steam Drum
- Mud Drum
- Risers
- Downcomers
- Economiser
- Air Heater
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
HOT WELL DEAERATOR
EXTERNAL TREATMENT
MAKE UP WATER AND SOLIDS
RETURNED CONDENSATE WATER AND HEAT
SATURATED STEAM EVAPORATED WATER
FEEDWATER WATER AND SOLIDS
Continuous blowdown to remove dissolved 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
Intermittent blowdown to remove suspended solids in boiler water
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

Make Up

Feedwater

Condensate
Return
Basic Boiler Calculations

• Feedwater = Make up + Condensate Return
Basic Boiler Calculations

Steam Make (Flow)

Feedwater Flow

Blowdown
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

<table>
<thead>
<tr>
<th></th>
<th>Make-Up</th>
<th>Condensate</th>
<th>Feedwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Hardness</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>M Alkalinity</td>
<td>200</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td>350</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Silica</td>
<td>6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>% Condensate</td>
<td></td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>
Basic Boiler Calculations

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

<table>
<thead>
<tr>
<th></th>
<th>Make up</th>
<th>Condensate</th>
<th>Feed water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Hardness</strong></td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>M Alkalinity</strong></td>
<td>200</td>
<td>10</td>
<td>105</td>
</tr>
<tr>
<td><strong>TDS</strong></td>
<td>350</td>
<td>15</td>
<td>182.5</td>
</tr>
<tr>
<td><strong>Silica</strong></td>
<td>6</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td><strong>% Condensate</strong></td>
<td></td>
<td>50</td>
<td></td>
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</tbody>
</table>
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

Without deposits

With deposits

Metal

Fireside

Waterside

600°F

500°F

800°F and above
Energy Loss from Scale Deposits
(from Energy Conservation Programme Guide for Industry & Commerce)

<table>
<thead>
<tr>
<th>Scale Thickness, inches or mm</th>
<th>Energy Loss %</th>
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<td>8</td>
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<tr>
<td>0.8 mm</td>
<td>7</td>
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<tr>
<td>1.2 mm</td>
<td>6</td>
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<tr>
<td>1.6 mm</td>
<td>5</td>
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<tr>
<td>2.0 mm</td>
<td>4</td>
</tr>
<tr>
<td>2.4 mm</td>
<td>3</td>
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</table>

- Iron & Silica Scale
- High Iron Content Scale
- "Normal" Calcium Carbonate Scale
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

Deposition

Polymer 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

<table>
<thead>
<tr>
<th>Drum Pressure (kg/cm²)</th>
<th>Iron (ppm Fe)</th>
<th>Copper (ppm Cu)</th>
<th>Hardness (ppm CaCO₃)</th>
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<tbody>
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<td>0 - 21</td>
<td>0.10</td>
<td>0.05</td>
<td>0.30</td>
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<tr>
<td>22 - 31</td>
<td>0.05</td>
<td>0.025</td>
<td>0.30</td>
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<td>32 - 42</td>
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<td>0.02</td>
<td>0.20</td>
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<td>53 - 63</td>
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<td>0.05</td>
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<td>71 - 105</td>
<td>0.01</td>
<td>0.01</td>
<td>0.0</td>
</tr>
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</table>
Internal Treatment Programmes

- Phosphate/Polymer
Phosphate/Polymer Treatment

- **Reactions:**

\[ \text{Ca} + \text{PO}_4 + \text{OH} \rightarrow \text{Ca(OH)PO}_4 \]

- Calcium Phosphate Hydroxide
  - Hydroxyapatite

\[ \text{Mg} + \text{SiO}_3 + \text{OH} \rightarrow \text{Mg(OH)SiO}_3 \]

- 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 $\text{PO}_4$ depending on hardness in the feedwater
  - usually associated with boiler pressure
  - and environmental legislation
- M alkalinity of 700 ppm as $\text{CaCO}_3$ (25 % of TDS)
- Polymer : min 360 ppm as SP8100
- Still the most used method for treating low pressure boilers
Phosphonate/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

Boiler 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

Test Conditions
900 psig (63 kg/cm²)
All-polymer Programme
Ca/Mg/Fe present
Research Boiler Studies

Under Potential Fouling Conditions

(Equal Polymer Actives)

Deposit Weight Density

300 psig (21 kg/cm²)  600 psig (42 kg/cm²)  900 psig (63 kg/cm²)

- **OPTISPERSE AP**
- **Traditional All-Polymer**
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

Relative Corrosive Attack

8.5 pH

12.7 pH

Safe Range
Caustic Concentration Mechanism

- Magnetite
- NaOH
- Steam Out
- NaOH
- Boiler Water in
- Fe$_3$O$_4$ Porous Deposit
- NaOH
- NaOH
- NaOH
- NaOH
Boiler water in

magnetite

steam escapes

porous deposit

\[ \text{HPO}_4^{2-}, \text{Na}^+, \text{HPO}_4^{2-}, \text{Na}^+ \]

Prevention
Minimising Caustic Concentration and Corrosion using Phosphate

\[ \text{NaOH} + \text{Na}_2\text{HPO}_4 \rightarrow \text{Na}_3\text{PO}_4 + \text{H}_2\text{O} \]

Caustic Soda | Disodium Phosphate | Trisodium Phosphate | Water
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/cm²
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**