15 Boiler Water Treatment

The main objectives of boiler water treatment are to:

1. Prevent scale
2. Prevent corrosion
3. Control sludge
4. Prevent foaming and carryover
5. Maintain proper water chemistry

These effects improve efficiency, safety, steam quality, and boiler life.

15.1 Water Treatment Adjustments

The following rules provide a practical water-treatment guide for a steam traction boiler. If you remember only one section from this chapter, remember this one.

Sodium carbonate (washing soda or soda ash) can be used to address most water chemistry problems.

- If hardness is high, add sodium carbonate.
- If pH is low, add sodium carbonate.
- If alkalinity is low, add sodium carbonate.
- If TDS is high, perform a blowdown.

Because sodium carbonate affects hardness, pH, and alkalinity simultaneously, boiler water should be retested after treatment to ensure all parameters remain within their desired ranges.

The remainder of this chapter explains the measurements, the chemistry behind them, and the procedures used to obtain them.

15.2 Minimal Low-Cost Monitoring Kit

1. pH strips
2. Hardness test strips
3. Alkalinity test kit
4. TDS/conductivity meter

These four tests cover most of the important indicators for:

- Scale prevention
- Corrosion prevention
- Sludge control
- Carryover control
- General water chemistry control

15.3 Water Hardness

Water hardness is the concentration of dissolved calcium and magnesium salts in the water. These minerals are the primary cause of scale formation in boilers. As water is heated and steam is produced, hardness minerals can precipitate from solution and form deposits on boiler tubes, heating surfaces, and other internal components.

Scale acts as an insulator, reducing heat transfer and increasing fuel consumption. Severe scale formation can lead to overheating of boiler metal and reduced boiler life.

Hardness is typically reported in parts per million (ppm) as $CaCO_3$.

15.3.1 Measuring Hardness

The simplest method for a steam traction boiler is to use hardness test strips. The strip is immersed in the water sample for the time specified by the manufacturer and then compared with a colour chart.

Hardness test kits based on titration may also be used. These generally provide more accurate results than test strips.

15.3.2 Interpreting Results

For practical traction-boiler operation, the following classifications are useful:

0–50 ppm	Low hardness
50–100 ppm	Moderate hardness
100–200 ppm	High hardness
Above 200 ppm	Very high hardness

For a steam traction boiler, hardness should be kept as low as practical. Lower hardness means less scale formation and reduced need for chemical treatment.

15.3.3 Treatment

The most common treatment for hardness in a steam traction boiler is sodium carbonate (Na_2CO_3), also known as washing soda or soda ash.

Sodium carbonate reacts with dissolved calcium salts and converts them into calcium carbonate sludge. The sludge can then be removed by blowdown rather than remaining as a hard scale that deposits on heating surfaces.

Adding sodium carbonate therefore:

- Reduces scale-forming hardness.
- Increases alkalinity.
- Raises pH.

Because sodium carbonate affects all three parameters, the boiler water should be retested after treatment.

15.4 pH

pH measures how acidic or alkaline the boiler water is.

For a steam traction boiler, the water should remain mildly alkaline. A pH between approximately 9 and 11 is generally preferred. Low pH increases the risk of corrosion, while excessively high pH may contribute to foaming and other water-quality problems.

pH is easily measured using pH test strips or a pH meter.

If pH is too low:

- Add sodium carbonate.
- Retest after treatment.

15.5 pH vs Alkalinity

pH and alkalinity are two different but related controls.

- pH measures how alkaline the water is.
- Alkalinity determines how much reserve capacity the water has to stay alkaline when conditions change.

To explain further, imagine a shallow shelf cut into a steep hillside.

- pH determines the height of a position on the shelf.
- Alkalinity measures the width of the shelf.

Acidic contamination pushes the position along the shelf, changing its height. If the shelf is wide, a change in position results in only a small change in height. If the shelf is narrow, the same change in position results in a much larger change in height as the position approaches the steeper slope.

For example, two boilers could both have a pH of 10.0, but one has low alkalinity and the other has high alkalinity. If acidic contamination enters:

- The boiler with low alkalinity will experience a rapid drop in pH.
- The boiler with high alkalinity will experience only a small change in pH.

The alkalinity acts as a chemical buffer, absorbing the effects of the contamination and helping maintain a stable pH. Chemically, this buffering action is provided primarily by hydroxide (OH^-), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-) ions dissolved in the water. These species react with incoming acids before the acids can significantly change the pH. When acid enters the water, these species consume it:

$$H^+ + CO_3^{2-} \rightarrow HCO_3^-$$

$$H^+ + HCO_3^- \rightarrow H_2CO_3$$

as long as enough buffering species remain.

The key insight is: pH measures the current condition of the boiler water. Alkalinity measures how resistant that condition is to change. Testing becomes most useful when boiler-water chemistry is being actively adjusted and there is a desire to understand why pH is changing rather than simply observing that it has changed.

Adding washing soda: Na_2CO_3 does two useful things. First, it raises the shelf; that is, pH increases. Second, it widens the shelf; causing alkalinity to increase. So washing soda both:

1. Makes the water more alkaline.
2. Makes that alkalinity more resistant to change.

15.6 Determining the Alkalinity Endpoint

The alkalinity endpoint is reached when enough acid has been added to consume the water's buffering capacity. Once these substances have been neutralized, the water has lost its ability to resist further decreases in pH.

The most accurate method of determining the endpoint is to use a pH meter. A measured sample of boiler water is placed in a container and a standard acid, usually sulfuric acid or hydrochloric acid, is added slowly while the sample is stirred. The pH is monitored continuously. For a total alkalinity determination, the endpoint is reached when the pH falls to approximately 4.5. The volume of acid required to reach this pH is then used in the alkalinity calculation.

A simpler and more traditional method uses an indicator dye such as methyl orange. A few drops of indicator are added to the boiler-water sample before the acid is introduced. The indicator changes colour as the pH decreases. The endpoint is reached when the solution changes from yellow to a persistent orange-red colour, which corresponds approximately to a pH of 4.5. The volume of acid added up to that point is recorded and used to calculate the alkalinity.

The test process is called titration: a method of chemical measurement in which a reagent of known concentration is added to a sample until a defined endpoint is reached, allowing the concentration of the substance being measured to be determined.

Commercial alkalinity test kits operate on exactly the same principle. The sample is treated with an indicator and then titrated with a standardized acid solution. The endpoint is identified by a colour change, and the number of drops of acid required is converted directly into alkalinity expressed as parts per million as calcium carbonate (ppm as $CaCO_3$).

Returning to the shelf analogy, the endpoint represents the point at which the entire shelf has been crossed. The acid has consumed all of the available buffering capacity. Water with low alkalinity reaches the endpoint after only a small amount of acid is added, whereas water with high alkalinity requires a much larger amount of acid before the endpoint is reached. Thus, the volume of acid required to reach the endpoint is a direct measure of the water's buffering capacity.

15.7 Determining alkalinity

Alkalinity is measured in **parts per million (ppm) as** $CaCO_3$. For a steam traction boiler, a practical target range is **100–300 ppm as** $CaCO_3$. Below about **100 ppm**, the boiler water has limited buffering capacity and may respond rapidly to acidic contamination. Above about **300 ppm**, the water may become more prone to foaming, carryover, and elevated dissolved solids.

To measure alkalinity, a standard acid such as **sulfuric acid (**H_2SO_4**)** or **hydrochloric acid (**HCl**)** is added drop by drop to a measured sample of boiler water. The acid gradually neutralizes the buffering chemicals in the water, primarily hydroxide, carbonate, and bicarbonate ions. When the alkalinity endpoint is reached, the volume of acid used is recorded.

Alkalinity is then calculated as:

$$A = \frac{V_a \cdot N \cdot 50000}{V_s} \text{ where } \begin{cases} A \rightarrow alkalinity \\ V_a \rightarrow volume_{acid} \\ N \rightarrow normality_{acid} \\ V_s \rightarrow volume_{sample} \end{cases}$$

For the common case of a **100 mL sample** titrated with **0.02 N acid**, the calculation simplifies to:

$$A = V_a \cdot 10$$

Examples:

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10 mL acid = 100 ppm alkalinity
15 mL acid = 150 ppm alkalinity
20 mL acid = 200 ppm alkalinity
25 mL acid = 250 ppm alkalinity
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The greater the volume of acid required to reach the endpoint, the greater the alkalinity and the greater the water's ability to resist changes in pH.

15.8 Procedure for Determining Boiler-Water Alkalinity Using a Test Kit

This procedure assumes that a commercial alkalinity test kit is available and that the kit provides a standard acid reagent and an endpoint indicator.

15.8.1 Equipment

- Alkalinity test kit
- Clean sample container
- Boiler-water sample
- Measuring cylinder or test tube supplied with the kit

15.8.2 Procedure

1. Collect a representative sample of boiler water and allow it to cool to room temperature.
2. Fill the test tube with the volume of sample specified by the test kit instructions. Many kits use either a 50 mL or 100 mL sample.
3. Add the number of drops of indicator specified in the test-kit instructions. This is typically a small fixed quantity, such as 2 to 5 drops, and does not vary from sample to sample.
4. Gently mix the sample to distribute the indicator.
5. Add the standard acid reagent one drop at a time while gently swirling the sample after each drop.
6. Continue adding acid until the indicator changes colour permanently. For most total alkalinity tests, the endpoint is indicated by a colour change corresponding to a pH of approximately 4.5.
7. Record the total number of drops or the total volume of acid required to reach the endpoint.

15.8.3 Calculating Alkalinity

Commercial alkalinity test kits are usually calibrated so that the number of drops of acid required to reach the endpoint can be converted directly to alkalinity. The conversion factor is supplied by the manufacturer and is based on the acid concentration, sample size, and drop volume. In some kits, each drop corresponds to a fixed alkalinity value such as 10 ppm as $CaCO_3$. In other kits, the drop count must first be converted to a volume of acid before the alkalinity equation can be applied.

15.9 Total Dissolved Solids (TDS)

TDS limits vary widely between boilers and treatment programs. Operators should establish a baseline reading and monitor trends over time. A steadily rising reading indicates increasing concentration of dissolved solids and the eventual need for blowdown.

A TDS meter does not directly measure dissolved solids. Instead, it measures the electrical conductivity of the water and then estimates the concentration of dissolved solids from that measurement.

Pure water is a poor conductor of electricity. When minerals and salts dissolve in water, they form ions that carry electrical current. As the concentration of dissolved ions increases, the conductivity increases.

Examples of dissolved substances that contribute to TDS include:

- Sodium carbonate (Na_2CO_3)
- Sodium sulfate (Na_2SO_4)
- Sodium chloride (NaCl)
- Calcium salts

- Magnesium salts
- Various boiler-treatment chemicals

The TDS meter reports the estimated concentration of dissolved solids, usually in parts per million (ppm).

For a steam traction boiler, TDS is useful because it indicates how concentrated the boiler water has become. As steam is produced, pure water leaves the boiler while most dissolved solids remain behind. The concentration of dissolved solids therefore increases with time.

A rising TDS reading indicates that dissolved salts are accumulating in the boiler water. Excessive TDS can contribute to foaming, carryover, and the deposition of solids. When TDS becomes excessive, blowdown is used to remove a portion of the concentrated boiler water and replace it with fresh feedwater.

Unlike a hardness test, which measures specific scale-forming minerals, a TDS meter measures the combined effect of all dissolved ionic substances in the water. It therefore provides a general indication of water concentration rather than the concentration of any particular chemical.

15.10 Summary

A simple traction-boiler water treatment program can be managed using four measurements:

Measurement	Purpose	Typical Action
Hardness	Detect scale-forming minerals	Add sodium carbonate
pH	Detect corrosion risk	Add sodium carbonate
Alkalinity	Measure buffering capacity	Add sodium carbonate
TDS	Measure concentration of dissolved solids	Blow down boiler

By regularly monitoring these four values, boiler water can be maintained in a condition that minimizes scale, corrosion, foaming, and carryover.