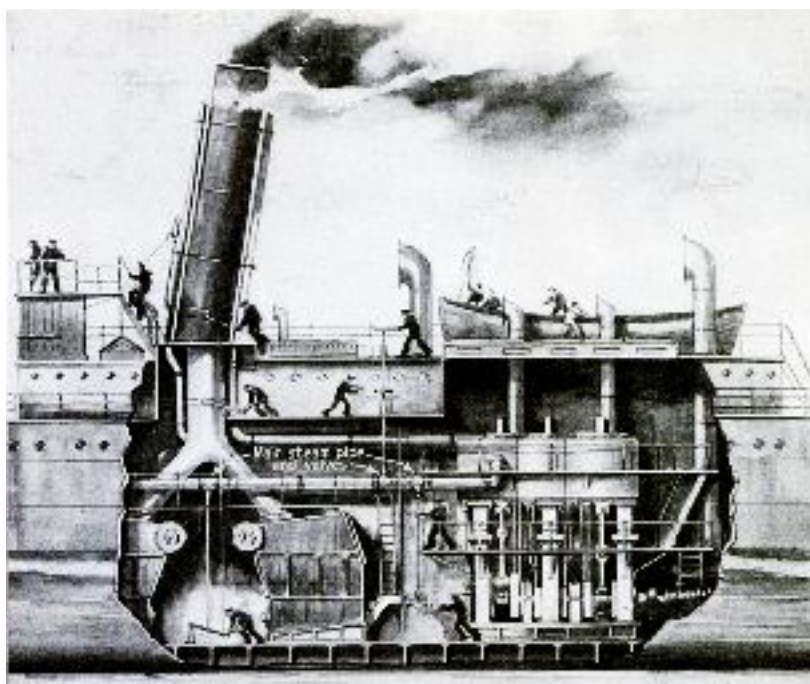


## Steamship Solution Chemistry

You are a steamship boiler operator. Boiler water must be regularly tested to ensure it is in proper working order. Your task is to test the condition of the boiler water by performing chemical tests with samples of boiler water. You will then write a report about the condition of the boiler water and recommend to the captain the steps that must be taken to keep your boiler in working order. A successful report will include experimental data and results, and an argument supported by the data and scientific and historical documents.



### Project steps

1. The day before the test, read *Boiler Operator's Scientific Maintenance Overview* and *Boiler Operators in History*. Answer the Boiler Operator Questions.
2. Test the boiler water by performing experimental tests.
3. Prepare a report with the experimental data and results. Include recommendations to fix any problems found.

**Boiler Operator Questions.** Use proper vocabulary when possible.

1. What is the solvent in boiler water? What other soluble and insoluble species are found in boiler water?
2. If hard water is used to fill a boiler, what problems can occur? Explain your answer.
3. How can a chemist test for the presence of dissolved ions in water?
4. Cool boiler water will become very hot when operating. How can a solubility curve be used to predict the effect on solubility of solutes in the water?
5. Write a double replacement reaction equation that starts with calcium sulfate and produces calcium phosphate. How would this reaction be useful in controlling scale in a boiler?
6. Propose a way to reduce the concentration of hydrogen ions in the boiler.

## Boiler Operator's Scientific Maintenance Overview

The beating heart of a ship is the steam produced from an efficiently-running boiler. Well-trained boiler operators must use solution chemistry to keep those boilers working. This page is meant to be a brief summary of boiler maintenance.

### Scale and Corrosion

*Scale* and *corrosion* are the two of the most serious challenges facing marine boiler operators.

Scale is the build-up of insoluble material on the inside of the boiler. It can clog pipes and prevent heat exchange between the metal and water (which can cause overheating and metal failure). **Scale is usually made of calcium sulfate ( $\text{CaSO}_4$ ) and silicates (containing  $\text{SiO}_3^{2-}$ ).** Calcium ions and silica are introduced from sea water leakage into the boiler water. Calcium phosphate and other insoluble calcium compounds form less problematic sludge instead of scale.

Corrosion causes the thinning of metal in the boiler. The iron metal (Fe) loses electrons to become  $\text{Fe}^{3+}$  (rust). **Acidic protons ( $\text{H}^+$ ) or dissolved oxygen gas ( $\text{O}_2$ ) cause corrosion.** Presence of either of these species will accelerate corrosion because they gain electrons from iron. Phenolphthalein and other pH indicators can be used to measure  $[\text{H}^+]$ .

### Hard Water and Soap

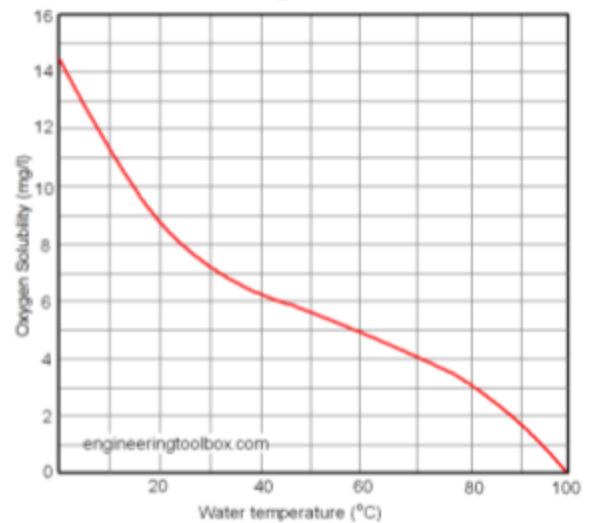
Soap is made of fatty acid molecules that dissolve in water, forming a surfactant. The presence of aqueous  **$\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions result in hard water.** These ions react with fatty acid anions to form an insoluble precipitate. As a result the soap does not form a surfactant and does not lather. If a soap solution does not lather or form bubbles, the solution likely contains has a large number of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions.

### Carryover and Blowdown

Large concentrations of impurities in boiler water can cause foaming and splashing of water inside the boiler. This splashing is called *carryover*. Instead of the steam being composed of pure water, carryover makes water droplets that leave residues and scale on other parts of the engine (like turbine blades and control valves). **Dissolved ions, oils, sludge, and other insoluble species can cause carryover.** Boiler operators need to ensure that they add only the purest possible solvent to boilers to reduce the chances of carryover.

Boiler operators can reduce carryover by performing a *blowdown*. The operator purposefully sets the boiler to eject a plug of water with a high concentration of solutes and insoluble species. Fresh water must then be added to the boiler.

Solubility of  $\text{O}_2$  by temperature



Retrieved from <https://i.stack.imgur.com/OkTAi.png>

## Steamship Solution Chemistry: Experiment

Your task is to test the condition of the boiler water by performing chemical tests with samples of boiler water. You will then write a report about the condition of the boiler water and recommend to the captain the steps that must be taken to keep your boiler in working order.

**Procedure:** Complete the procedure for the boiler water sample, then for the fresh water sample.

1. Record the temperature on the sample label.
2. Shake/stir the sample, then pour about 20 mL of boiler water sample into a beaker.
3. Observe the sample for initial appearance: clarity or presence of insoluble precipitates.
4. Add one drop of phenolphthalein to the beaker. Take observations.
5. Discard the liquid in the beaker and rinse.
  
6. Pour about 20 mL of sample into an empty bottle that can be capped.
7. Add a pipet-full of soap solution to the bottle.
8. Close the cap and shake. Open the cap and observe the results.
9. Discard the liquid in the bottle and rinse.
  
10. Pour about 20 mL of sample into a beaker.
11. Insert the conductivity meter. Take observations .
12. Add about 20 mL of sodium carbonate solution. Mix and let settle. Take observations.
13. Discard the liquid in the beaker and rinse.

### Observations:

<b>Boiler Water Sample Test</b>	Boiler water	Fresh water
Temperature when collected		
Initial appearance		
Addition of phenolphthalein		
Mixing with soap solution		
Conductivity meter		
Addition of sodium carbonate		

# Boiler Water Condition Report and Recommendations

Submitted by: \_\_\_\_\_ Date: \_\_\_\_\_

## Current boiler water conditions (acceptable/excessive) and explanations

[H<sup>+</sup>] is \_\_\_\_\_ as shown by:

[Ca<sup>2+</sup>] is \_\_\_\_\_ as shown by:

[SiO<sub>3</sub><sup>2-</sup>] is \_\_\_\_\_ as shown by:

[O<sub>2</sub>] in solution is \_\_\_\_\_ as shown by:

## Available fresh water conditions (acceptable/excessive) and explanations

[H<sup>+</sup>] is \_\_\_\_\_ as shown by:

[Ca<sup>2+</sup>] is \_\_\_\_\_ as shown by:

[SiO<sub>3</sub><sup>2-</sup>] is \_\_\_\_\_ as shown by:

## Analysis

The potential for corrosion is \_\_\_\_\_ (high/low) because:

The potential for scale build-up is \_\_\_\_\_ (high/low) because:

## Recommendation(s) to the Captain to fix any potential problems with explanations

I recommend:

# Teacher Instructions

## Curriculum Standards

NGSS HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

Massachusetts HS-PS1-9(MA). Relate the strength of an aqueous acidic or basic solution to the extent of an acid or base reacting with water as measured by the hydronium ion concentration (pH) of the solution. Make arguments about the relative strengths of two acids or bases with similar structure and composition.

Massachusetts HS-PS2-7(MA). Construct a model to explain how ions dissolve in polar solvents (particularly water). Analyze and compare solubility and conductivity data to determine the extent to which different ionic species dissolve.

Rhode Island PS1 (9-11)–1. Students demonstrate an understanding of characteristic properties of matter by utilizing appropriate data (related to chemical and physical properties), to distinguish one substance from another or identify an unknown substance.

NGSS cross-cutting concept 1: Patterns

NGSS cross-cutting concept 3: Scale, proportion, and quantity

NGSS Science Practice 3: Planning and Carrying Out Investigations

NGSS Science Practice 4: Analyzing and Interpreting Data

NGSS Science Practice 7 Engaging in Argument from Evidence

## Materials per group

- Boiler water sample (see below for solution preparation)
- Fresh water sample (see below for solution preparation)
- ~5 mL of soap solution, either in 2 pipets or in a small beaker
- 20 mL of sodium carbonate solution
- phenolphthalein
- conductivity meter (Flinn)
- 2 x 100 mL beakers
- 25 mL graduated cylinder
- A bottle with a cap, so that students can vigorously mix for soap test

## Solution preparation

### Boiler water samples (only give one sample to each group)

Sample A	Sample B
100 mL water ~5 drops 1 M NaOH to make it basic ~1 scoop $\text{CaCl}_2$ to make it hard Write $90^\circ\text{C}$ on a label on the container	100 mL water ~5 drops 1 M HCl to make it acidic ~1 scoop $\text{CaCl}_2$ to make it hard ~1 scoop $\text{Na}_2\text{SiO}_3$ to make it have a silicate solid Write $90^\circ\text{C}$ on a label on the container

### Fresh water samples

Sample X	Sample Y
100 mL distilled water	100 mL tap water ~1 scoop $\text{CaCl}_2$ to make it hard

### Soap solution

Shave about 10 g soap off a bar of Castille soap (containing no sodium lauryl sulfate on the ingredient label) and vigorously mix with ~100 mL of distilled water. Decant the solution, trying to exclude bubbles and undissolved soap.

### Sodium carbonate solution

Add about 30 g of sodium carbonate to 300 mL water. Mix until dissolved.

### Sample Allocation

Allocate samples so that there are four combinations of solutions (and analyses)

Samples A + X	Samples B + Y
Samples A + Y	Samples B + X

### Data interpretation

Oxygen content is inferred entirely from temperature when sample is collected.

$[\text{H}^+]$  is determined from the phenolphthalein indicator.

$[\text{Ca}^{2+}]$  is determined from the soap test.

$[\text{SiO}_3^{2-}]$  is determined from examining whether an insoluble solid is in the original water sample.

## Extensions

Writing chemical equations and drawing models of the ions in solution (with shells of hydration) would be a good way to demonstrate understanding of reactions, the dissolving process, the forces involved in solutions.

Asking for an explanation of the soap test would be appropriate and would assess understanding of surface tension and surfactants.

Equilibrium, the common ion effect,  $K_{sp}$  and LeChatelier's Principle can be assessed by posing hypothetical questions about adding additional solutions to the boiler water.