CORROSION RATES
Measuring the rate of iron corrosion

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Languages available
English, Hungarian

Summary
There are several methods to determine corrosion rate, for example, weight loss measurements and electrochemical methods. The simplest way of measuring the corrosion rate of a metal is to expose the sample to the test medium (e.g. seawater) and measure the loss of weight of the material as a function of time. This activity is an investigation of the aqueous corrosion of iron assuming uniform corrosion. Instead of measuring the weight loss of the corroding iron, when an iron plate is dipped into aqueous solutions (test media), this method measures the increase in the accumulating iron ion concentration in the test medium by photometric method in the form of Fe^{3+} complex. This is almost as simple as using weight loss measurements. The activity is completed with a calculation of the corrosion rate and the costs involved in using this method.

Activity type **D**
Use of scientific knowledge and understanding to solve problems
Working in teams to solve problems
Resource/budget management

Techniques
VIS spectrophotometry

Field
Environmental

Time
Practical lessons: 180 minutes
Theory lessons: 20 minutes
Out of class time: 70 minutes

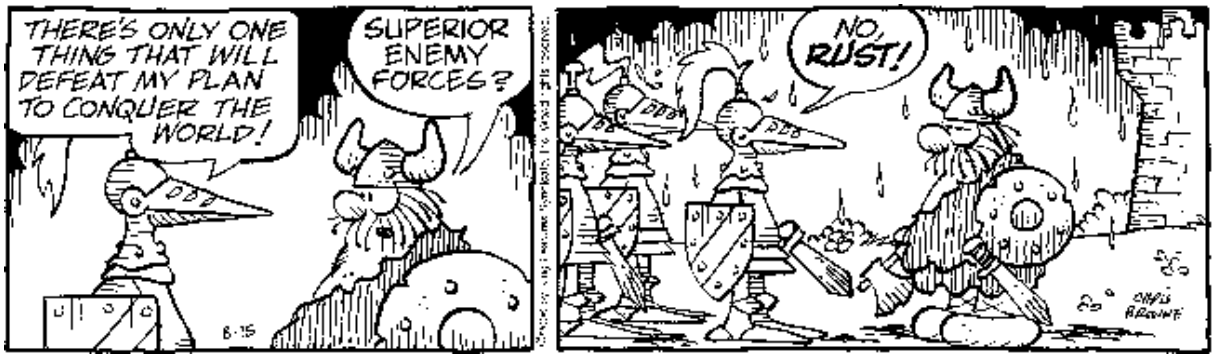
StandardBase procedures
Determination of iron in water using visible spectrophotometry

StandardBase techniques
Ultraviolet and Visible (UV-Vis) Spectrophotometry

Other resources
University of Miskolc, Faculty of Materials Science and Engineering (Hungary)
www.mak.uni-miskolc.hu/
http://www.key-to-steel.com/Articles/Art60.htm
http://www.gamry.com/App_Notes/DC_Corrosion/GettingStartedWithEchemCorr
Measurements.htm

Student's document

CORROSION RATES: Measuring the rate of iron corrosion



There was a notice (on a poster) in a corrosion exhibition in Brussels (1937):

> "While you read this
> 760 kg iron
> has been corroded!"

Metal corrosion results in the deterioration of functional properties, e.g. mechanical strength. Even a negligible amount can cause serious damage where the corrosion is non-uniform, i.e. pitting, stress corrosion cracking. Corrosion has many serious economic, health, safety and technological consequences for society. Studies in a number of countries have attempted to determine the national cost of corrosion. The most extensive of these studies was one carried out in the United States in 1976 which found that the overall annual cost of metallic corrosion to the U.S. economy was $70 billion (US billion: 10^9), or 4.2% of the gross national product.
Can you imagine how big a problem corrosion is for the whole the world?!

This activity will help you develop the following skills:

- Using scientific knowledge and understanding to solve problems
- Working in teams to solve problems
- Using VIS spectrophotometer
- Calculating corrosion rates
- Calculating (estimating) the financial cost of the measurement

Your brief
Suppose you are working in a materials testing laboratory. You have to plan a simple method to determine the iron corrosion rate in different test media. You are given a piece of iron (carbon steel) test material and you have to monitor its corrosion in aqueous (or acidic) solutions. After taking the measurements, you will have to calculate the corrosion rates and iron waste. You will then have to estimate the financial cost of the measurements.

Your investigation
You will work as a member of a group. There should be at least two groups for this activity.

Group (A) will investigate the corrosion of iron test-material in tap water (or other corrosive medium, e.g. 1% by mass hydrochloric acid)
Group (B) will investigate the corrosion of iron test-material in seawater (or artificial sea water – NaCl solution)

When your group has finished the laboratory work, you will be asked to estimate (calculate) the corrosion rate of the test material in the aqueous environment. You will be asked to estimate the financial cost of your measurements.

Estimated time
2 x 45 minutes + 4 x 45 minutes (for each group)

You will be asked to make a detailed work plan. You should gather information on available chemicals and equipment, preparation needed (solutions, standards), safety points, calibration curve and metal dissolution rate or corrosion rate. After finalising your plan (your teacher will help and evaluate), groups must coordinate their timetable.

A risk assessment must be carried out before starting practical work.

Your findings
You will find the procedure on the **Student sheet**.

After the measurements have been made, complete the tables on the **Student data sheet** and calculate the corrosion rate.

Estimate the financial cost of the measurement!

Remarks
When estimating expenses for the measurement, include the cost of
- using the analytical laboratory (with VIS spectrophotometer – approximately 80 €/hour)
- wages of technicians (approximately 25 €/hour/person)
- chemicals used

After finalising your report, describe what you learned about resources and budget management, in 50-100 words.

Student self assessment
Complete the checklist below. If there are more than three "NO" answers, please consult your teacher.

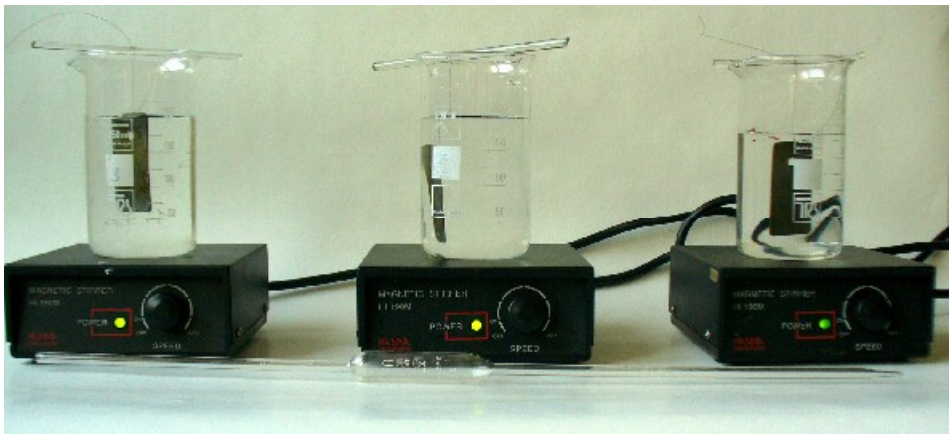
Using scientific knowledge and understanding to solve problems
1. Can you search for information after putting in a keyword on the Internet?
2. Have you found useful information other than the suggested articles and websites?
3. Can you summarise what is meant by *corrosion*?
4. Do you know the Lambert-Beer law?
5. Do you use the VIS spectrophotometer in practice?
6. Did you understand the meaning of corrosion rate?
7. Can you suggest a way of estimating the cost of rust on an iron structure?

Student sheet: Procedure

www. standardbase.com
Determination of iron in water using visible spectrophotometry

Pre-treatment of iron test material
Dip the iron test material into *w* = 5-10% HCl solution for 2 minutes. After removing, wash it in distilled water.

Sample preparation
Measure 200 cm^3 corrosion medium (seawater or *w* = 3% NaCl solution) into a 250 cm^3 beaker. Measure the area of test material (recommended test material: carbon steel; area about 15-20 cm^2). Dip the iron test material into the solution. Mix the solution with a magnetic stirrer.



Measurement
Dip the iron test material into the corrosive medium (tap water and sea water or some kind of acidic solution, e.g. 1% by mass hydrochloric acid). After 20-40-60 minutes, investigate the increase in the iron ion (Fe^{2+} + Fe^{3+}) content of the corrosive medium. Prior to the Fe^{3+} rodanide complex formation, use the same oxidising procedure as in calibration.

Pipette out 10 cm^3 from the corrosion medium into 100 cm^3 volumetric flasks (20-40-60 minutes after dipping the test-iron material).
Before adjusting to the mark, add into the volumetric flask 2 drops 5% H_2O_2 solution and 2 drops of cc. nitric acid and 1 cm^3 20% KSCN reagent.

Making a calibration curve
Add into the 100 cm^3 volumetric flasks 0-4-12 cm^3 of the standard solution (adjust the quantities to your samples), and approximately 50 cm^3 distilled water. Add the reagents (2 drops 5% H_2O_2 solution and 2 drops of cc. nitric acid and 1 cm^3 20% KSCN) into the volumetric flasks and fill to mark.

Remark
The Fe^{3+} content will about 0.4 – 0.8 mg Fe^{3+}/dm^3 after 60 minutes in the corrosive medium (seawater).

Measure the absorbance of the solutions with the spectrophotometer, using a wavelength of 540 nm (within 60 minutes after addition of reagents).

Student data sheet: Tables

Suggested tables to complete:

$c(Fe^{3+})$ mg cm^{-3}	$l_{cuvette}$ cm	λ nm	A
0.4	1	540	
0.8	1	540	
1.2	1	540	

Time min	A	$c(Fe^{3+})$ mg cm^{-3}	R_{corr} g m^{-2} d^{-1}
20			
40			
60			

To calculate the corrosion rate – assuming uniform type of corrosion and constant corrosion rate over time –

$$R_{corr} = m/(S \times t) \quad [\text{g m}^{-2} \text{ hour}^{-1}]$$

Where
m is the mass of corroded metal (m can be calculated after the determination of the Fe^{3+} content in test medium)
S is the area of test metal
t is time

Extrapolate the iron corrosion rate for 1 year!

Teacher's document

Overview

Simulating work in a materials laboratory, students investigate the aqueous corrosion of iron assuming uniform corrosion. They calculate the rate of corrosion and estimate the cost of carrying out the procedure.

Developing students' skills

Students learn to:

- Use knowledge and understanding to tackle scientific problems: corrosion and corrosion rate
- Observe, measure, analyse and evaluate scientific data
- Work with others, exchanging information
- Manage resources and budget
- Estimate the cost of their measurements

Organising and managing the class

Minimum group size: 2
Group (A) will determine the corrosion rate of iron in tap water
Group (B) will determine the corrosion rate of iron in seawater (or NaCl solution)

Students may need help with working relationships in their group.

Session plan for teachers

- Teacher's introduction to the scenario (20 minutes)
  - outline the available equipment (and chemicals)
  - statement of expected output (content, format)
- Gathering information (25 minutes)
  - diagnostic assessment with questions related to the subject
- Organisation of the teamwork (45 minutes)
  - outline the available equipment
- Preparing sample, measuring the iron content in the corrosive media (135 minutes)
- Making final report, evaluating results (45 minutes)

Technical notes
The students dip their iron samples into different corrosive media using magnetic stirring. Every 20 minutes (after the start: 20-40-60 minutes), students pipette out 10 cm^3 from the corrosive media, add reagents and measure the absorbance of solutions at 540 nm.

This activity needs only an analytical laboratory with VIS spectrophotometer and glassware for normal laboratory preparations.

Equipment and materials
Materials and their CAS numbers

Ammonium iron(II) sulfate hexahydrate ($Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$)	7783-85-9
Hydrogen peroxide (H_2O_2)	8007-30-5
Nitric acid (HNO_3)	78989-43-2
Hydrochloric acid (HCl)	7647-01-0
Potassium thiocyanate (KSCN)	333-20-0

Instruments
- VIS spectrophotometer
- calibrated analytical balance
- magnetic stirrers

Glassware
- 1000 cm^3 volumetric flasks (Class A)
- 250 cm^3 volumetric flasks (Class A)
- 100 cm^3 volumetric flasks (Class A)
- 250 cm^3 beakers
- funnels
- 25 cm^3 burette
- 20 cm^3 pipette (Class A)

Solutions
Standard iron(II) solution
Accurately weigh out 0.7020 g of ammonium iron (II) sulfate-6-water, and dissolve in 250 cm^3 1 mol/dm^3 hydrochloric acid. Make the solution up to 1 dm^3 with distilled water (iron free).
1.00 cm^3 standard solutions contain 0.1 mg iron (II).

Reagent solutions
- *w*= 20% KSCN reagent
- *w*= 5% H_2O_2 oxidising reagent
- cc. HNO_3 oxidising reagent

TESTING PRIOR KNOWLEDGE

Choose the correct answer.

1. Dissolve 1.404 g $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in a 1000 cm^3 volumetric flask. What will be the Fe^{2+} content in 1 cm^3 of solution?
   a. 1.8 mg
   b. 0.2 mg
   c. 0.1 g
   d. 0.5 mg

2. If the transmission of solution is 50%, the absorbance is...
   a. 1.500
   b. 0.500
   c. 5.72
   d. 0.301

3. Aqueous corrosion of iron requires:
   a. H_2O
   b. O_2
   c. both
   d. air

4. What mass of iron is present in 0.5267 g of ammonium-iron(II) sulfate-6-water?
   a. 10 mg
   b. 75 mg
   c. 100 mg
   d. 750 mg

Note: answers are given in red. These need to be removed before the test is used.

TESTING PRIOR KNOWLEDGE

Choose the correct answer.

1. Dissolve 1.404 g $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in a 1000 cm^3 volumetric flask. What will be the Fe^{2+} content in 1 cm^3 of solution?
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