TEACHENGINEERING.ORG

Are You Feeling Neutralized?

U.S. National Science Foundation
Engineering & Applied Science
UNIVERSITY OF COLORADO BOULDER

Background

- You are a part of an engineering firm that was contacted by a small town.





- This town has many industrial facilities that sit close to a river facility on the east side, and there is a large mining operation on the west side.





- The town is also prone to receiving large amounts of rain.

The Issue

- People from the town have been noticing that the water supply has a metallic taste lately.

- They've also seen the water color change to kind of a blue-green color.

- And some people have even gotten sick!







Humm, what may be...



Industrial Plants



Mining



River





Frequent Rain



Metallic Taste



Blue/Green Water Stains



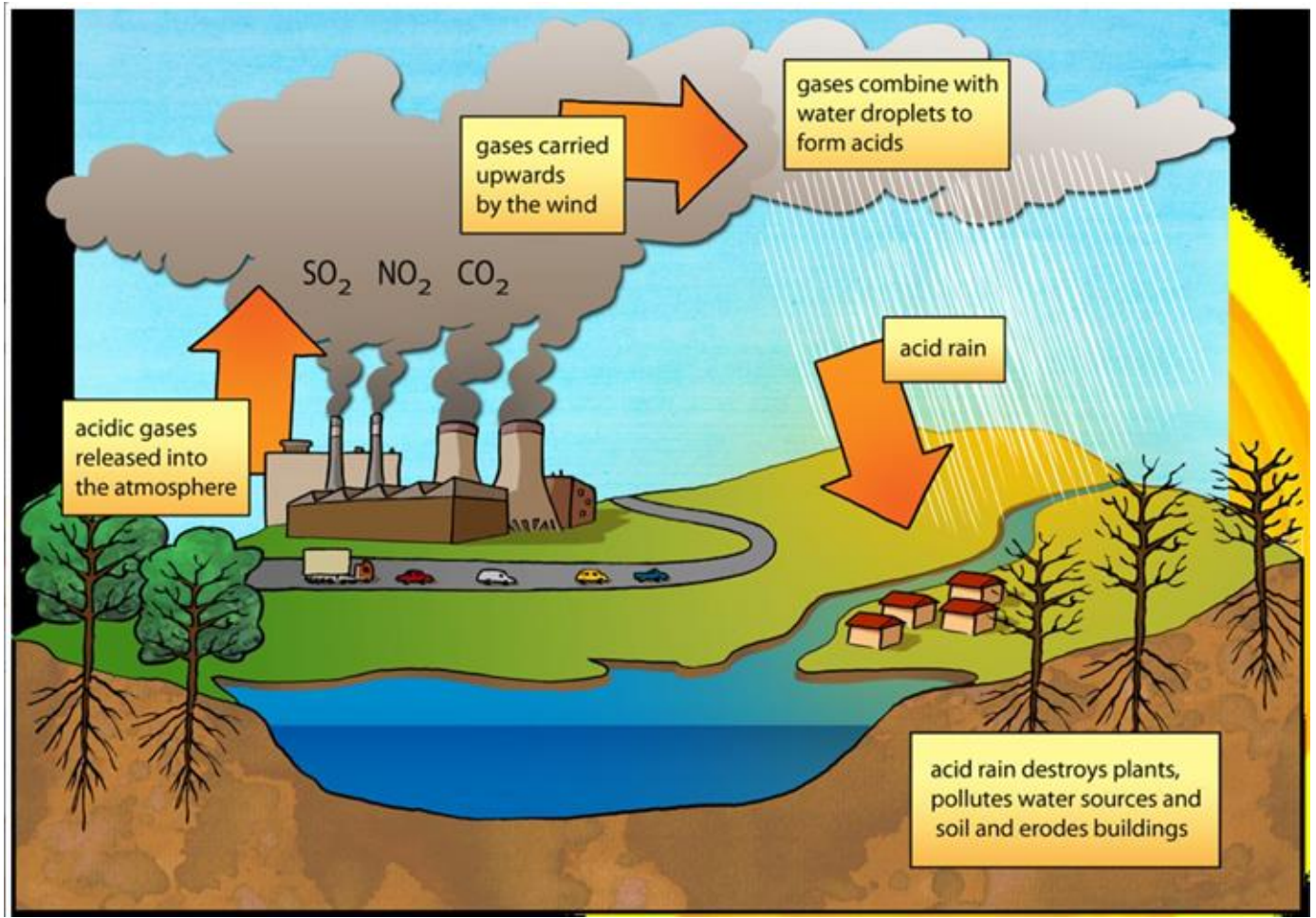
Sickness

...causing the issue with the water supply? Take 90 seconds to discuss with your team. Be prepared to share your reasoning.

The Culprit... Acid Rain!



Acid Rain!


gases carried upwards by the wind
gases combine with water droplets to form acids
SO_2 NO_2 CO_2
acid rain
acidic gases released into the atmosphere
acid rain destroys plants, pollutes water sources and soil and erodes buildings

Acid Rain → Produces Acidic Runoff Water → Can Corrode Copper Pipes



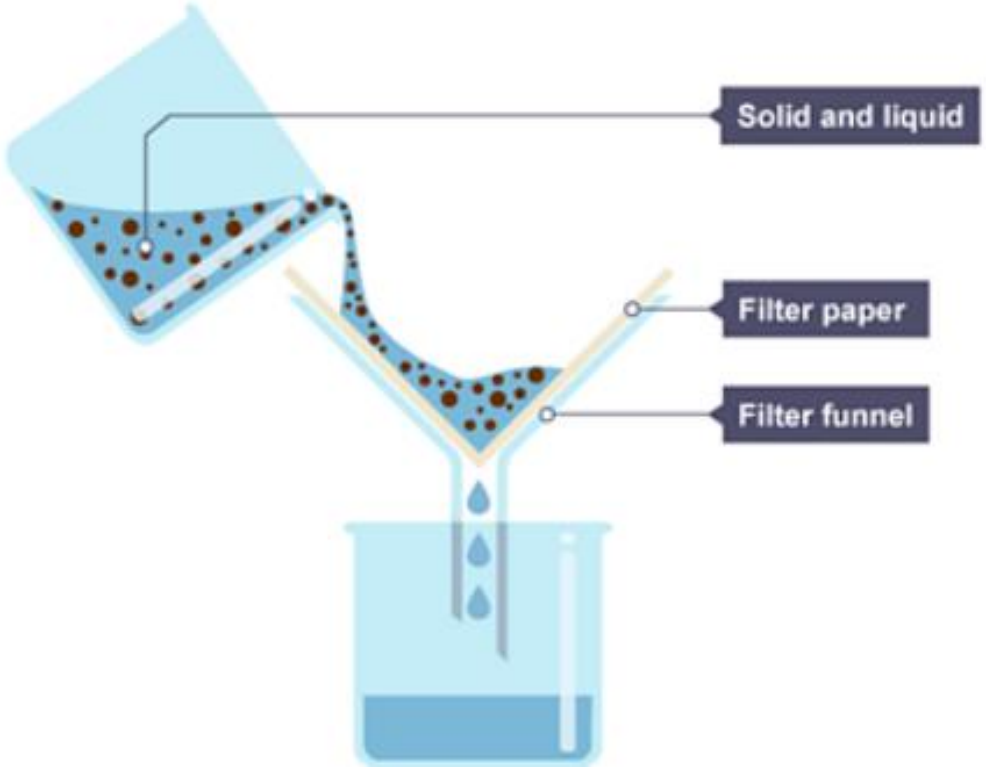
This can lead to copper and other metals leaching into water, which can be hazardous!

The Question

- How can we make the water supply safer to use and drink - “acid free”?

- How can we test and determine whether it’s safe?

Well, let's first talk about **filtration**! What is it?



Let's **click below** to learn more about the basics of filtration.



Filtration - the simple process of separation of substances for purification.

Okay, let's see how engineers use the process of filtration in water treatment →

HOW INDUSTRIAL WATER FILTRATION WORKS

TREATING ACIDIFIED WATER (ACID RAIN)

Water flows through a series of treatment stages.
Each stage removes contaminents and neutralizes acidity to produce clean, safe water.

ACIDIFIED RAW WATER IN
From rivers, lakes, or reservoirs affected by acid rain.



1 SCREENING
Removes large debris like leaves, sticks, and trash.

2 pH ADJUSTMENT (NEUTRALIZATION)
Adds a base chemical (lime or sodium hydroxide) to raise pH and neutralize acidity.

3 COAGULATION & FLOCCULATION
Chemicals are added to clump tiny particles into larger flocs.

4 SEDIMENTATION
Heavier flocs settle to the bottom of the tank.

5 FILTRATION
Water passes through layers of filter media to trap remaining particles.

6 DISINFECTION
Disinfectants (like chlorine or UV) kill harmful bacteria and pathogens.

7 CLEAN WATER STORAGE
Clean water is stored in a reservoir before distribution.



CLEAN WATER OUT
To homes, businesses, and industries.

WHAT IS ACID RAIN?
Pollutants in the air combine with water vapor to form acids (sulfuric and nitric acids) that fall to Earth in rain. This makes the water more acidic (low pH).

CONTAMINANTS REMOVED
- Suspended Solids
- Turbidity (Cloudiness)
- Organic Matter
- Bacteria & Pathogens
- Chemicals & Heavy Metals
- Odors & Taste
- Excess Acidity (Low pH)

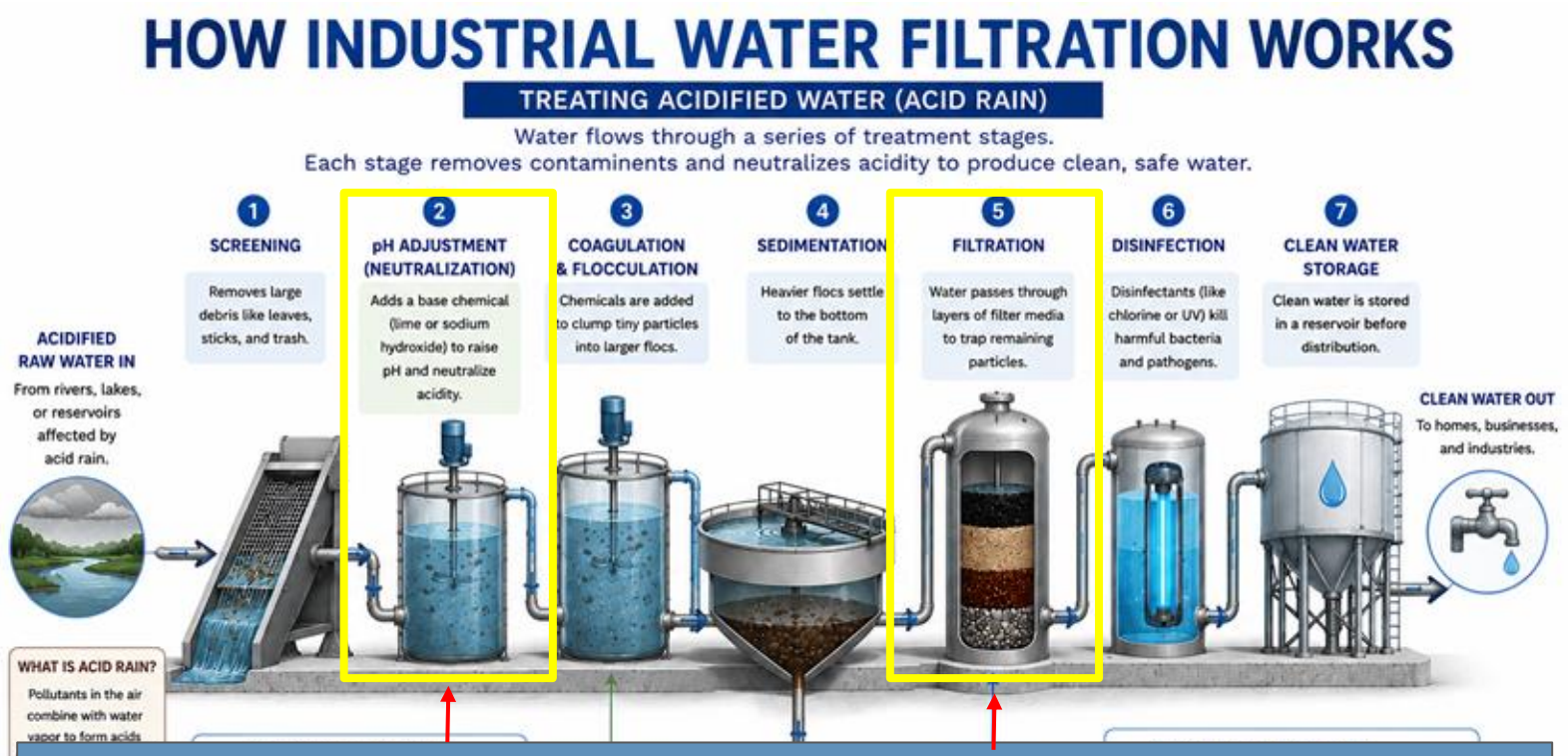
CHEMICALS ADDED
Lime ($Ca(OH)_2$) or Sodium Hydroxide (NaOH) neutralizes acids and helps protect pipes and equipment.

WASTE / SLUDGE
Removed solids are treated and disposed of properly.

FILTER MEDIA

RESULT: CLEAN, SAFE WATER
- Neutral pH (healthy for people and the environment)
- Safer to Use
- Protects Health
- Supports Communities and Industry

KEY IDEA: Acidified water is neutralized, cleaned, and disinfected step-by-step. Each stage targets specific contaminants until the water is safe, clear, and ready to use.



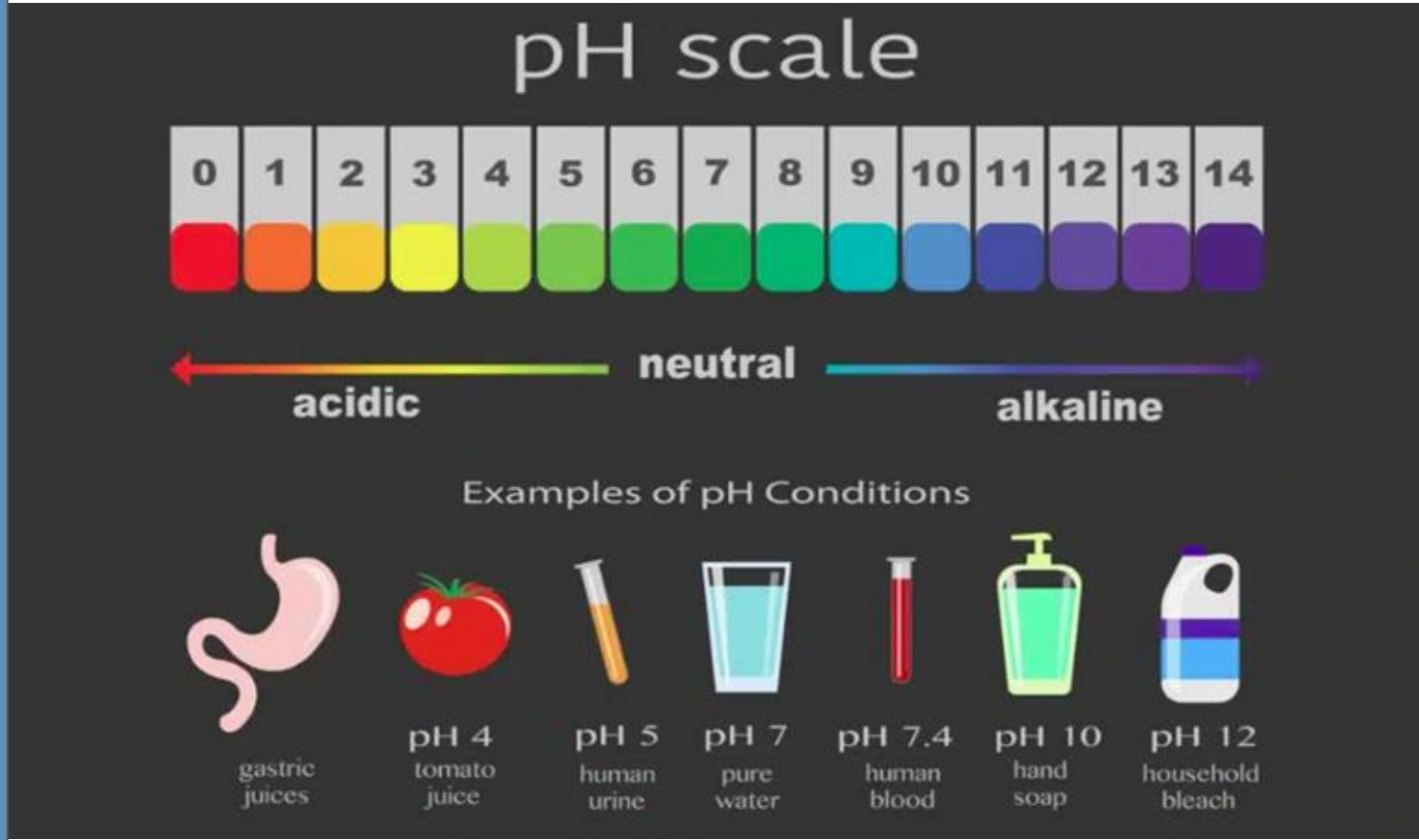
As you can see, engineers must take runoff water through several process steps in order to make our water clean, clear, and drinkable. However, for the sake of what we can do in class, we will focus on **these two steps** in the water treatment process!

A little background on acids

pH Scale

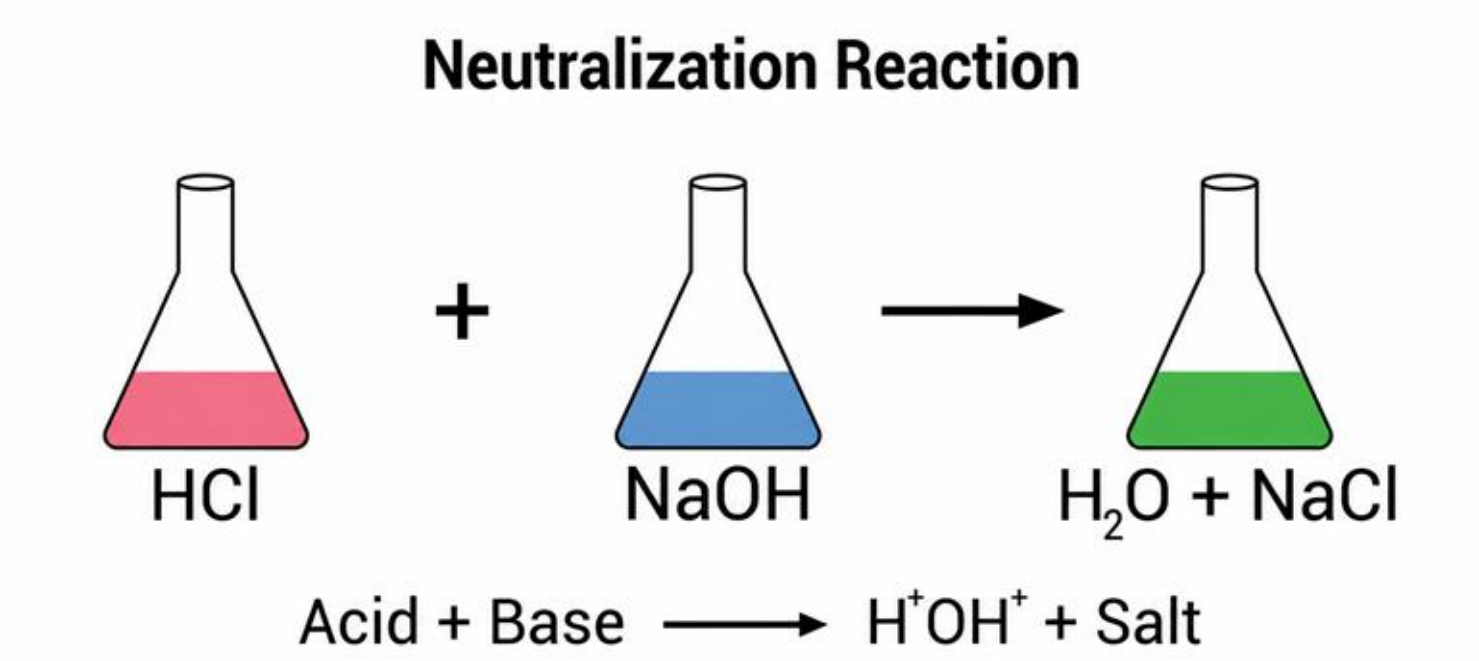
Used to measure the acidity or alkalinity of a substance based H^+ or OH^- ion content contained.

pH values on both extremes of the scale can indicate possibly harmful substances or conditions.



Neutralization Reactions

Occurs between acidic and alkaline (basic) solutions. In this process, harmful characteristics of acids and bases can be neutralized or “cancelled out” when mixed with one another.



NEUTRALIZATION: ACID + BASE → SALT + WATER + CARBON DIOXIDE

When an acid reacts with a base, they neutralize each other to form salt and water.
When carbonate or bicarbonate bases are used, they also produce carbon dioxide gas.

Examples: "Active Ingredient" Neutralization Reactions

ACIDS

VINEGAR (ACETIC ACID)



CH_3COOH

Weak acid
Sour taste
pH ~ 2–3

CITRIC ACID



$C_6H_8O_7$

Weak acid
Sour taste
pH ~ 2–3

ACIDIC

+

BASES

BAKING SODA (SODIUM BICARBONATE)

$NaHCO_3$



Weak base
Slightly bitter
pH ~ 8–9

TUMS (CALCIUM CARBONATE)

$CaCO_3$



Weak base
Slightly bitter
pH ~ 8–10

BASE (ALKALINE)

+

→

NEUTRALIZATION PRODUCTS

$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$



Sodium acetate (salt) | Water | Carbon dioxide gas

NEUTRALIZED! (SAFE, NEAR pH 7)

$C_6H_8O_7 + CaCO_3 \rightarrow Ca_3(C_6H_5O_7)_2 + H_2O + CO_2$



Calcium citrate (salt) | Water | Carbon dioxide gas

NEUTRALIZED! (SAFE, NEAR pH 7)

Note: You will receive a random acid and base combination. This is to simulate the unknown variables that environmental and chemical engineers must contend with in working to neutralize various acidic compounds in water.

Be aware that a small amount of gas will also be produced.

Your Task!

- You will be a team of **chemical & environmental engineers**!
- As a team, you will create a **neutralization water filter** that will counteract the acid in the water and make it safe again!
- You will also create a **simulated contaminated "acid rain" (SCAR)**  water sample to test your filter.
- Your filter should also filter out other contaminants as well!

Activity Overview!

BUILD & TEST YOUR BOTTLE FILTER

ENGINEERS DESIGN SOLUTIONS TO CLEAN & NEUTRALIZE WATER!

WATER BOTTLE



Clean 500 mL water bottle

+

FILLER INGREDIENTS
(YOUR CHOICE – RANDOM ORDER)

Choose up to FIVE (5) different materials and layer them in any order you think works best!



Gravel



Sand



Rice



Soil



Activated Charcoal



Large Pebbles



Gauze



Cloth or Coffee Filter



Sponge

? Other

Tip: Use cloth, paper towel, gauze, or sponge as separators between some layers if needed.

+

NEUTRALIZING MATERIAL
(ADD IN A LAYER)

You will add one of these active ingredients to your filter.



Baking Soda (Sodium Bicarbonate)

OR



Crushed TUMS (Calcium Carbonate)

These help neutralize acid, which in turn, can protect copper pipes from corrosion.

+

SIMULATED CONTAMINATED ACIDIC RUN-OFF (SCAR) WATER



Simulated acidic run-off water (SCAR) (contains vinegar or citric acid, hydrogen peroxide, and soil to mimic pollution)

FILTERED WATER (RESULT)



Cleaner, neutralized water with reduced particles and contaminants

STEPS TO BUILD & TEST YOUR FILTER

1 PREPARE



Gather all materials. Cut cloth, gauze, and sponge to fit.

2 BUILD YOUR FILTER



Layer up to FIVE different materials in any random order. Add baking soda or TUMS as one layer in your filter (6 total layers).

3 PREPARE TEST WATER



Mix simulated SCAR water (vinegar or citric acid, H_2O_2, and soil).

4 TEST BEFORE FILTERING



Measure and record pH, clarity/turbidity, and any copper reaction.

5 FILTER THE WATER



Slowly pour test water through the filter. Record flow rate.

6 TEST AFTER FILTERING



Measure and record pH, clarity, and check for corrosion again.

GOAL: Produce clear, neutral water (pH close to 7) with minimal corrosion and a steady flow rate.

Your job as an engineer is to design, test, and improve your solution!

There is no single "right" order – test, evaluate, and improve!

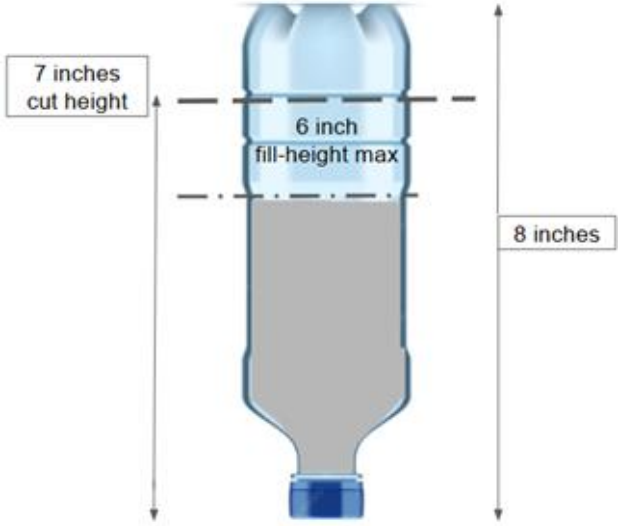
To Break It Down:
1) Plan Your Water Filter



You will use the following:

- water bottle
- ruler
- pair of scissors
- marker
- various filler materials: cotton balls, clothe, gauze, coffee filter, pebbles, rice, or sponge material, etc.

2) Draft a Design



- Sketch out the layers of your filter.

3) Construct Your Filter

- You can apply the filler materials and active ingredient as you choose, but you must build your filter within the constraints described in activity handout.

4) Obtain Your “Active Ingredient” Neutralizing Materials

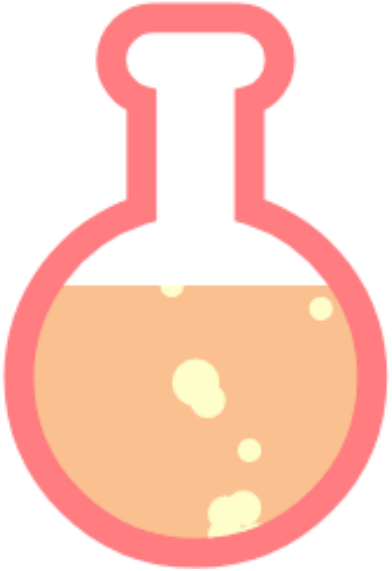
- Antacid

  or
- Baking soda



5) Create Your SCAR Water Solution





You will need:

- hot plate
- medium-sized beaker (400-500 mL)
- thermometer
- 150 mL of citric acid or acetic acid (vinegar)
- 150 mL of hydrogen peroxide
- stopwatch or timer

6) Evaluate Your SCAR Solution

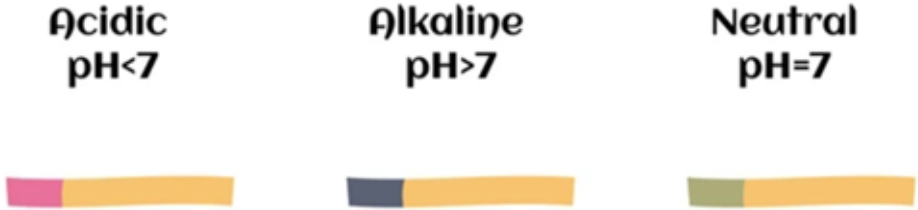
- Observe your unfiltered solution.
- Measure pH (pH Meter or pH Paper).



pH Meter



Universal pH Paper



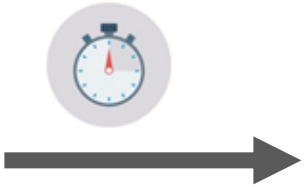


6) Evaluate Your SCAR Solution (continued)

- Evaluate the corrosion reaction of your SCAR water with copper metal (to make sure your “acid rain” solution is “working”)!



Place penny in cup & add small amount of SCAR water.



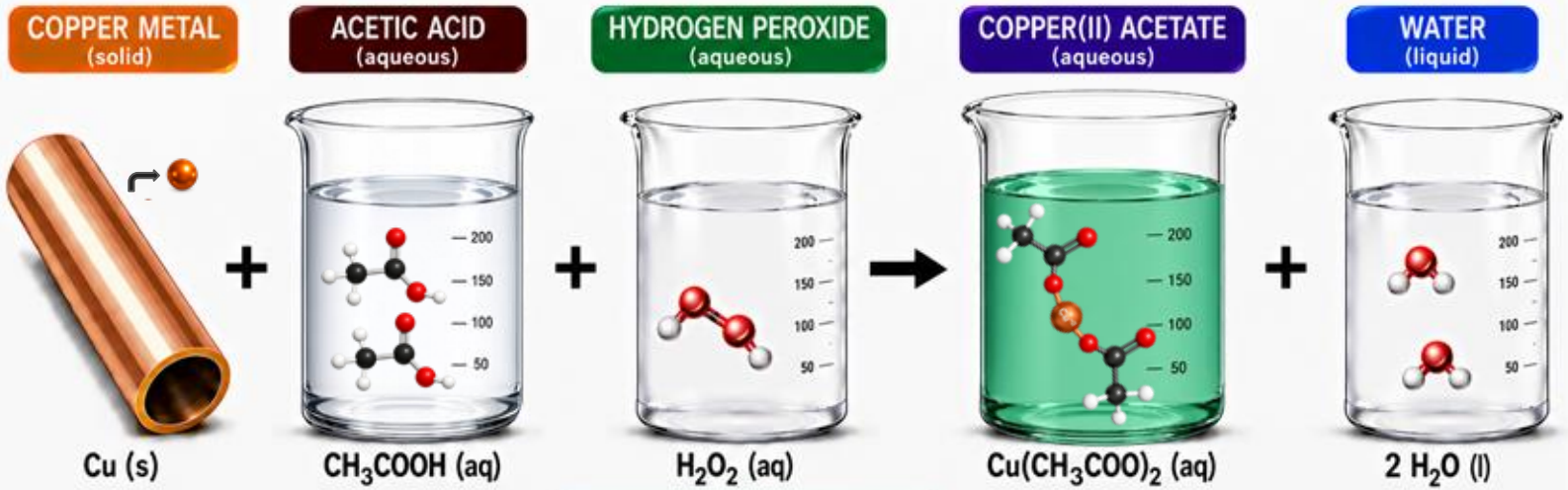
Let solution sit for 5 min.



Evidence of reaction: blue/green solution, bubbles forming,copper tarnishes.

Chemistry of copper corrosion due to acetic acid

Corrosion Simulation: Reaction of Copper with Acetic Acid/ Hydrogen Peroxide Catalyst



BALANCED CHEMICAL EQUATION

$Cu\ (s) + 2\ CH_3COOH\ (aq) + H_2O_2\ (aq) \rightarrow Cu(CH_3COO)_2\ (aq) + 2\ H_2O\ (l)$

Copper (solid)	Acetic Acid (aqueous)	Hydrogen Peroxide (aqueous)	Copper(II) Acetate (aqueous)	Water (liquid)

Oxidized copper = corrosion.

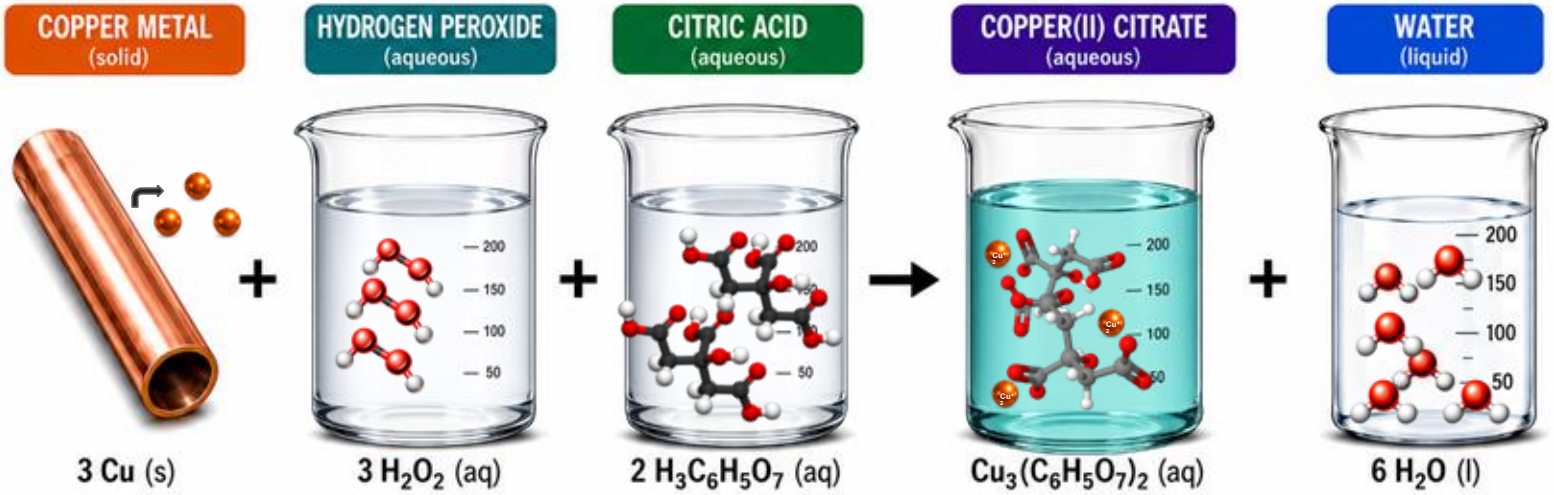
This corrosion creates Copper (II) Acetate, a blue-green dissolved salt (aqueous) that forms from Copper's reaction with Acetic Acid (i.e. vinegar), which can be toxic to ingest.



Note: Hydrogen peroxide (H_2O_2) is the oxidizing agent that supplies oxygen to oxidize copper and form water.

Chemistry of copper corrosion due to citric acid

Corrosion Simulation: Reaction of Copper with Citric Acid / Hydrogen Peroxide Catalyst

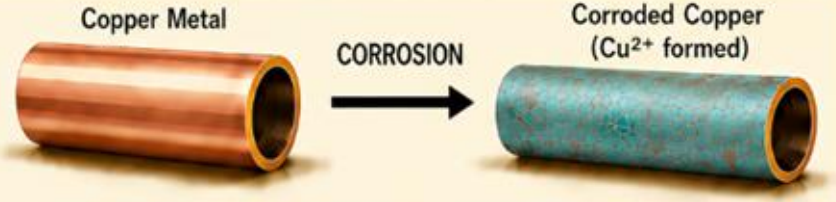


BALANCED CHEMICAL EQUATION

3 Cu (s)	+	3 H_2O_2 (aq)	+	2 $H_3C_6H_5O_7$ (aq)	→	$Cu_3(C_6H_5O_7)_2$ (aq)	+	6 H_2O (l)
Copper (solid)		Hydrogen Peroxide (aqueous)		Citric Acid (aqueous)		Copper(II) Citrate (aqueous)		Water (liquid)

Oxidized copper = corrosion.

This corrosion creates Copper (II) Citrate, an aqua-blue or blue-green dissolved salt (aqueous) that forms from Copper's reaction with Citric Acid (i.e. found naturally in citrus fruits), which can be toxic to ingest in large amounts.



Note: Hydrogen peroxide (H_2O_2) is the oxidizing agent that supplies oxygen to oxidize copper and form water.

… And don’t forget to add your organic material!

(i.e., dirt, mulch, leaves, twigs, etc.)



Your SCAR water is READY!

7) Test Your Neutralization Filter

As you test your filter, be sure to measure:

- pH of filtered solution.
- Filtered water's reactivity with copper.
- Clarity of filtered water (turbidity).
- Flow rate.



-> One important note on the flow rate...

FLOW RATE: How Fast Does Water Flow Through Your Filter?

Flow rate is the volume of water that passes through your filter in a given amount of time.

WHY FLOW RATE MATTERS

TOO SLOW:
Water takes too long to filter. The filter may clog.

JUST RIGHT:
Water filters at a steady pace. Better filtration and neutralization.

TOO FAST:
Water moves too quickly. Contaminants may not be removed.

WHY IT MATTERS:
A good flow rate gives your filter time to clean and neutralize the "acid rain" water for safer, higher quality results.

WHERE WE USE FLOW RATE

Environmental engineers design filters and water treatment systems with the right flow rate to ensure systems are efficient, effective, and reliable.



HOW TO MEASURE FLOW RATE

Measure how much filtered water (volume) comes out in a certain amount of time.

1. Add a known volume of "acid rain" water to the top of your filter.
2. Place an empty beaker below the filter to collect the filtered water.
3. Start the stopwatch as water begins to drip out.
4. Stop the stopwatch when you have collected a known volume (ex: 100 mL).









CALCULATE FLOW RATE

$$\text{Flow rate} = \frac{\text{Volume (mL)}}{\text{Time (s)}}$$ (mL per second)

EXAMPLE:
You collect 100 mL of water in 80 seconds.
Flow rate = 100 mL / 80 s = **1.25 mL/s**

WHAT DO YOUR RESULTS MEAN?



REMEMBER: The right flow rate helps your filter clean the water, neutralize acidity, and protect copper pipes!

8) Last: Evaluate and Redesign

Did your design:

- Neutralize the acid?
- Improve the quality of the water?
- Allow for a sufficient flow rate?
- Stop the reactivity with the copper sample?

Engineers always look to learn from and improve upon their designs!

Now Let's Begin!



Click here for your team's **acid source** & **"active ingredient" neutralizing agent** selection!

