Electro-Clean:

Instructions and User Guide for 2-L Batch Reactor

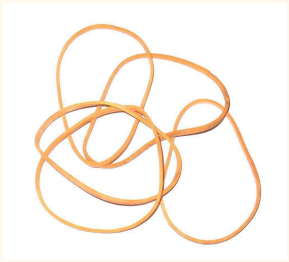
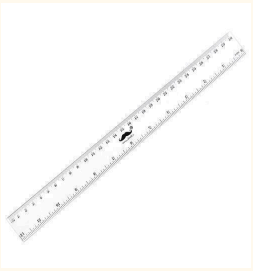
~ Last revised July 31, 2024 ~

These instructions provide an easy-to-follow set of steps to build a low-cost reactor for the production of 7 Liters of a chlorine-based disinfectant.

Table of Contents

Materials and Tools List

MATERIALS FOR ASSEMBLY OF 2-LITER REACTOR

 12 AWG Wire, red (30 cm) and black (40 cm)	 12 Gauge Open End Power Cord	 1-cm diameter Copper Coated Graphite Rods (2)	 Razor/Utility knife
 Scrub Brush or Used Toothbrush	 Paper Towel or Napkin	 2-cm Diameter Heat Shrink Tubing	 Scissors
 Kitchen Lighter	 Rubber Bands (5)	 Pliers	 Ruler
 Screwdriver	 Multimeter (or Ammeter)	 5V Switched-mode Power Supply, 20-40 Amp	 2-Liter Plastic Bottle

MATERIALS NEEDED FOR MAKING DISINFECTANT

 Salt	 5-Gallon Food Grade Bucket with Lid	 Measuring Cup	 Kitchen Scale
 Chlorine Test Strips	 pH Strips	 White Vinegar	 Baking Soda
 Long Mixing Spoon/Tool	 7 L Drinking/Tap Water		

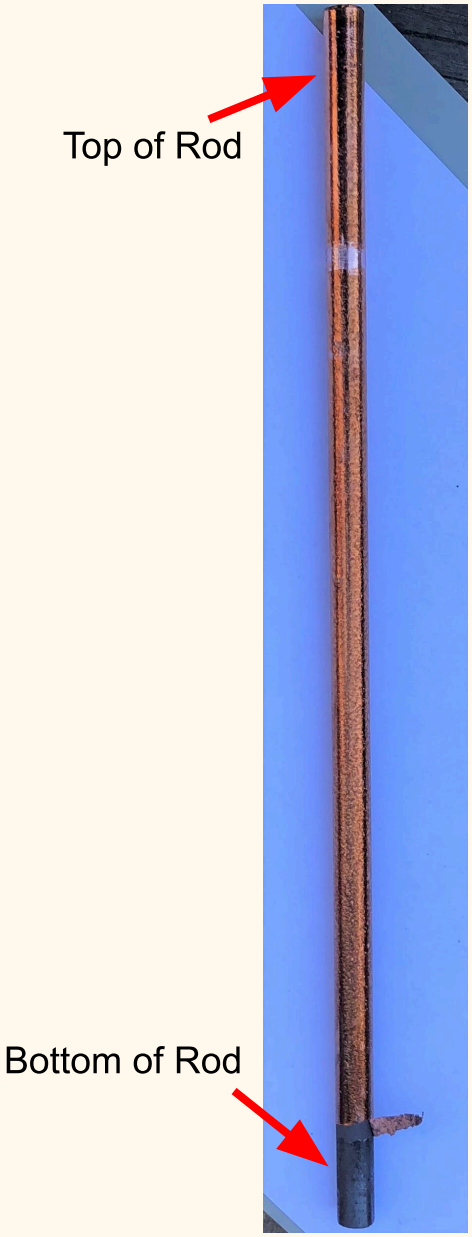
Notes on Materials List

- If available, copper-coated graphite rods are preferred. Uncoated graphite rods are also acceptable.
- If heat shrink tubing is not available, an alternative is to use a 5-cm length piece of PVC / rubber household pipe or garden hose (1-2 cm diameter). Cut the garden hose lengthwise and wrap around one of the electrodes just to separate them (electrical wire tied to electrodes will stick out of the slit). This will prevent short-circuiting in the air-exposed portion of the electrodes.

Part 1. Assembling the Reactor

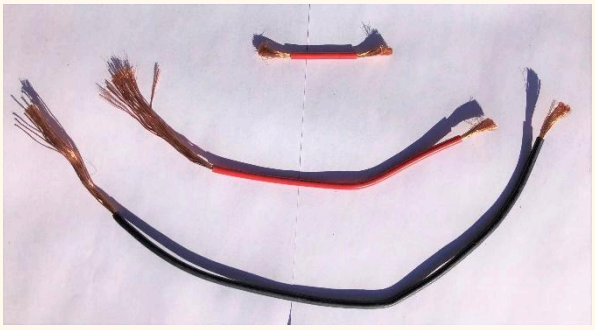
Step 1: Peel Most of the Copper Off the Rods

- Using the razor, carefully slice the copper coating and start peeling it off from the ***bottom*** end, as shown in the left picture below. Then use your fingers to continue peeling the copper, leaving about 2cm of copper at the top of the rod, as shown in the right picture below.
- Repeat the process with the other rod.



Step 2: Prepare the Wires

- Using scissors, cut the red/black 12 AWG wires so that you have:
    - One **8 cm red** wire
    - One **22 cm red** wire
    - One **40 cm black** wire
- Using the razor:
    - On the **8 cm red wire,** strip 2 cm of coating off *both* ends of the cable.
    - On the **22 cm red wire,** strip 2 cm of coating off *one* end of the cable and 8 cm off the other end.
    - On the **40 cm black wire,** strip 2 cm of coating off *one* end of the wire and 8 cm off the other end.
    - See right image below for the final result.

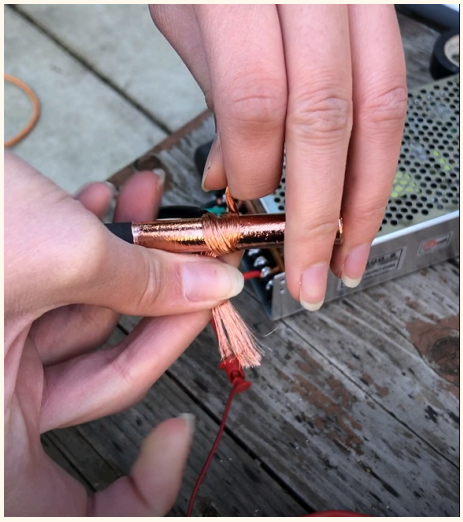


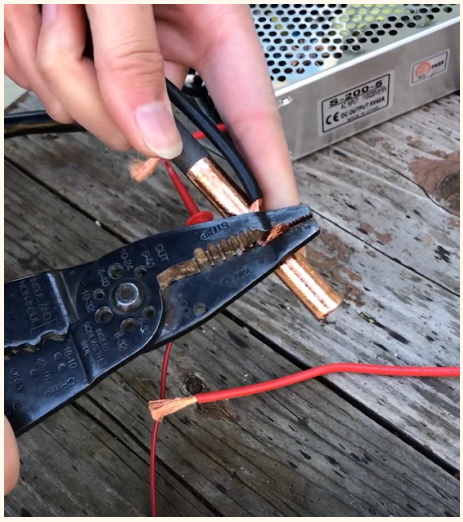
- Using the razor, also strip 2 cm of coating off *all three cables* (green, white, black) of the open end power cord to expose the copper strands.

Step 3: Assemble Electrodes

3A: Wrap wires tightly on rods

- Take the **22 cm red** wire and the **40 cm black** wire, and separate the copper strands into two, as shown on the image on the right.



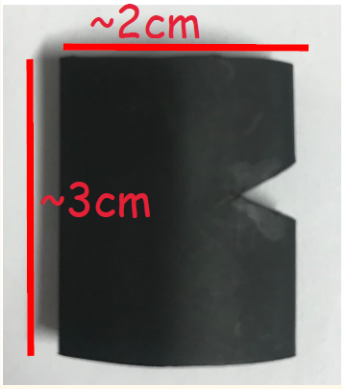


- Take the **22 cm red** wire and wrap the two strands around the copper end of one of the rods in opposite directions (like hugging).
- Continue wrapping the two strands around the copper end and use pliers to twist the two strands together. Make sure the strands are wrapped ***very tightly.***

- Repeat the process with the **40 cm black** wire and the other rod. Both rods should look like the picture to the right.

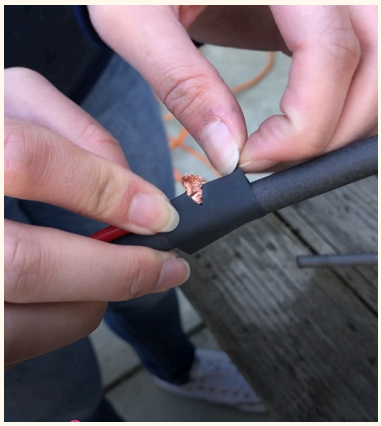
3B: Secure wires on rods with heat shrink tubing

- Take the heat shrink tubing, and use scissors to cut two pieces of 3 cm in length.
- Lay the piece of tubing flat and cut a small triangular notch in the middle of the tube to create a small hole. These will cover the copper strands on the rods. See image below.

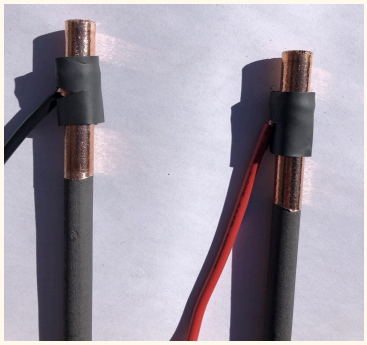


- Next, slip the piece of tubing onto the bottom end of one of the rods. See image below.

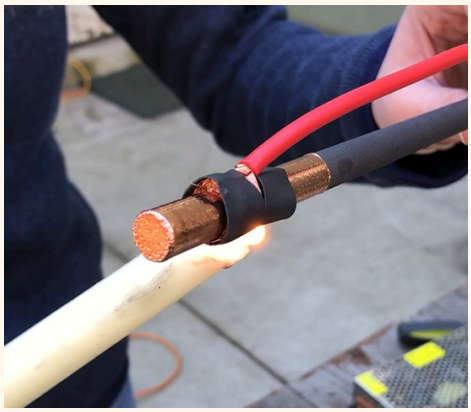
- Take the wire that is attached to the rod, and feed it through the small hole in the heat shrink tubing. See images below.



- Repeat the process with the other piece of tubing and the other rod. Each rod should look like the image on the right.

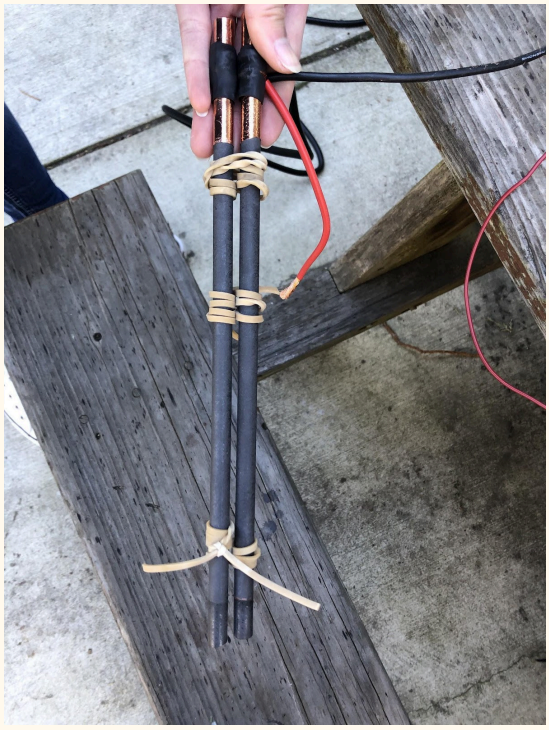


- Take the lighter, and heat up the tubing until it shrinks. See images below.



3C: Secure rods together

- Secure both rods together by wrapping rubber bands (top, middle, and bottom) around both rods, as shown on the right.
    - The two rods should be next to each other separated by the rubber bands but not touching each other.
    - You may also cut rubber bands to wrap the rods and then tie them together (shown on bottom of rod placement).
- Notice there is a gap between the two rods. This is intentional, the rods are NOT supposed to touch each other.

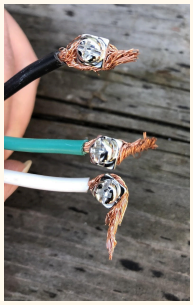


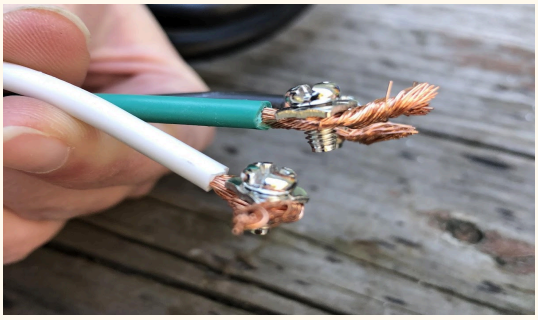
Step 4: Set up SMPS

4A: Connecting wires to the SMPS

- Using a screwdriver, unscrew the following bolts on the SMPS (located next to each other):
    - 1) Below L symbol
    - 2) Below N symbol
    - 3) Below Earth ground symbol

- Wrap the bare cables of the power cord around each bolt as shown below:





- Using the screwdriver, screw the bolt to the respective symbol, making sure the wires do not come out: (see image below)
    - 1) **Black wire** below **L symbol**
    - 2) White wire below **N symbol**
    - 3) **Green wire** below **Earth ground symbol** (shown at right).

- Using a screwdriver, unscrew the following bolts on the SMPS
    - 1) **+V symbol**
    - 2) **-V symbol**

- Wrap the **8 cm red** wire (not attached to a rod) and the **40 cm black** wire (attached to a rod) around each bolt.

- Using the screwdriver, screw the bolt to the respective symbol, making sure the wire does not come out (see image to the right):
    - 1) **8 cm red** wire below **+V symbol**
    - 2) **40 cm black** wire below **-V symbol**

4B: Connecting wires to multimeter

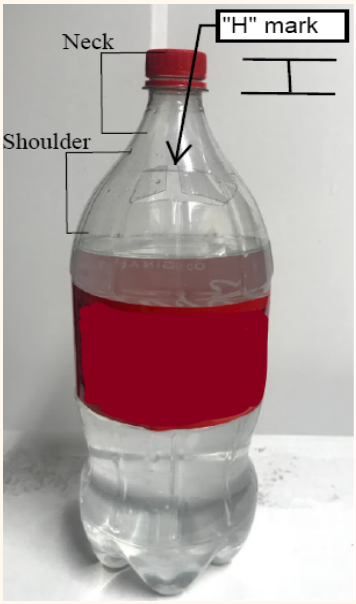
(NOTE: IF USING ANALOG AMMETER, SEE APPENDIX 2).

- Connect the free end of the **8 cm red** wire that is attached to the SMPS to the red wire of the multimeter.

- Connect the black wire of the multimeter to the **22 cm red** wire (which is connected to the other rod). (See image to the right).

4C: Preparing the bottle.

- Using the razor, cut a H shaped mark on the shoulder of the 2L plastic bottle as shown on the image below.



Part 2. Making Disinfectant

Run the reactor in a well-ventilated area, or outside.

Step 1: Making the Salt Water

Note: 1000 mL = 1 L

- Using the measuring cup, measure 1.8 L of drinking water and put it inside the 8L bucket.
- Dry the measuring cup and place it on top of the kitchen scale.
- Set the scale to zero and weigh 54 grams of salt.
- Add the salt into the water in the bucket and stir until no salt grains are visible (approximately 30 seconds). You can use your ruler or a long spoon to stir.
- Using the measuring cup, transfer the 1.8 L of well-mixed salt water from the bucket to the 2 L plastic bottle. Continue to swish the salt water solution as needed to ensure the salt is not left at the bottom of the bucket while the 1.8 L is transferred.

Step 2: Producing the Disinfectant Solution

- Before starting this step, note that the reactor will be running for 1 hour and 30 minutes.
- Place both the rods inside the plastic bottle through the horizontal H cut.
- Make sure the connections for the SMPS are correct.
- Have a timer ready to measure the time.
- Connect the SMPS to a power outlet and start the timer.
    - You should be able to see bubbles form immediately after the connection.
    - **If the multimeter (or ammeter) is measuring more than 10 Amps, *unplug SMPS from the power outlet immediately***. The multimeter (or ammeter) should always measure less than 10 Amps.

- Monitor and record the current (Amps) passing through the system every 15 minutes for the next 1 hour and 30 minutes. This is to estimate average current passing through the system, which is used to estimate final concentrations of HOCl produced in the reactor.
- After the reaction process is complete, unplug the SMPS from the outlet.

Step 3: Measuring the Free Chlorine Concentration

- Use the chlorine strips to measure the free chlorine concentration, following instructions on the packaging.
- If the free chlorine concentration created from the reactor is between 800-1000 mg/L, you have successfully created the disinfectant stock solution.
    - If this range is not achieved, move forward but revise dilution calculations in Appendix 1 accordingly. Alternatively, do some troubleshooting before continuing: verify current is ~ 5 Amps, check that electrical connections are tight, and continue running the reactor for an additional 30 minutes or so, then remeasure free chlorine.

Step 4: Diluting the Disinfectant Solution

- Refer to **APPENDIX 1** for instructions to dilute the stock solution created in the 2L bottle to the appropriate concentration for specific uses.
- Specific uses include:
    - Surface disinfection
    - Hand sanitizing
    - Produce washing
- Dilutions will be made in the 8L bucket
- Not all of the stock solution will be used depending on the specific use
- **Note:** remember your plastic bottle has a hole. When pouring the stock solution from the 2L bottle, pour with the H cut facing up.

Step 5: Adjusting the pH of the Solution

- Follow this step after diluting the stock solution for your specific use.
- Using the measuring cup, measure 50 mL of white distilled vinegar.
- Pour the vinegar into the bucket and mix well.
- Use the pH paper strip to measure the pH of the disinfectant by dipping the paper strip into the solution. If the pH paper reads between 5 and 6, the disinfectant is ready to use. See photos below of pH paper after being dipped in disinfectant solution and compared to pH chart
    - If the pH paper reads above 6, add a capful of white vinegar and mix well. Measure pH again. Repeat until the pH is between 5 and 6.
    - If the pH paper reads below 5, add a generous pinch of baking soda and mix well. Measure pH again. Repeat until the pH is between 5 and 6.

pH around 4

pH around 5-6

Step 6: Storage of the Disinfectant Solution

- Cap the 8L bucket with a lid.
- Keep the 8L bucket in a cool area away from sunlight.
    - Keeping the disinfectant away from sunlight will help maintain its disinfecting power for a longer period of time.
- Make sure the pH of the disinfectant is between 5 and 6 before using it.
    - See Step 5 for adjusting the pH of the solution.

Appendix 1- Dilutions Guide

Overview

Use	Final HOCl Concentration (mg/L)	PH
Surface Disinfection	~ 250	~6
Hand Sanitizing	~ 150	~6
Sanitizing Produce	~ 50	~6

Dilution Calculations

Use the following **formulas** to determine the volume of the stock solution required for creating a disinfectant of a desired concentration, as outlined in the above table:

$$C_1 \times V_1 = C_2 \times V_2$$

and

$$V_{water} + V_1 = V_2$$

C_1 is the "stock" concentration of the HOCl solution in the 2L bottle [mg/L] **

V_1 is the volume of "stock" solution to be used in the dilution process [Liters]

C_2 is the desired final concentration based on the specific use [mg/L]

V_2 is the final volume, which will vary for your specific use [Liters]

V_{water} is the volume of water you want to add to V_1 to reach your final volume, V_2

***Below calculations assume ~1000 mg/L for HOCl stock solution concentration, C_1. If the instructions are followed as written, the disinfectant solution produced in the 2L reactor bottle should be approximately 1000 ppm as HOCl, or free chlorine.*

Part A. Surface Disinfectant (goal of 250 mg/L as HOCl)

Depending on the starting concentration of the stock solution created in the 2L bottle, dilution volumes will vary.

- **EXAMPLE CALCULATION:**
  The concentration you started with is C_1= 1000 mg/L

  The final concentration you want is C_2 = 250 mg/L

  The final volume you want is V_2= 7 L

  Use the formula, $C_1 \times V_1 = C_2 \times V_2$, to solve for the volume of stock solution to be used, V_1

$$V_1 = \frac{C_2 \times V_2}{C_1} = \frac{250\ mg/L \times 7\ L}{1000\ mg/L} = 1.8\ L$$

Now solve for the volume of water you need to dilute V_1 in the bucket.

$$V_{water} = V_2 - V_1 = 7\ L - 1.8\ L = 5.2\ L$$

Thus, you will need to add the 1.8 L of the stock solution from the 2L bottle and 5.2L of water to the 8L bucket for dilution. Mix the solution well with the long mixing spoon or ruler.

Part B. Hand Sanitizer (goal of 150 mg/L)

Depending on the starting concentration of the stock solution created in the 2L bottle, dilution volumes will vary.

- **EXAMPLE CALCULATION:**
  The concentration you started with is C_1= 1000 mg/L

  The final concentration you want is C_2 = 150 mg/L

  The final volume you want is V_2= 7 L

  Use the formula, $C_1 \times V_1 = C_2 \times V_2$, to solve for the volume of stock solution to be used, V_1

$$V_1 = \frac{C_2 \times V_2}{C_1} = \frac{150\ mg/L \times 7\ L}{1000\ mg/L} = 1.1\ L$$

Now solve for the volume of water you need to dilute V_1 in the bucket.

$$V_{water} = V_2 - V_1 = 7\ L - 1.1\ L = 5.9\ L$$

Thus, you will need to add the 1.1L of the stock solution from the 2L bottle and 5.9L of water to the 8L bucket for dilution. Mix the solution well with the long mixing spoon or ruler.

Part C. Sanitizing Produce (goal of 50 mg/L)

Depending on the starting concentration of the stock solution created in the 2L bottle, dilution volumes will vary.

- **EXAMPLE CALCULATION:**
  The concentration you started with is C_1= 1000 mg/L

  The final concentration you want is C_2 = 50 mg/L

  The final volume you want is V_2= 7 L

Use the formula, $C_1 \times V_1 = C_2 \times V_2$, to solve for the volume of stock solution to be used, V_1

$$V_1 = \frac{C_2 \times V_2}{C_1} = \frac{50\ mg/L \times 7\ L}{1000\ mg/L} = 0.4\ L$$

Now solve for the volume of water you need to dilute V_1 in the bucket.

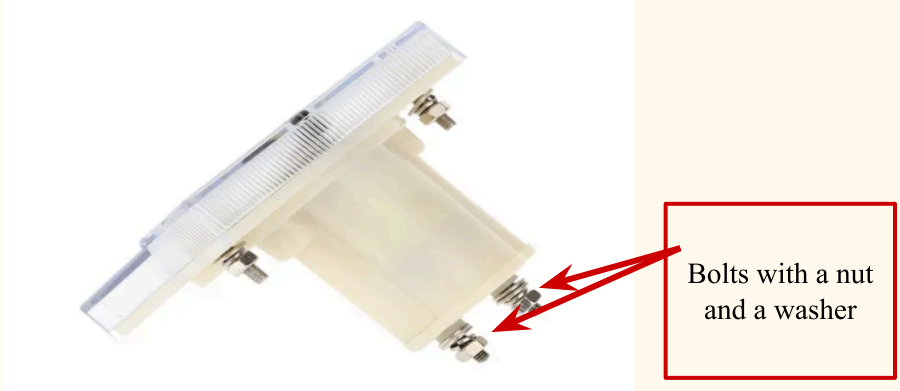
$$V_{water} = V_2 - V_1 = 7\ L - 0.4\ L = 6.6\ L$$

Thus, you will need to add 0.4 L of the stock solution from the 2L bottle and 6.6 L of water to the 8L bucket for dilution. Mix the solution well with the long mixing spoon or ruler.

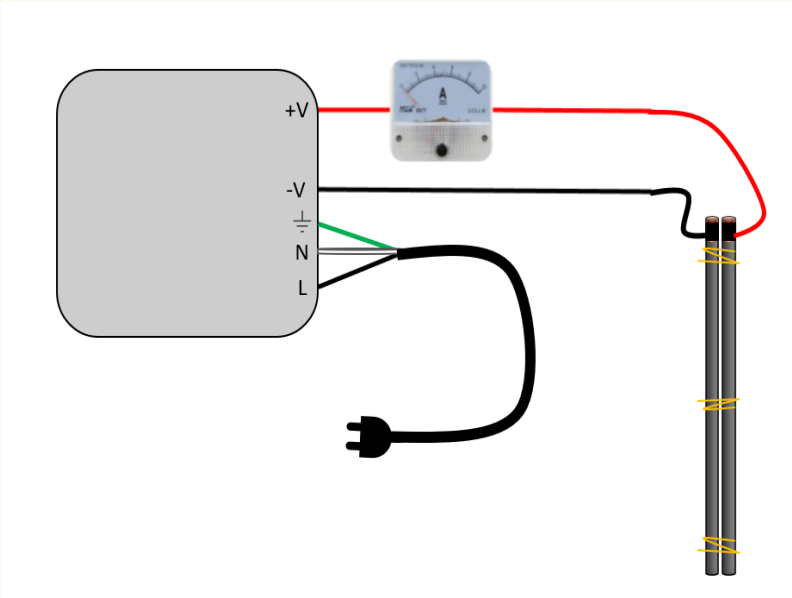
Appendix 2- SMPS Connections

Alternative Step 4B for Part 1: Connecting Wires to Ammeter

- Unscrew the washer and nut from each bolt at the back of the ammeter.



- Wrap the end of the **8 cm red** wire that is attached to the SMPS around one of the bolts of the ammeter.
- Wrap the end of the **22 cm red** wire (which is connected to a rod) around the remaining bolt of the ammeter.
- Screw the washers and nuts back on their respective bolt, making sure the bare cables wrapped around each bolt are securely fastened. (See diagram below. Components are not to scale).



Important Background Information

What is a chlorine-based disinfectant?
A chlorine-based disinfectant is a disinfectant that contains one or more chlorine atoms (Cl). One common chlorine-based disinfectant is bleach, which contains a molecule named sodium hypochlorite (NaOCl).

Which chlorine-based disinfectant are we going to be producing?
At the end of this process, we will be producing hypochlorous acid (HOCl). Hypochlorous acid is a powerful disinfectant. In fact, it is 80 times more powerful than bleach (sodium hypochlorite, NaOCl).

Why is sodium hypochlorite (bleach) more accessible than hypochlorous acid?
Unfortunately, the amount of hypochlorous acid (HOCl) in water reduces faster than the amount of sodium hypochlorite (NaOCl) in water. Thus, a bottle containing HOCl is only effective for approximately 2 weeks, whereas a bottle containing NaOCl is effective for years.

What is "electrolysis" and how is it used to produce hypochlorous acid?
Hypochlorous acid can be easily produced by electrolysis of salt water and the addition of either distilled white vinegar or diluted muriatic acid at the end. Electrolysis is the process of passing electricity through a system in order to drive a chemical reaction. When passing electricity through water that contains salt, the production of HOCl and NaOCl is possible.

Why do I need to add either distilled white vinegar or muriatic acid?
During electrolysis of salt water, chlorine gas is produced. When chlorine gas comes into contact with water, it reacts with water molecules to create two types of molecules: Hypochlorous acid (HOCl) and hypochlorite (OCl-). When the water has a low pH, more HOCl molecules exist in the water. Similarly, when the water has a high pH, more OCl- molecules exist in the water. By adding a small amount of either distilled white vinegar or dilute muriatic acid in the water, you lower the pH of the water; thus, favoring the formation of HOCl. Similarly, by adding baking soda the PH of the water is increased.

Has HOCl been used as a disinfectant before, or is it still in the experimental phase?
Although the Electro-Clean design from the Gadgil Lab hasn't partnered with a client to distribute the product, there are many other companies that are selling the same product (HOCl-based disinfectant), but marked up at a much higher cost! Here are a few links, if you are interested: Force of Nature, Liberty, Briotech, Clean Republic, Lumion.

Would you like to learn more about the process?

Please visit our website: https://gadgillab.berkeley.edu/electro-clean/

FAQs and Safety Notes

Q: The instructions say to use a SMPS with a 20-40 Amp maximum, is this dangerous?

A: No, but you should make sure to follow some safety precautions:

- Never unscrew the cover of the SMPS while it is plugged in. In general, you never need to open up the SMPS.
- Do not touch the wire connections with your hands or anything made of metal.

Q: Are bubbles normal when running the reactor?

A: Yes, these bubbles are O_2 and H_2, the product of water splitting.

Q: What current is expected during the 1.5 hr reactor run?

A: The current might vary over time, but not drastically. It should stay in the range of 4 to 8 Amps. The current should NOT reach 10 Amps. Although you will be using a SMPS with a 20-40 Amp maximum, there is too much resistance in the system and you will likely not see the current reach 10 Amps.

Q: How many times can I run the reactor? Will I need to replace any parts before using it again?

A: The anode (which is the rod attached to the red wire) will last between 50-80 hours of electrolysis. You will know the rod needs to be replaced if it looks thin and your current starts to drop. You will need to remove the rubber bands and the heat shrink wrap to disconnect the rod and a new piece of heat shrink wrap to secure the wires on the rod. Everything else should last much longer!

Q: I only have a small ruler that doesn't measure up to 40 cm, is that okay?

A: Yes, you can use your small ruler to estimate the length. The lengths of the wires do not need to be extremely precise. It is better to cut your wire lengths slightly too long than too short.

Q: Is it okay to smell the disinfectant?

A: Yes, it's okay to do a "sniff test" of the disinfectant. It should smell like a swimming pool. As long as you run the reactor outside or in a well ventilated area it is okay.

Q: When using the disinfectant on surfaces, do I need to wipe it away?

A: It is recommended to wipe the disinfectant after letting it sit on a surface for about 10 seconds. Otherwise it could corrode some surfaces, such as metal surfaces.

This peer-reviewed open-access publication (link below) gives more useful information about the lifespan of the disinfectant, its performance compared to alcohol-based disinfectants, regulatory hurdles, and other practical problems.

https://doi.org/10.1371/journal.pgph.0002213