Title:	*My (Aluminum) Anodizing Procedure*
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Abstract:	
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1 Motivation

I have been interested in being able to anodize my own (milling) creations for quite some time. My interest came to a head while building an electronics package for one of my projects which entailed a front-panel and a fair amount of labeling. Nothing I tried even passed the *finger nail test*... being able to connect a DB-9 connector with occasional finger nail touching of the front panel... without leaving small scratches! I also assumed that my rather small needs (no production-level quantities) would likely translate into substantial setup charges with any outside vendor I might choose to employ, let alone to-and-from logistics.

When I stumbled on to a method which side-stepped using sulfuric acid (H_2SO_4), I decided it was time to venture into doing my own anodizing[1]. One of my anodizing results is shown here in Figure 1 and Figure 2.

Although I have not done a formal hardness test of the non-anodized versus anodized aluminum, I found the resistance to scratching to be phenomenally better. I intend to anodize a lot of my work going forward, even if I do not add the final coloring step.

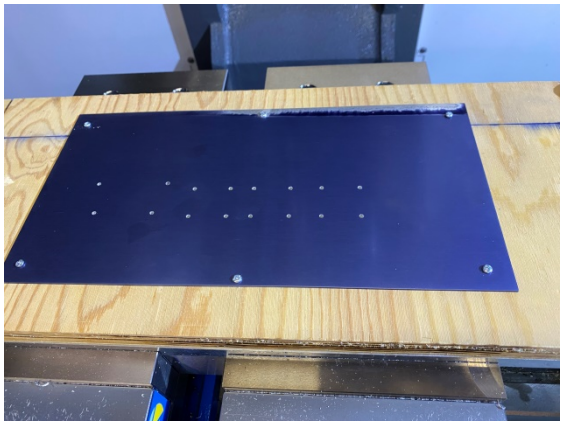

Figure 1 Anodized sheet of 6061 1/8" thick aluminum being milled

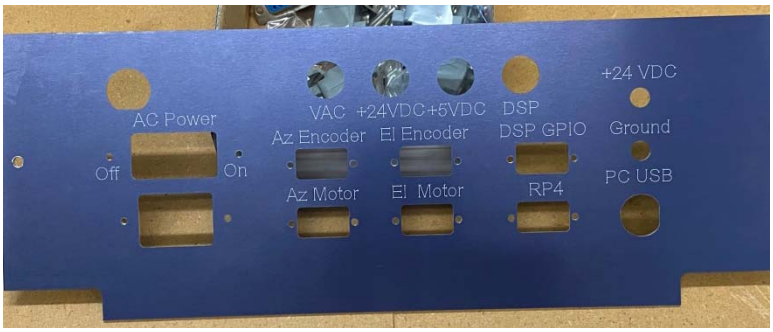

Figure 2 Finished front panel with diamond-scribed labeling

1.1 Full Disclosure

Many YouTube videos will lead you to believe anodizing your own aluminum is an easy cake walk. This may be the case if you follow the video to the tee, but invariably there are modifications or differences which can become real stumbling blocks, and/or the video leaves out details which you end up implementing in a different manner. My advice...count the (possible) cost before you start the journey!

Along this line, think through the entire process you intend to follow *before* you buy the first widget. Cost out a bill of equipment needed because it will be higher than you think; it was for me even though I did do the initial costing exercise.

[1] See §5

If you are doing a front-panel like I have shown here, but you don't have the means to mill, drill, and etch the anodized surface, think again.

In my experience, the biggest stumbling blocks I encountered were:

- I did not want to spend the money for high-quality Caswell-type dye materials and opted for Rit dye instead. Different dye colors can behave radically different! I had first-time success with Rit Navy Blue and Royal Purple, but Rit Black was a total bust. (In my opinion, I believe the particle size of the Black dye was too large to enter the pores created by the anodizing process.) Of course I tried to use Black first, and only after multiple failures did I try a different Rit color with good success.

- Some web-based sources advocated using titanium wire to provide the anodizing current to the aluminum piece being anodized. I found this to be a stumbling block in some cases, and now I only use aluminum wire. Good electrical conductivity between the wire and piece being anodized is crazy crucial. Otherwise, the electrical current will take the minimum resistance path offered and you can end up anodizing "the wire" rather than the target object.

- Different dye colors, even if they work, work best at different temperatures. I hate to use the word *experiment*, but some is required.

- The naturally-forming oxide layer on bare aluminum is a very poor electrical conductor!

2 Getting Started

Key points:

1. Use only pure (distilled) water throughout all of the processes.
2. *ALWAYS* wear skin and eye protection at all times.
3. Do not touch metal surfaces bare-handed as this inevitably leaves oils which will interfere with a good anodizing outcome.
4. If sandblasting the target object, always degrease the object first to avoid pounding possible oil contaminants into the metal surface.

Additional notes:

1. As far as dye is concerned, I found that using Procion dye was a total bust! The anodizing steps otherwise went as planned but the prepared aluminum would simply not accept an iota of the dye. In sharp contrast, Rit dye worked wonderfully for me. The Rit dye (Navy Blue, for example) is a liquid dye whereas the Procion dye is a powder. I suspect the powder's particle size was too large to lodge within the fine surface structure created by the anodizing process.

2. As far as the electrical current required during anodizing, 2.8A to 10A per square foot is recommended. Most commercial type II anodizing is done at 12A / ft^2. Another reference[2] recommends 20 mA to 30 mA of current per square inch...which equates to 2.88 A/ft^2 to 4.32 A/ft^2. Higher current supposedly results in a harder surface.

    - The Caswell website recommends either
        - 1 Amp for 240 minutes per 50 in^2
        - or 1 Amp for 120 minutes for 25 in^2
    - This creates an anodized layer of 0.001 inch.
    - ***I roughly used this guideline and had good success.***

3. Commercial anodizing is done at 70° F or lower. DO NOT anodize at above 75° F. Do not go under 60° F.

[2] U27733 How to Anodize Aluminum at Home – 30mA per Square Inch.pdf.

3 Aluminum Part Preparation

To prepare the aluminum for anodizing[3]:

1. Lightly sand with aluminum oxide sand paper. If using soap, avoid any soap used for "soft hands" as this will contaminate the metal.
2. If sandblasting, carefully clean the surfaces first so that the sandblasting does not pound oils and contaminants down into the metal. I used *Simple Green* for this step per Figure 6.
3. Alternatively, I plan to sand blast some parts which should also help to remove surface pollutants.
    a. Etching the surface with lye and distilled water for 3-5 minutes is recommended
        i. *Only use the lye step if an etched surface is desired.*
    b. Rinse with distilled water.
        i. *If the water beads up on the surface, the surface is still contaminated.*
        ii. *Very key- if the rinse water seems to "stick" anywhere along the surface, it is not clean.*
        iii. Multiple references caution against attempting to anodize through the oxide layer that naturally forms on aluminum over time.

4. A cathode is required in the process, and lead seems to be the recommendation. I used two fairly large lead sheets, one at each end of the bath.
5. Need aluminum wire to hang / rack the aluminum to be anodized.
    a. This is a tricky topic for sure. If the electrical connection to the part is not excellent but the connecting wire is also immersed in the $NaSO_4$ solution, it is easy to get fooled by anodizing action with the wire rather than the part! The current naturally takes the path of least resistance so this electrical connection must be good!
    b. Some people advocate using titanium wire instead of aluminum wire, but it is fairly resistive. If a long wire is used down into the bath, a fair amount of heat can be produced thereby complicating efforts to keep the bath cool. As stated earlier, I recommend only using aluminum wire.
    c. If aluminum wire is used for the connection, it gets anodized itself potentially causing the electrical connection to worsen over time. Any aluminum wire portion which is itself down in the anodizing solution will become anodized and can generally *not* be used again.
    d. I purposely stayed away from steel and copper wire for fear of contamination.
6. An agitator for the electrolyte solution is highly recommended.
7. One thing that's a good idea (at least it's good practice) is to slowly turn up the amps. This is what is done professionally – it's pretty common to have a 5 or 10 minute ramp up when starting a batch. You don't need to go this slow, but just don't instantly crank the power – take your time turning that knob up.
8. Heat up the dye. Get out that tea kettle and warm up the dye, checking the temperature with the meat thermometer. This can be a bit of a fussy step. Most dyes work well at around 140 F, but some colors perform slightly better at a lower temp, like 120° F. I'd recommend trying the first batch at 140 and if you're not happy with the results, try the next one a little cooler.
    a. I use cartridge heaters combined with a temperature sensor and controller for my work.
    b. When I have been uncertain about the needed temperature, I first heated the dye solution to 120° F and then let the temperature controller bring the temperature up to 140° F over time (requiring 10-20 minutes generally, depending upon volume and cartridge heater).

I copied/edited the next 4 sections from materials I found on the internet, and which guided my efforts too.

[3] How to Anodize Aluminum at Home – Make It From Metal https://makeitfrommetal.com/how-to-anodize-aluminum-at-home/

Get your Baths Ready

- Ok for this step we're going to set up a couple of baths. I know other people may to this step differently, but this is what works for me.
- Set up one tub of distilled water. It's good if it's a fair bit larger than the parts. For example, if you have a part that's as big as your fist, use at least half a gallon of distilled water.
- Put some distilled water in a spray bottle. Not mandatory, but it's very handy.
- Next set up one tank with a mix of baking soda and distilled water. This will neutralize the acid and make it more likely that there won't be any blemishes on the parts. I usually use a ratio of 3 tablespoons of baking soda per quart of water. There's nothing sciency behind this, it's just what I do. You don't need a ton of this mixture, just enough to cover the parts so they can soak for a few minutes.
- Then open up the lid on the kettle with the dye in it. You can just dip the parts in directly.

Part Dunking

- Turn off the power to the anodizing tank. Lift the parts partially out of the tank and give them a few sprays of distilled water. I spray down directly into the tank so it doesn't make a mess.
- Now swish the parts around in the distilled water tub. You just want to rinse off as much of the acid as possible.
- Then put the parts in the baking soda tub. Swish it around a bit and let it sit for around 5
- minutes.
- Now rinse off the parts again in distilled water. Be thorough.
- Double check the temperature of the dye and adjust as needed.
- Dunk the parts in the dye. Stir it around vigorously enough to knock off any bubbles on the parts, but don't make a massive mess. This stuff is a pain to clean.
- You should be able to see the parts instantly start to take the dye. If the process didn't work, the dye will just drip off. If it did work, the part will start to change color. Let the parts soak in the dye for 10-15 minutes.
- Later on you can tune this soak time depending on how deep of a color you want.

Sealing

- This part is really easy. Once the soak in the dye is done, boil the parts for about 15 minutes.
- This is where it's handy to have either an extra kettle or a hot plate where you can boil a pot of water.
- This will just toughen up that dye and make it less likely that the dye will discolor or easily come off. Even if you didn't dye the parts, this is a good idea.

Power Supply

- Target 12A / ft^2 capability
- If a voltage greater than 15V is needed to achieve the desired current draw, double check the electrical connection(s) to the part being anodized!

4 My Setup

My setup requires a fair amount of space. You may have to modify what I have chosen to do for your own purposes. If you are only going to anodize small pieces, using smaller containers will benefit you in multiple ways.

Figure 3 Dedicated shelving for my anodizing setup. All but the boiling water final step in Figure 6 is shown left-to-right. The anodizing tank is in the center. Temperature controllers are on the top shelf, far left. Anodizing power supply is on the top-shelf at center. The recirculating pump and ice-cold water reservoir are on the bottom shelf.

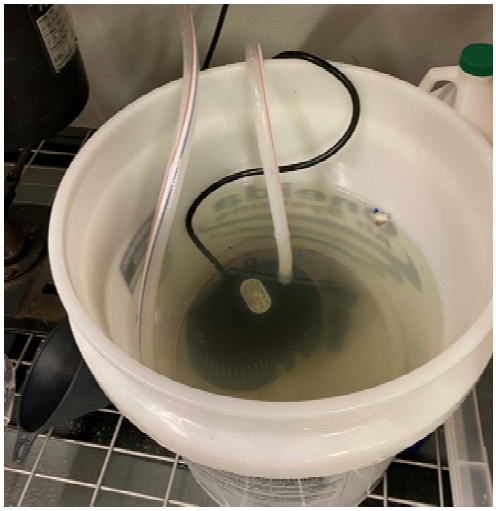

Figure 4 Bottom shelf ice-cold water reservoir. I fill the tank up about halfway with tap water and then drop in plastic bottles of frozen water to cool the water. The recirculating pump is controlled (on/off) by one of the temperature controllers easily to an accuracy of 0.5^{o} F.

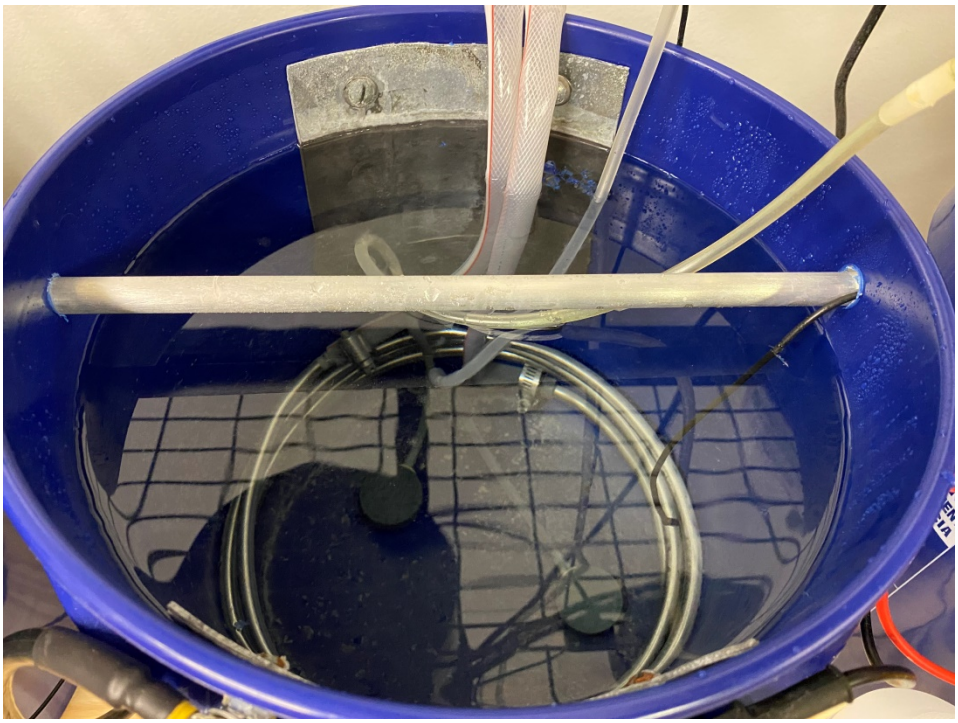

Figure 5 View looking down into the anodizing tank. Lead plates serve as cathodes at 6 o'clock and 12 o'clock around the perimeter. The stainless steel cooling coil is shown at the bottom as well as the fish tank bubblers if you look closely. Parts being anodized are hung from the 1/2" aluminum rod using aluminum wire. The temperature sensor at the bottom of the tank is connected to the temperature controller by the small black cable shown exiting the tank at about 2:30 o'clock. As shown in Figure 3, a tight-fitting lid is used for all of the tanks.

Table 1 Equipment/Materials List for Anodizing Aluminum

Item	Cost Each, $	Link	
Equipment			
Bayite Temperature Controller	30.00	https://www.amazon.com/gp/product/B01KEYDNKK/ref=sw_img_1?smid=A2EFSDTWMPHWEA&psc=1 I use 4 of them, but you may be able to get by with fewer.	
Lead Cathode	20.00	https://www.amazon.com/KRT-Lead-Sheeting-Sheet-Rolls/dp/B01I289NRM/ref=sxin_16_ac_d_bv?ac_md=2-1-QmV0d2VlbiAkMTUgYW5kICQyNQ%3D%3D-ac_d_bv_bv_bv&content-id=amzn1.sym.14453ffd-7768-40d0-9a7f-8d0063113f56%3Aamzn1.sym.14453ffd-7768-40d0-9a7f-8d0063113f56&crid=3OTCY42YHJJ3A&cv_ct_cx=lead+sheet&keywords=lead+sheet&pd_rd_i=B01I289NRM&pd_rd_r=3e2bc392-12f9-4067-865d-b4b931b23b76&pd_rd_w=YGFhs&pd_rd_wg=v6efH&pf_rd_p=14453ffd-7768-40d0-9a7f-8d0063113f56&pf_rd_r=BXMBPC45NSHVCR74C581&psc=1&qid=1656730202&sprefix=lead+sheet%2Caps%2C167&sr=1-2-270ce31b-afa8-499f-878b-3bb461a9a5a6	

Item	Cost Each, $	Link	
DC Power Supply	160	https://www.amazon.com/TekPower-TP1830SB-Adjustable-1-5-15V-Reglator/dp/B01KPBAN6O/ref=sr_1_7?crid=E8XP9KJACYNA&keywords=dc+power+supply+30a&qid=1656730302&sprefix=dc+power+supply%2Caps%2C171&sr=8-7 Many options here. A constant-current source is best, but I am using a voltage-only controlled supply and I manually increase the voltage over the 2+ hour anodizing time to keep the current roughly constant. Although not shown in the pictures, I have found a 0-30V 10A to be better for anodizing, and this is about half the cost.	
Tubs		I started with rectangular tubs but found that suspending cartridge heaters, etc. to be difficult. Ended up opting to use 5 gallon containers from Lowes as shown in the photos. I use 5+ of these.	
Fish Tank Bubbler	16	https://www.amazon.com/gp/product/B01EBXI7PG/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1	
Cartridge Heaters	10	If you end up running multiple heaters in parallel, it is easy to overwhelm a typical 20A circuit. Better to use lower-wattage heaters and take more time. Less wattage is needed if the heated solutions are insulated to avoid heat-loss. I recommend using 250W to 500W cartridges. https://www.amazon.com/gp/product/B08LKTTY7R/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1 I used 3-4 of these.	
Anodizing Tank Cooling Coil	43	Using stainless steel for the cooling coil is not the best solution possible, but it the one I have been using. Over time, the sodium bisulfate solution will slightly erode while also likely contaminating the anodizing solution. I have had no issues thus far over 2+ months. I purchased 16 feet of 3/8” stainless steel tubing and ran surgical tubing to/from it and a re-circulating fish tank pump. https://www.amazon.com/gp/product/B07L6MZK56/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1	
Re-Circulating Fish Tank Pump	36	https://www.amazon.com/gp/product/B094H2GT42/ref=ppx_yo_dt_b_asin_title_o02_s00?ie=UTF8&psc=1	
Aluminum Wire	9	https://www.amazon.com/gp/product/B07HFVW34D/ref=ppx_yo_dt_b_asin_title_o02_s00?ie=UTF8&th=1	
Surgical Tubing		To connect recirculating water pump to cooling coil. You will need hosing clamps of some kind to connect this tubing to the steel cooling coil (must be water tight).	
Chemicals			
Simple Green degreaser		Purchased at auto supply store like AutoZone	
Lye		I tend not to use this now and go with either a smooth surface or sandblasted surface. I understand this can be used to remove oxide layers or previous anodizing, however.	

Item	Cost Each, $	Link	
Sodium Bisulfate, NaSO4	40	This is a swimming pool chemical and it goes by multiple trade-names. I purchased mine through Walmart as Rx Clear pH Minus. I had to buy 6 pounds.	
Baking Soda, Neutralizer			
Plating Dye	≈ $8	for 8 oz Rit liquid dye	
ph Test Strips	5	Very handy for checking the anodizing bath. Ideally want it to have a pH of 1 to 2. https://www.amazon.com/gp/product/B00S730YWG/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1	
Miscellaneous			
Shelving			
Wood Shelf		I use the wood shelf to intercept incidental liquid drops from landing on my cement floor and the lower shelf.	
Electrical Wire		To run from anodizing power supply to tank connections	
Aluminum Hanging Rods		I used ½ inch rods, drilled holes at each end for cotter pins	
Stainless Steel Hardware		To secure lead cathode plates to sides of tank, and provide studs to run electrical hook-ups to	
Small Fan		Especially handy if you use the lye step because it gives off serious fumes	
Respirator		Don't need to be smelling any of this stuff.	
Spray Bottle		For distilled water, used to spray anodized pieces between steps	
Eye Protection		A must!	
Latex Gloves		Buy a box of 100+	
Lab Smock		Protect yourself and your clothing	

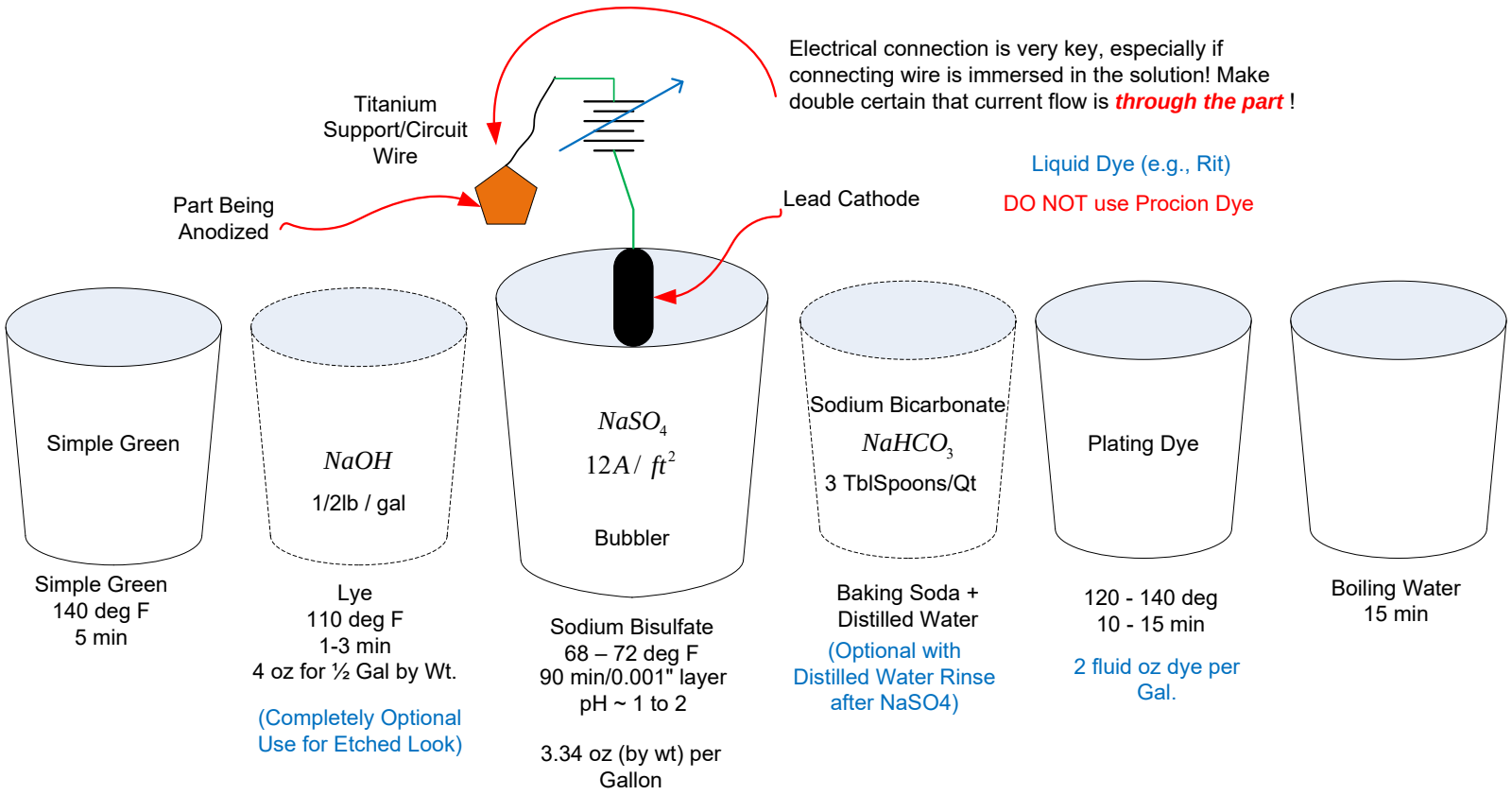

Figure 6 Anodizing setup[4]. Dashed-line items are optional.

The reference found in footnote #3 stated "40 grams of sodium bisulfate in 160 ml of water".

$$\frac{40\,g}{160\,ml}\frac{0.0353\,ounce_{by\_weight}}{g}\frac{1\,ml}{0.352\,ounce_{fluid}}\frac{1\,ounce_{fluid}}{0.0751\,gal}=\frac{3.34\,ounce_{by\_weight}}{gal} \quad (1)$$

[4] U28292_Anodizing_Aluminum_Setup_Figure.vsd.

5 Appendix: Late Notes

1. There is some evidence that 130° F is too hot for the Rit dye (at least Navy Blue). One run led to the anodized metal refusing all dye coloring. A subsequent run purposely started with the dye temperature at 90° F and slowly ran the dye bath temperature up to 130° F. This resulted in a perfect anodizing run.
2. Current drain for a sand-blasted part is considerably more for the same part without sand blasting. This is believed to be due to an increase in effective surface area created by the blasting.

6 Appendix: Sodium Bisulfate (Instead of Sulfuric Acid)

My procedure[5] makes use of Sodium Bisulfate (NaHSO4) which is a sodium salt of sulfuric acid rather than straight sulfuric acid. It is also possible to etch the aluminum before anodizing using a solution of sodium hydroxide, but I'm planning to engrave the anodized aluminum with a diamond drag cutter instead.

As far as health concerns[6]:

> Sodium Bisulfate is basically half neutralized Sulfuric Acid in powdered form. Some of its advantages include safety, environmental and shipping concerns. Sodium Bisulfate is much safer than liquid acids. OSHA classifies sodium bisulfate as an irritant, sulfuric acid is classified as corrosive. The NFPA (National Fire Protection Association) Hazard rating for sodium bisulfate is 1-0-1, whereas sulfuric acid is 3-0-2. This corresponds to sulfuric acid having serious health effects and sodium bisulfate having slight health effects.
>
> If sodium bisulfate is spilled, the power can be swept up and put back into its container.
>
> I saved the toxicity report for Sodium Bisulfate as U27731 and U27732.

[5] First recognized as an alternative in U27749.
[6] Ibid.