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Fabricating a Fused, Borosilicate, 96-well Plate

by

Doni J. Hatz*

ABSTRACT

A researcher needed a glass 96-well plate usually used for chromatography high throughput screening cell culture and DNA extraction. These plates were made of clear, rigid plastic the surface of which can react with chemicals and cause a cloudy frosted effect. Using fusing and slumping tools and techniques common for soft glass plate, we were able to make the glass well plate for the client.

INTRODUCTION

A 96-well plate is usually used for chromatography high throughput screening cell culture and DNA extraction. These plates made of clear, rigid plastic can react with chemicals that can distort or react with the surface causing a cloudy frosted effect. It is called 96-well because of 96 little cups that are fused on a glass plate.

In this case, the researcher wanted to be able to look through the bottom of the plate. He challenged me to make a borosilicate copy of the plastic tray. I remembered that Tracy Drier had presented a poster fabricating an 81-well plate using larger tube sections, so I knew it was possible.

Immediately, I contacted Tracy Drier at the University of Wisconsin-Madison. He presented a poster at the ASGS 56th Symposium in Alexandria, Virginia in June 2011. The poster was converted to a *Fusion* article which was published in the November 2011 issue. Since I have followed his method, he graciously allowed me to copy and paste his clear concise instructions here.

I located the article published in *Fusion* and started to compile a list of items to purchase. I had only fused plates together once at a Bullseye Glass Company class in Portland, Oregon using soft glass COE 96, which is quite different than using borosilicate plate at COE 33.

Fused glass is common in art glass where the glass plate is fired in a kiln to soften enough until it fuses the tubes to the bottom plate. In this case, however, "tubing sections will be placed on end and heated to softening in an oven until they bond with the underlying flat plate. The piece will then be cooled rapidly until just above the annealing temperature. Moving quickly through this range is necessary to avoid devitrification of the piece. Final controlled annealing and cooling will assure that the piece will not crack."[1]

Prior to the 96-well, a 24-well plate was made with borosilicate glass tubes fused on the surface of a borosilicate 2 mm thick 4" x 6" plate. That worked well, but ideally the 96-well was what was needed for the smaller volume wells.

MATERIALS PREPARATION

The tubes for the 96-well tray were fabricated using 7 mm o.d. standard wall tubing by

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[1] Tracy Drier, "Construction of a Fused, Borosilicate, 81-Well Plate for Sample Stirring," *Fusion* LIX.4 (November 2011): 22.

11 mm height. The base plate was 2 mm thick x 4”x 6”. The plastic 96-well tray had 8 mm o.d. wells, but to reduce the volume, we used the 7 mm o.d. tubing that creates a 2 mm gap between tubes. It was necessary to keep the exact dimensions of the plastic 96-well tray that fits inside an analytical instrument. The 96 pieces of 7 mm o.d. tubing were cut using a diamond saw with a stop set to produce the uniform length. Ten pieces of 7 mm o.d. tubing fit on the diamond saw tabletop to cut them in bulk. Each glass tube piece was inspected for flatness on a square ruler. If needed, a little touch up on the end was done with the flat lapping wheel.

OVEN FOR FUSING THE GLASS

I did not have access to borrowing a fusing oven where the heating elements are in the lid of the top loading oven. In this case, a Wilt Industries Model 120 front loading oven 18” L x 12” W x 12” height worked well for this process. The kiln shelf was elevated on a ½” thickness steel plate with three metal spacers to elevate the kiln shelf off the metal plate so as to provide heat all around the glassware (Photo 1).

Photo 1

Hot glass will adhere to the shelf untreated. Shelf primer is necessary to prevent the glass plate from sticking to the surface. Prepare the kiln shelf with fresh new separator solution. Bullseye Thin Fire Shelf Paper is another option to place underneath the borosilicate plate glass. Use the Hake Brush to paint on kiln wash in uniform strokes across the surface. Consider a respirator or N95 mask if you are mixing a large quantity of separator powder.

I highly recommend documenting each step as you adjust some processes from your observations.

KILN SHELF PREPARATION FOR FUSING THE GLASS

I researched methods to apply the kiln wash, and I highly recommend Bullseye Glass website tutorials.

A visit to the local ceramic studio was in order to purchase a kiln shelf 8”x 8” (1/2” thickness), kiln wash (shelf primer), thin fire shelf paper and Hake Brush (also called a kiln brush.)

Mixing the kiln wash solution can be messy: consider wearing safety glasses, gloves and lab coat or apron. Kiln wash is a clay-based release made with three ingredients: kaolin, alumina hydrate and pink colorant. Mix 1 part dry primer with 5 parts water in a small bucket or container that you can seal with a plastic lid. Slowly add the dry primer to the water and let hydrate. Stir frequently because the solution settles.

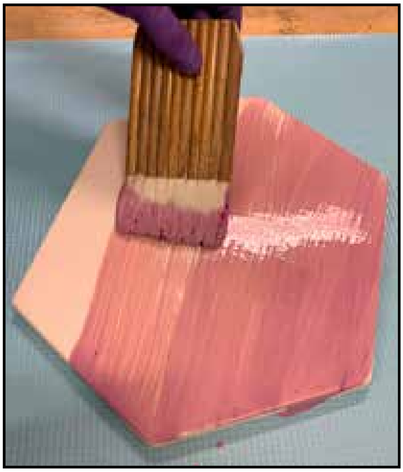


Photo 2

Clean the surface of the kiln shelf so that it is free of dust and particulate. Use the Hake Brush to paint the kiln shelf solution on the shelf; the long fine hairs of the brush reduce brush marks. Saturate the Hake Brush well, wipe off excess on the edge of the bucket, apply the primer to the shelf in long smooth strokes. Allow to dry. Continue front to back in strokes perpendicular to the first coat. Give the brush a stir to keep the solution in suspension, and continue to coat the surface corner to corner. Change directions with each application. Paint five coats (Photo 2).

BAKING THE KILN SHELF

Once the shelf is dry, it is ready to set up in the oven. Place the kiln shelf in the oven, and bring it up to 500°C; ramp up as fast as possible. Leave the door open ½" to vent the evaporation of kiln wash. Hold the oven temperature for 20 minutes, then complete the cycle by letting it cool rapidly. Once it has cooled to room temperature, it is ready to use. Make sure that it is cool before placing glass on the surface of the shelf. Firing will release moisture that can cause bubbles in the kiln wash. If this happens, it needs to be removed with an abrasive pad until it is smooth, then re-coat the surface of the kiln shelf.

TESTING DIFFERENT SURFACES

Three different tests were performed to evaluate surface smoothness on the bottom of the 2 mm thick borosilicate glass plate. Small scrap pieces of glass plate with a few 7 mm tubes were placed on top of the kiln shelf with only the kiln wash coating. The next test included the thin kiln shelf paper, and lastly a test using graphite paper.

There was no significant difference. The texture on the bottom of the glass plate was the same as using the kiln shelf with the kiln wash treatment (Photo 3).

Photo 3

Graphite test: document – take pictures, document in notebook (Photo 4).

Photo 4

Another aspect to this 96-well tray were clusters of the 7 mm tubes. Each grouping of glass tubes was made in a specific alignment joined together with tight tolerances. There was a 1 mm i.d. hole between the tubes that was 4 mm up from the bottom. The tubes were aligned to fit the grid of the 96-well configuration (Photos 5 & 6).

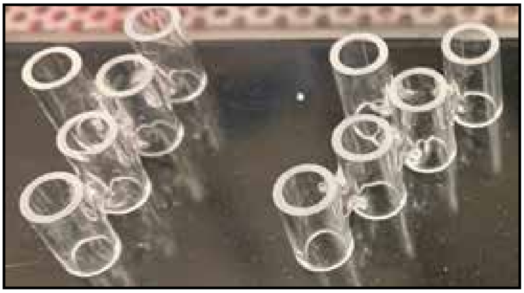


Photo 5

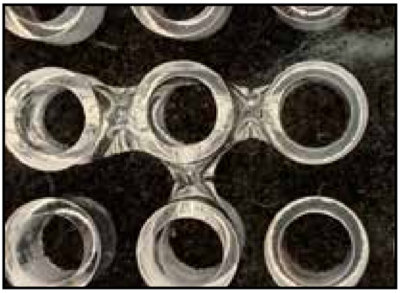


Photo 6

The alignment of the clusters using the plastic grid (Photo 7).

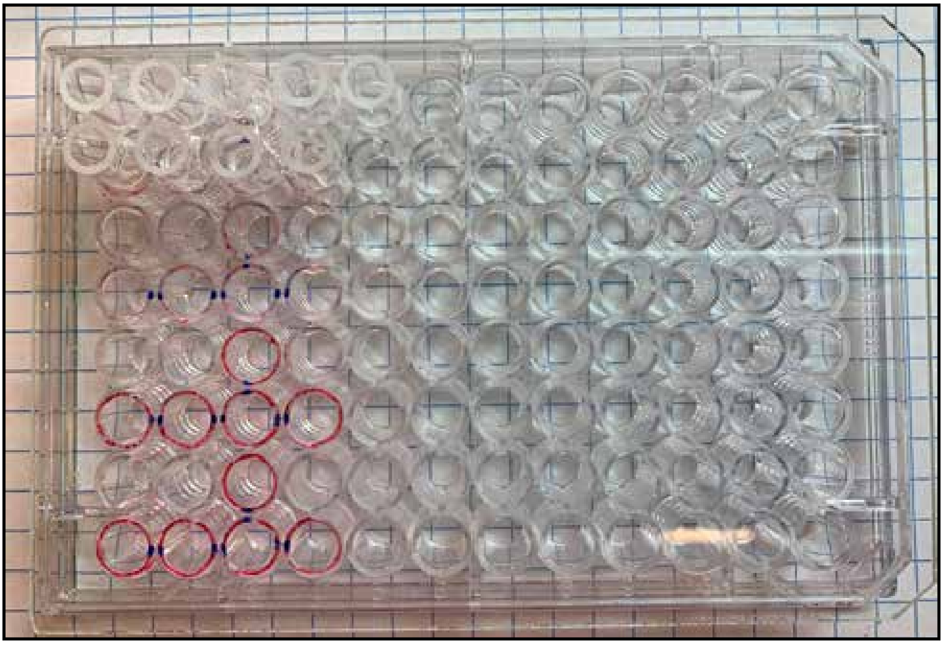


Photo 7

PREPARE THE PLATE FOR FUSING

Trim the 2 mm thick borosilicate plate to 4” x 6” and notch two corners on one end like the plastic piece. It is important to know how the researcher is using the plate and notch the correct side.

When working with the plate, protect the surface from scratches with 4” wide masking tape on both sides of the plate (Photo 8).

Check the side view of the plate to confirm alignment of the 7 mm o.d. tubes on the plate, then carefully move to the kiln shelf in the oven (Photo 9)

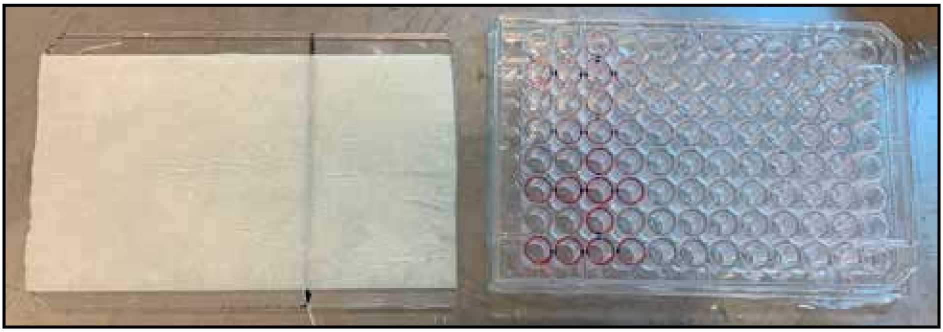


Photo 8

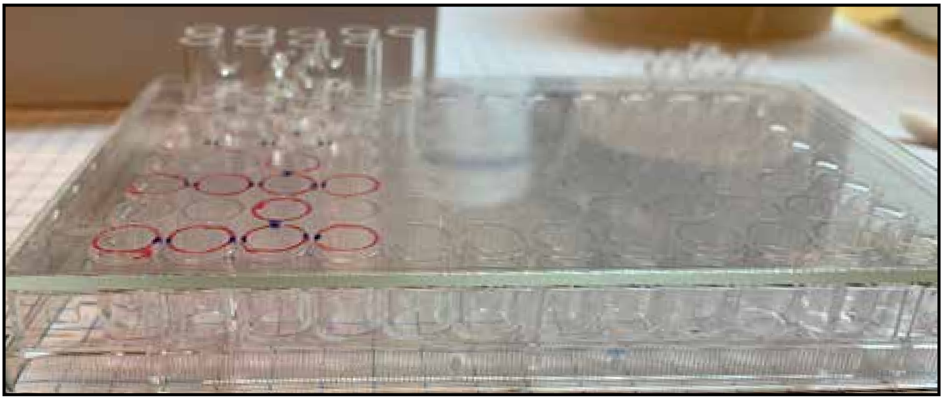


Photo 9

FIRING SCHEDULE

Tracy Drier wrote that "It is important to watch the oven as the temperature reaches softening; the tubing will sag, bulge, and deform if the piece holds temperature for too long and gets too hot.

- Raise the temperature from room temperature up to 820ºC as fast as possible.
- Hold at 820°C until tubing is fused onto the plate. Open the kiln occasionally to visually inspect the fusing progress. The piece is watched until flow between the plate and tubing is visible at their contact points.

> **Critical temperatures for clear borosilicate glass:**[2]
>
> - **Strain temperature: 515°C (960°F)**
> - **Annealing temperature: 565°C (1050°F)**
> - **Softening temperature: 820°C (1508°F)**
> - **Working temperature: 1220°C (2228°F)**

- Once the fuse has been achieved, repeatedly open and close the door to quickly drop the temperature down to just above annealing, 565°C. This is known as "crashing"the kiln. Moving quickly through this range will help prevent devitrification of the piece.

Now reset the controller for the annealing schedule to allow the strain to be released from the piece. Though borosiliate is far less sensitve to thermal shock than soft glass, it is still

[2] E.L. Wheeler, Scientific Glassblowing (New York: Interscience Publishers, Inc., 1958): 18.

crucial for the integrity of the work to kiln anneal. Northstar Glass provides the [following] borosilicate annealing schedule.

As the wall thickness and complexity of the piece increase, the first [hold] stage (A/T - 52°C) becomes more critical in the overall annealing process. This temperature is just below the strain point and allows the piece to cool slowly and come to a steady state before continuing with the ramp down. Additional [hold temp] points allow the piece to cool in a controlled fashion and to stabilize before continuing to cool.

ANNEAL TIME: 1 hour for every 6 mm (0.25 inches) of piece thickness

SOAK TIME: ***(A/T = Annealing Temperature)***

A/T – 52°C (125°F): 50% of the Anneal Time for pieces 0.25 inches thick or less

A/T – 93°C (200°F): 25% of the Anneal Time

A/T – 177°C (350°F): 25% of the Anneal Time

A/T – 288°C (550°F): 25% of the Anneal Time

This schedule is provided for clear and colored borosilicate glass. The variety of metals and other components in colored glass dictate the need for this very conservative annealing schedule. With clear glass, the strain point is the main concern and once below that, the piece can be cooled more quickly than the schedule suggests. The final ramp down in temperature was eliminated.

After crashing the kiln, our annealing schedule was as follows:

TEMPERATURE (°C)	TIME (MINUTES)
565°	30
500°	12
450°	6

After 6 minutes at 450°C, the oven was shut off and allowed to coast down to room temperature."[3]

The 96-well cooling down in the oven (Photo 10).

Photo 10

THE FINAL STAGE: GRINDING THE BOTTOM SIDE OF THE PLATE

Inspect the polishing pads before use. No matter what, there can be dirt or debris that can embed itself in the magnet backed pad. This can affect the flatness and cause an uneven grind on the plate. Carefully inspect and remove little pieces prior to grinding the glass.

It is good to have extra pieces of plate to evaluate and see if there are rogue diamonds on the pad. Identify areas on the surface or buy a new pad. After use, rinse each pad; remove as much of the glass powder as possible or it can build up in the pad (Photo 11).

After the plate is annealed and cooled down, it is time to grind the bottom surface of the 2 mm thick 96-well plate to an optical polish. The glass is quite clear after firing, but

[3] Drier, 23-25

Photo 11

it takes on a texture from the fusing plate. It is necessary for this researcher to be able to photograph the transformation within the well or cup.

POLISHING THE GLASS 96-WELL PLATE

A Wilt Industries flat lapping wheel using 24” diamond and polishing pads worked well for this project. Here is the porosity of pads used: 220 diamond pad, 325 polishing pad, 600 polishing pad, 1200 polishing pad, and finally cerium oxide (Photo 12).

Photo 12

Sometimes there is a rogue diamond and the process is started all over again from the beginning (Photos 13-20).

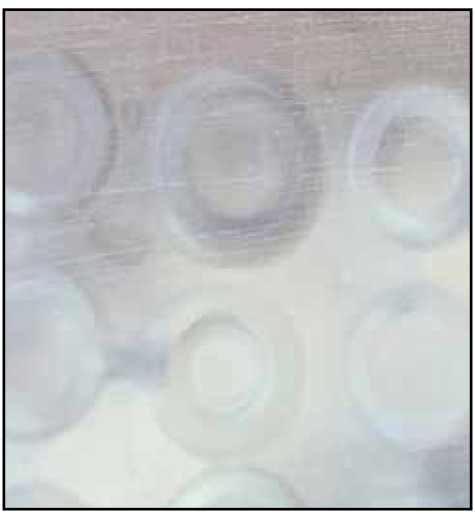


Photo 13

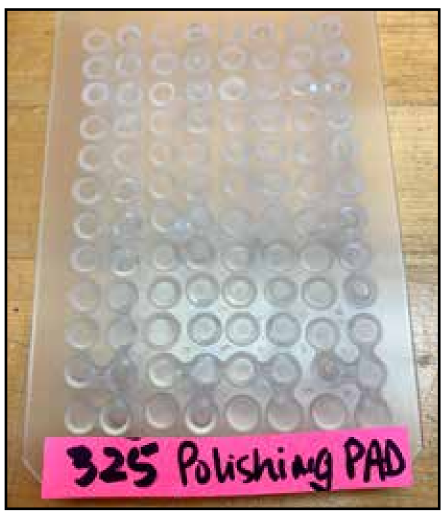


Photo 14

Photo 15. *Close up of 1200 grit*

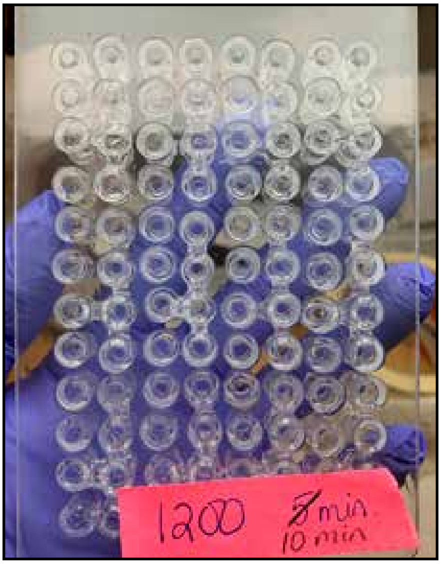


Photo 16

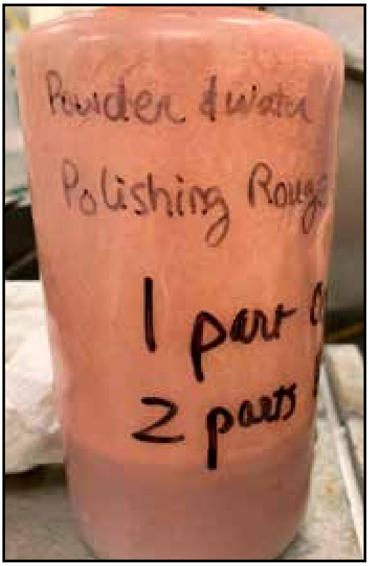


Photo 17

Photo 18

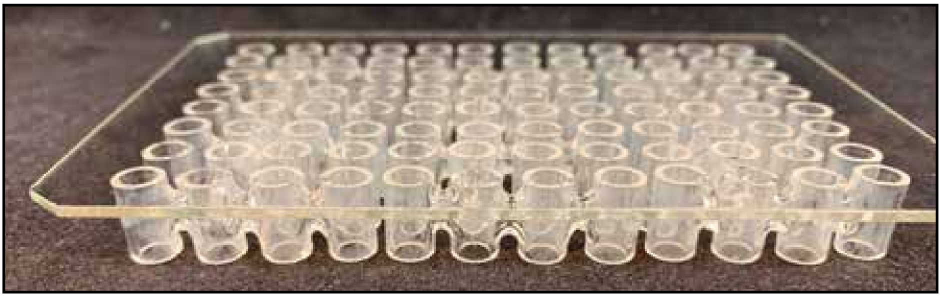
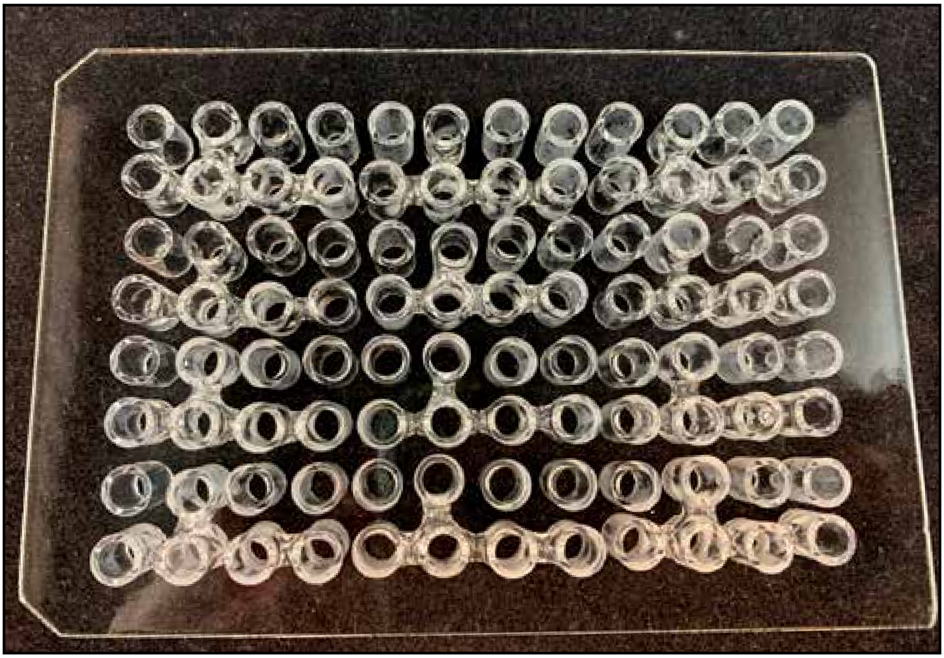


Photo 19



ACKNOWLEDGEMENTS

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Fixtures in the Glass Shop

by

Patrick DeFlorio*

ABSTRACT

A brief medley of handy fixtures used in a glass shop during the last 50 years.

It is true that we are surrounded in the modern world by marvels the development of which could not be possible without the aid of glassblowers. It is equally true that fixtures made the development faster and more precise. There is always a compromise between the cost of a fixture and the desire to produce the best possible product.

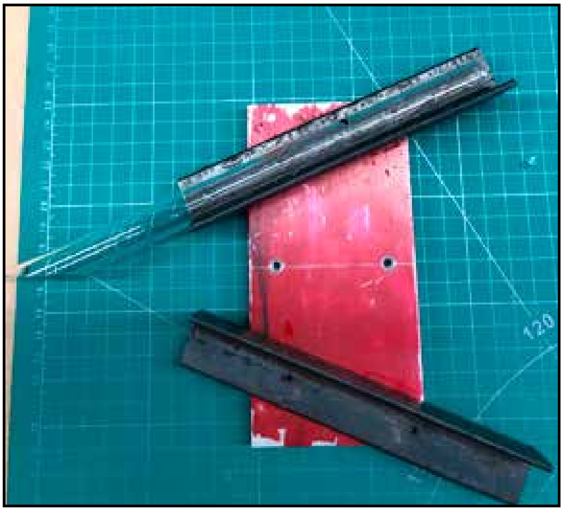

Photo 1. *Y tube laying out saw cut*

I like to use a self-healing cutting mat (Photo 1) to see how a desired part along with possible clamping points and the direction of restriction glass and possible fixtures will go together. In the case of a Y olfactometer tube used for insect studies, is there enough room to work the inside corner of the seal? (Photo 2) Allow enough room between the

Photo 2. *Y tube complete*

* Yankee Glassblower, Inc., P.O. Box 486, Concord, MA 01742. Email: pdeflorio@comcast.net.

heated glass and any metal surface that can cause a crack. Think about how much force will be needed to hold the glass against the fixture and its direction. Some parts and fixtures will allow for annealing in place; other times the fixture needs to be quickly removed. The amount of heat the fixture is exposed to will be a guide in the selection of material. Fiberglass tape can prevent cracking between hot glass and metal. Try to choose a material and sizes that will be easy and cheap to obtain.

When I have a good idea about my design, I next make a sketch using graph paper with notes. Notes should include vendor part numbers, special fasteners, etc. This will be turned into a CAD drawing allowing me to draw to scale from the tiniest to the largest parts. We presently use PC Draft Professional. Using different layers for fixture and glass helps. Making the glass one color and materials a different one gives a clear picture (Photo 3). The glass layer can be printed separately for fabrication. Similar parts can be easily drawn by modifying the original file. Drawings are printed and scanned as a hedge against the program becoming obsolete.

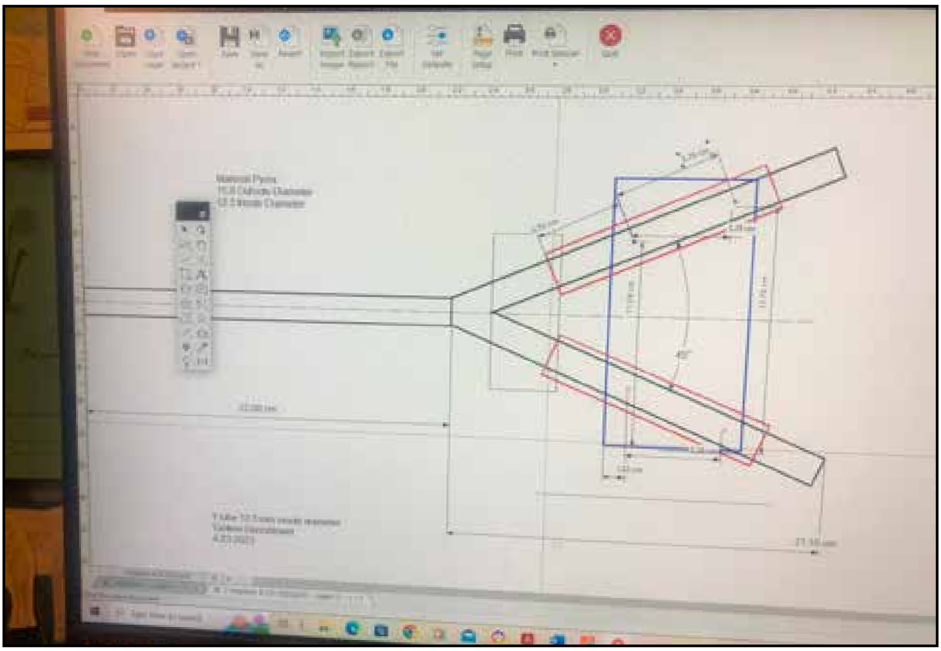

Photo 3. *Y tube with fixture*

The materials selected should consider the purchase and the processing price. A large piece of steel being bored to size can cost quite a bit of labor. Is there a consumer product that can be modified?

We used the steel lid from a peanut can (Photo 4) to retain 75/50 socket joints for joining to mullite (Photo 5). Mullite has an expansion of 54 x 10^{-7} and a maximum temperature rating of 1450°C. An aluminum disc 6" diameter x 1" thick was secured to a 1" diameter rod 18" long by a 5/16" bolt in the center. The disc was bored on one side .250" deep to hold the outer diameter of the socket. The peanut lid was drilled in three places with

Photo 4. *Steel lid of peanut can*

Photo 5. *Pyrex to mullite seal*

a 1/16” hole. Nickle wire was run through the hole to springs with enough tension to hold the socket in place (Photo 6). The socket was preheated, and the mullite was preheated slowly for ½ hour before sealing. The seal was worked 10 minutes keeping the heat on the mullite. Blow and let the glass sag several times to prevent any re-entry angle from an incomplete seal. Do not allow the graphite to touch the mullite as it may result in cracking. The peanut lid was cut in half with sheet metal sheers allowing it to be removed from the aluminum and flame annealed. The finished piece was oven annealed. There will always be strain when this is cool because of the different coefficient between the glass and mullite. Gene Nelson demonstrated this at the Mobile Alabama Symposium.

Photo 6. *75/50 Socket holder*

Fixtures can make the wet saw more precise and more productive. We have found many uses for Trex Decking, and it is a composite made of 95% recycled material. It does not warp or split like wood on the saw and is more rigid than other plastics at the home improvement store. The dimensions we use are 1” x 6”; carpenters have lots of this as scrap. Trex is easily cut on the band saw and can be tapped for threads, but they are pretty weak. When we need to cut a beaker or other glass with a lip, we use a set of rollers (McMaster Carr # 2297T11 Small-Diameter Abrasion-Resistant Conveyor Rollers) which will allow us to turn the glass without scratching it (Photo 7). Drill and countersink two holes 5/16” diameter 3” apart and the fixture can be secured to the table of a Pistorius Saw without C Clamps. A 1” square by 6” long piece can

Photo 7. *Roller*

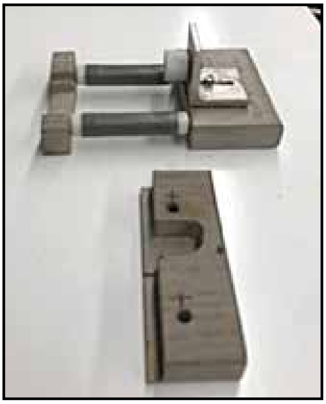

Photo 8. *Trex fixtures*

have a shelf milled in one side to cut small tubing easily (Photo 8).

We even used Trex for a bending job where the inlet and the outlet had to be parallel and a certain distance apart. The piece was fabricated but the final bend was not completed. The piece was made by holding the inlet in a fixture and letting the outlet set into a vee groove machined in another piece of Trex. We worked ~150 mm from the plastic so it did not melt (Photo 9).

Photo 9. *Plastic bend fixture*

Induction seals and fixtures used for bending glass in an oven can be made with "Unfired Lava Grade A" (Superior Ceramics of St. Albans, VT). The material is hydrous aluminum silicate and the color is grey. Unfired lava grade A can be machined with high-speed steel tools. Always use a vacuum and the right mask when cutting or machining ceramics. After being machined, pieces can be fired between 1010°C and 1093°C. Large pieces may crack: do not exceed 1093°C as it will change the grain structure and create cracks. After firing, the material will expand 2% and the color will turn pink. After firing, you need to use carbide tooling or grinding to process ceramics, but the parts are much more durable and do not absorb moisture. The linear expansion is 36×10^{-7}.

We produced a tremendous amount of Kovar seals in the 1980's. Part of the process involved induction sealing 15 mm tubing with excellent concentricity. Glass was cut and sorted using gauge pins in .002" steps. Lava fixtures were machined .002" less than the glass (Photo 10). Before sealing, the fixtures were baked in an oven to remove any moisture. The fixtures stood up to the production of 150 seals a week for a decade.

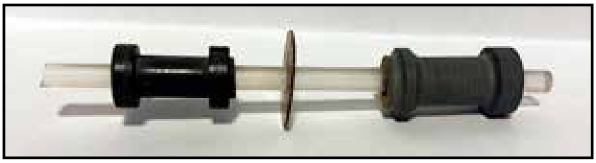

Photo 10. *Ceramic induction fixture*

A customer wanted 3 mm tubing bent to a 100 mm radius over 100 mm length. A fixture on a rotary table was made using a block of lava (Photo 11). A radius of 103 mm was machined and then, using a slitting saw, the 100 mm radius was cut using a 3 mm wide blade. The glass was cut extra long so that as it sagged, the final section would be pressed against the fixture. The results were excellent!

Photo 11. *Ceramic radius side*

Neon workers frequently use calcium silicate for forms. We have a bunch in the shop for specific jobs. Calcium silicate is a white board that can easily be cut with a band saw then sanded to remove any tool marks. The material is dusty and large pieces can easily be broken by accident. It will take hot Pyrex during bending but not a direct flame. We have used this to extend the life of our annealing ovens. Cracks appeared in the ceiling of the oven and rebuilding it would be an arduous process. We cut a ¾" thick board 2" less than the width and depth of the oven. Matching sets of stainless bar stock 2" x 1/16" and 2" x 1/8" hot rolled angle iron were drilled with ¼" holes. With the ceramic holding up the roof, holes were drilled through the fire brick allowing clearance for ¼" studs that would hold all this together. It has been three decades, and the ovens are still going strong.

Plywood is cheap and easily cut to shape. Occasionally, we have repairs of large 300 mm reactor heads. They are quite expensive, and the customer is in a hurry. I like to grind the broken joint ~12 mm above the surface of the head when repairing. Reactor heads do not fit well on a wet saw, so I use a dremel tool with a diamond blade. This is an unguarded blade, so I like to do the cutting myself with an assistant spraying water on the cut. After cutting it, I bring the head to my Bridgeport; since it is very heavy, there is no need to clamp the piece. We put the head in a tub, and using a metal bond drill 50 mm diameter, slowly grind the surface away until it is the correct height (Photo 12). The fixture to hold the head in my K lathe is made from two discs of ¾" plywood. The smaller one matches the inside diameter of the flange and the second one is the same diameter as the lid. The disc is mounted concentric and aluminum foil is tacked onto the face to avoid burning. Loops of 1/8" diameter stainless steel tubing catch the lip of the head and are pulled into place with wire and springs. A 1" plumbing floor flange is mounted on the back so the pipe can be held in the chuck of the lathe. If one of the outer joints is broken, a set of elbows and close pipe can help put the repair closer to the centerline of the lathe. Before the joint is repaired, the head is preheated with a large gas air flame for a half hour (Photo 13). It is much more effective to preheat the repair if it is close to the centerline. Usually the actual repair is quick: just use a National Torch with a #3 tip to heat both surfaces and make a nice stick. Remove the joint holder and work the seal using gravity to make it look nice. No need to worry about blowing into the head. Then put it in a hot oven.

Photo 12. *300-mm reactor head grinding*

Photo 13. *Preheating 300 mm head*

I like to use plywood for dewar seals if they are large enough. I turn the inside and outside diameters with ~ 1 mm clearance; plywood has a fibrous finish when turned, so it fills the gaps. This also allows a gap to blow. Glass is cheap, so I will use a half-length to start a seal and keep the wood ~150 mm from the seal. Use your judgement in the distance, it is better to be safer than to see smoke. I cover the hot face with aluminum foil and uncoated thumb tacks. The second plywood donut should be at least ~150 mm from the first. The greater the distance, the better the centering ability. When fabricating a seal, place both donuts on a plug and drill a set of holes so that threaded rods can be used to secure it in place. Ideally, a hook can be put on the outmost rod for pulling back while annealing. This apparatus will hold the glass, but it might want to walk in the lathe. Copper screening placed between the disc can provide enough interference that the glass will not move. You do not need a lot of holding power but there is nothing worse than a dewar seal moving while you are trying to work it! After I have worked the seal and maybe even put on the hose barb near the end, I reach in and pull the fixture back so I can really heat all the glass. When it is cool, remove the fixture and seal the second end.

Another unusual Dewar was a lamp sub-assembly made of Schott Ar-Glas. This is their lime glass; it is stocked in many smaller sizes. The expansion is 91 x 10^{-7} and annealing temperature is 525°C. In this case, the outer diameter tubing was 17 mm and the inner tubing was 5 mm. The 17 mm was flared to 45 mm +/-1 and the length of the flared section was 8 mm +/-2 mm. The overall length of the flared section was 50 mm +/-2 mm. We set up a graphite plate with the edges machined to make a V cross section (Photo 14). This was mounted on the lathe bed, and the tubing was heated with a soft flame from a 3/8" hush tip. With practice, the diameters were very consistent. Pieces scored 75 mm long were annealed.

Photo 14. *Flaring tool.*

My friend Trevor at Benson Machine in Winchester, NH made the assembly fixture. I had to hold the flare sub-assembly and the inner 5 mm ~200 mm long tubing concentric. The overall length was +/-2 mm. Using 2" diameter aluminum, two sections were formed. The first was 25 mm long and had a hole 0.1 mm bigger than the 5 mm tubing bored concentric to the o.d. half way though the disc. The second piece was 75 mm long, again with an oversized bore concentric to the o.d. A shoulder 19 mm long was turned to easily fit the inside of the 17 mm tubing, and a cone was machined back matching the funnel of the glass. A set of O-rings mounted on the turned diameter had just enough resistance to hold the flared assembly in place. McMaster Carr sells a nifty Item # 3126A83 Slotted Long Nose Spring Plunger $3.87. It is a set screw with a spring pushing a plastic pin. Trevor drilled and tapped two sets of 10-32 threads 120 degrees apart at both ends of the 2" diameter (Photo 15). By gently tightening the screws, it would provide a concentric grip despite the variation in glass diameter.

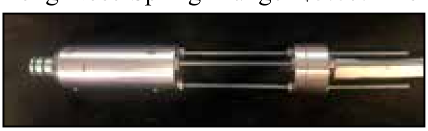

Photo 15. *Aluminum fixture*

The 25 mm disc was drilled parallel to the axis for clearance of 8-32 threaded rods again 120 degrees apart. The back of the long section was drilled and tapped for 8-32 threads. Using 8-32 rod and nuts, the fixture was assembled. The 5 mm bore of the short disc had an O-ring to make a seal and a hose barb to blow into the 5 mm tubing. The long section could be held in the lathe chuck. The 5 mm cut to length was put in place and then the 17 mm flared section. The O-rings provided a nice concentricity. Using a #2 on my National, the 17 mm was pulled down and blown flat just clear of the 5 mm tubing. The center was then heated with a Little Torch and #5 tip until the two glasses were completely sealed. The center was heated again and blown out. By heating for a short while, it worked in with no restriction. A little flame annealing was used to prevent breakage. Pieces were annealed vertically to avoid any movement.

Our shop has five Litton Lathes from an F to the K. On the headstock and tailstock are sets of holes only untapped by imagination! Fixtures secured to the headstock can produce extremely consistent lengths when paired with the right stops for glass. Fixtures secured to the tailstock are great for allowing adjustment as you work the glass. When forming a flange, a tailstock mounted fixture allows you to slowly gather and form the desired thickness and diameter.

We had a job that started with cutting 1 mm diameter glass tubing with a ½ mm inside diameter 16 mm long. The ends needed to be square and not have any residue. I am always having issues of cleanliness with outside vendors. When they use solvents on glass, the wet pieces look clean. In my shop when I am about to use a torch on the part, it looks dirty; I know wax and oil will not burn off cleanly. Fearing a problem with thousands of dirty small tubes, I decided to do the work myself. The solution was simple after we thought about it for a while. The tubing, 75 mm long, came in a plastic vial. We filled the vial with distilled water, placed it in my father's favorite beer stein and put it into the freezer overnight. The next morning, the coolant was disconnected from the wet saw. A stop was set for the length, and then dry ice was put on the aluminum angle iron fence of the wet saw. A large bath of deionized water was placed nearby for the cut parts. We placed the vial on the wet saw and cut through the glass more than 75 pieces at a time. Water melting from the inside provided coolant. The ice inside the tubes prevented swarf from getting inside. In a matter of minutes, thousands were cut! Once the pieces were removed from the bath and placed in a strainer, they dried.

Next, the customer wanted one end flared from the original .0394" to .044" +/-.002". We have an adapter that allows us to mount a 4-jaw chuck on our Litton U lathe (Figures 16 & 17). The jaws of the chuck are independently adjusted. This allows you to hold a piece more precisely than a normal 3 jaw chuck or purposely hold something off center. In this case, we wanted to hold a small Jacob's chuck and .019" gauge pin as true as possible. The glass pins would slide easily onto the pin. We used a microscope to be able to work at this small scale. We have made blocks that fit on the back of all our lathes using the 5/16-18 tapped holes in the back. A diameter is bored through the block that will be parallel to the axis: a single block allows better travel, but the second block provides more stability. This job needed a Little Torch with a #1 tip to swing into position just heating the end of the glass tubing. The Little Torch needs to use hydrogen in any tip below

Photo 16 & 17. *Flare 1 mm*

#4. This is because the velocity of a gas going out of the small tip exceeds its ability to burn. Hydrogen is not much hotter, but it has a very fast flame velocity. The Little Torch was mounted on a shaft with a lab clamp. The shaft rotated slowly until the first yellow sodium flare appeared. Using a .5 mm hard grade drawing graphite sharpened to a point, the glass was gently flared. A go gauge was machined out of a metal disc with a .046" hole; with practice, most pieces were within specification. The graphite was held in a small pin vise, and flaring was done with my palm resting on the heat shield.

Next, the customer wanted both ends flared, but by that time we were experts. I bought the graphite at a local art store. Softer graphite would not hold up to the heat, however. The graphite was never heated directly but rather just out of flame.

We had a job that involved sealing Kovar tubing 16 mm diameter by 11 mm long to glass. The finished piece had a capillary tube ring sealed to the tubing and a Kovar induction seal along with the 6 mm exhaust port. The depth of the face of the capillary was +/- .1 mm and the height of the Kovar induction seal was +/- .5 mm. Holding a short piece of tubing was a challenge. The solution involved using Hardinge 5C Collets; these are made for machine lathes and come in a variety of shapes besides round. Available shapes are square, rectangle and hex. They run .001 concentricity for stock items and .000002" special order. We found a decimal size that worked for us, and the back of the collet was threaded 1.238"-20. This allowed us to machine an insert that would hold the Kovar collar and set the depth of the capillary. We turned a piece of steel to support the collar and made an adjustable insert determining the capillary depth (Photo 18). A hexagonal collet block was fitted to a face plate on both our F and U lathes (Photo 19). A cap was made for the outboard sides of the spindles to center a draw bar that would tighten the collet. When the collar was tightened in the collet, it was a consistent distance from the spindle face. We mounted an indicator on the bar mounted on the back of the lathe. The assembly including the induction seal was mounted in the tailstock and moved towards the headstock until the correct indicator measurement.

Photo 18. *5C Collet and insert to make Kovar and ring seal*

Photo 19. *Collet block on lathe*

Hopefully some of these ideas will be helpful to other glassblowers. I want to thank my father William for allowing me to buy machine tools for our shop when we first started working together.

Perceptions of Scientific Glassblowing: What are We Doing to Change the Future?

by

Benjamin Revis*

ABSTRACT

A quick look at the perceived trend of scientific glassblowing from a hypothetical external evaluation of prospective perceptions. This presentation will discuss the need, the trend and the end. It evokes the question: What can we do to change the view?

Over the next few pages, I would like to take you on a journey through some thoughts and perceptions that have come to mind as I have personally wrestled with the topic of Sustaining Scientific Glassblowing.

But before we begin, we need to define the framework of our perspective as we look at available information and trends before arriving at the end and drawing conclusions.

Consider for the moment that you are in the position of an academic departmental supervisor, financial officer, dean, a journalist, maybe even a new graduate research student. You have been tasked with finding a scientific glassblower. Your task could satisfy many reasons, but the important perspective is that you are setting out to learn more about a scientific glassblower and where to find one.

One of the first questions you may ask yourself might be, what is a scientific glassblower? If you have a good working definition, it will help you with being more specific in your search effort. You finally put together an elevator pitch description that resembles the following: Most are aware of the scientific method: Observation, Hypothesis, Experiment, Analysis, and Conclusion. The ability to test an hypothesis by a safe, controlled experimental environment while being able to observe the process is essential for experimental scientists. The scientific glassblower helps design, build, maintain and troubleshoot the containers that allow the experimental scientists to perform their observations. More succinctly, a scientific glassblower is a design engineer specializing in the glass medium that allows the experimental scientists to perform their observations.

Another great step in being efficient with performing any search is to draw from what you already know and understand. As you think of glassware and the sciences, you come to the conclusion that chemists utilize glassware rather prolifically. Yes, the other science fields use glassware but not nearly as much as chemists. Further detailed analysis of the areas of chemistry demonstrates a strong interdependency, a symbiosis if you will, between education, research, chemical production industry, and instrument industry. (Image 1, *next page*) Scientific glassblowers could be found within the instrument industry category. In looking at these areas of the larger picture, it can be observed that each area provides its resources and receives resources from the others. All areas have a need for glassware simple, complex, or exclusive depending on needs. As you conclude with these thoughts, the idea may come to mind that since glassware is so globally utilized,

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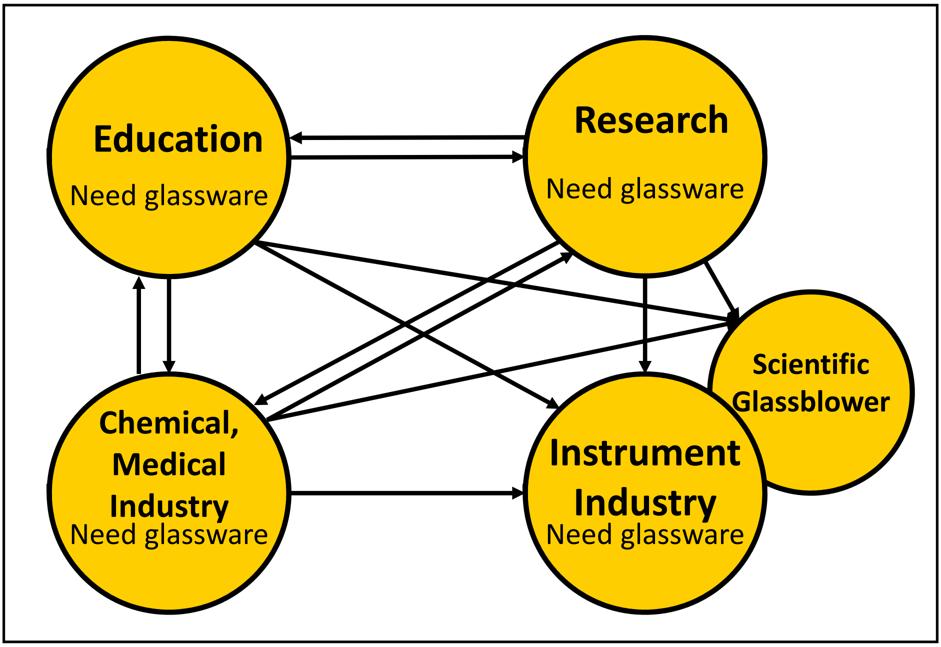

Image 1. *Interdependency diagram*

finding a scientific glassblower should not be difficult. So, the internet searching begins.

As you scour the internet with excitement, you begin finding results:

- "UM glassblower facing fire of campus politics" – 2004, *The Baltimore Sun*
- "The dying breed of craftsmen behind the tools that make scientific research possible" – 2016, *Los Angeles Times*
- IMPORTANT NOTE:
  "Mike Souza will be retiring from Princeton University as of June 30, 2022, and Princeton will be closing its glassblowing facility." – *Rutgers School of Arts and Sciences*
- "Full-time university glass blowers are considered tops in their field, but few institutions still offer such positions … . When Cal State L.A.'s longtime glass blower retired last year, the shop which he had run for 30 years closed down. Similar fates have befallen glass blowing at UCLA and NASA's Jet Propulsion Laboratory. At UC Riverside, which once had three full-time glass blowers and two glass shops, a glass blower now comes in one day a week." – *Los Angeles Times*, 2016

Remember your pretend role from earlier as research institution management, general public, news writer, etc. Review the findings again; what stands out? Some points might be:

- few institutions still offer such positions
- Cal State
- UCLA
- NASA's Jet Propulsion Laboratory
- UC Riverside
- Princeton

Academic and research icons are closing their shops. This should give you the desire to pause and digest what you have just learned. Maybe evoking the mental conundrum that glass is such an important part of science and chemistry based on what I knew before, how can these institutions be letting the resource go? Surely there is information that has been overlooked. So, you keep digging.

Looking at colleges and universities across Indiana, Illinois, and Iowa, 203 institutions have science programs and may have need for glassblowing services. Of the available data (Chart 1) your results give you, a mere 4% of these institutions have a scientific glassblowing facility as a resource. You contact the American Scientific Glassblowers Society to request the regular membership numbers as far back as possible. That should give a better, more stable picture of the career scientific glassblowers across North America (Chart 2, *next page*). Unfortunately, the trend of membership decreases from 557 in 1998 to 196 in 2021.

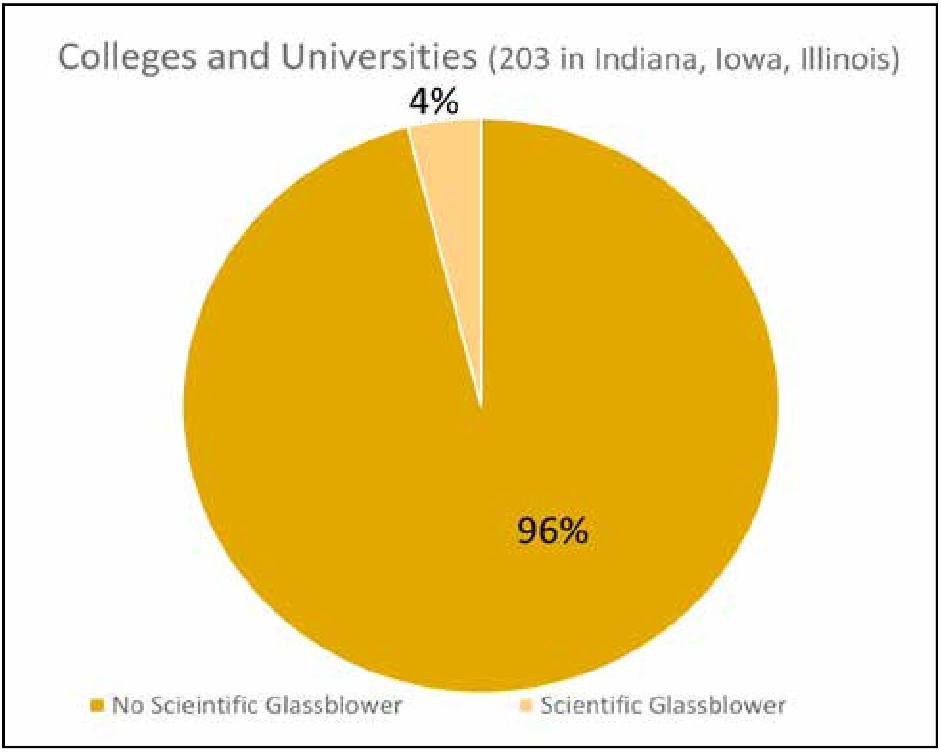

Chart 1. *Glassblower and no glassblower comparison*

You stop looking for information and begin to draw some conclusions:

Possible conclusion 1:

Based on the information quickly gained, technical scientific glassblowers are no longer necessary. Possible justifications:

- Peer pressure – Those other notable institutions apparently do not need that resource, so why should we?
- Easy way out – Good, now I have enough supporting information to not invest further after the current glassblower leaves.

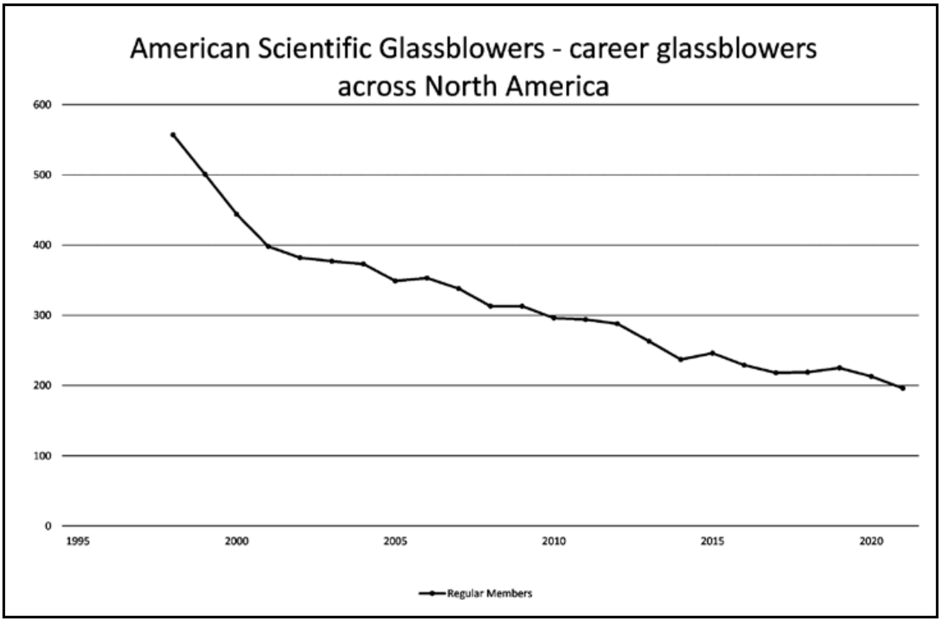

Chart 2. *Career glassblower trend*

- Uncertain value – I just do not know about the benefits of having and investing in this resource.
- Outsourcing - everything else is able to be outsourced, pass the burden to the glassware companies and take the budget line off our books. The researchers will figure out where to get what they need.

Possible Conclusion 2:

Why are the search findings showing such a poor perspective? The issue needs to be investigated further.

Are the perceived trends and articles due to:

- Hiring issues?
  - Where to find a pool of qualified candidates?
  - Does the glassblower candidate pool need a higher academic degree?
- Glassblower education challenges?
  - Are there challenges with recruiting the next generation into scientific glassblowing?
  - Are potential employer expectations not being met?
- A genuine reduced need of glassware?
  - Have other materials or processes fully replaced the use of glassware?
- The end user?
  - Is there a lack of understanding for the capabilities of glass?
  - Is the value and expectation of having a glassblower unknown?

As a scientific glassblower, thinking through this process can be very depressing … if we end the story here.

In 2017, a glassblower and a chemist came together through a discussion that led to a coordinated effort to co-plan a joint meeting between the American Scientific Glassblowers Society Midwest Section and the American Chemical Society Midwest Regional Meeting to be held in the fall of 2022. The theme of that meeting was as follows: "Sustainable Chemistry: Leading through change." The planning committee composed the following as part of their awarded ACS Innovative Programming Grant proposal: "In recognition of the paramount role of glassware in the chemistry lab, our goal is to build community and open communication between the scientific glassblowing and chemistry communities. Members of the American Chemical Society (ACS) and the American Scientific Glassblowing Society (ASGS) will mingle and hear presentations during joint programming and overlapping Society meetings during the 2022 MWRM. This venue presents a great opportunity for these interactions."

If you have followed along to this point, we have looked at the scientific glassblower career outlook, albeit very quickly and crudely. Yet, we have looked at trend and potential perceptions where the trend does not look good. Which brings us to the end – or is it? What can be done to impact and influence change in your areas of influence?

I hope that this paper sparks new thoughts and points of discussion.

The concluding 2022 MWRM planning committee's hopes for the joint ACS/ASGS meeting:

- Building a relationship between ACS and the glassblowing Society at this meeting will introduce a large number of chemists to resources in the glass and ceramics community. The programming specifically promotes exchanges between glassblowers and chemists to support teaching and research efforts.
- We hope that the programming will lead to continued interactions between research chemists in the Midwest region and glass-materials experts in the broader community. The chemistry community is aware of the value this expertise offers to research. The opportunity to establish new connections between these communities will be valuable.
- Joining future meetings/programming as a result of this event. This one-time fortuitous circumstance is a great way to develop future programming by bringing the glassblowers and chemists together.

A special thanks to all my fellow glassblowers who have suffered many hours of me hashing these ideas and perspectives out for myself. To the University of Iowa Department of Chemistry faculty and students who support these efforts. And lastly, to the 2022 ACS MWRM planning committee members (Tori Forbes, Renee Cole, Heriberto Hernandez, Scott Shaw, Andrea Van Wyk, Lucas Clausen).

Re-Creation Of Blaschka Invertebrate Models

by

Lauren Aria[1], Tracy Drier[2], Loren Stump[3], Andrew Bearnot[4], Erich Moraine[5], Ilia Guzei[5], Laura Monahan[6]

ABSTRACT

This paper investigates the previously overlooked physical re-creation of the Blaschka invertebrate models utilizing historically relevant tools and equipment. In June of 2022, glass artist Loren Stump visited the University of Wisconsin-Madison for three days to explore variables related to building period-appropriate Blaschka invertebrate models. The intention of this project was to create a proof-of-concept construction of Blaschka invertebrate parts and models. Loren was joined by other glass artists in this educational and collaborative project and investigation.

INTRODUCTION

Leopold and Rudolph Blaschka were a father-son duo creating an impressive array of plant and invertebrate models. Over seventy years, from 1863 to 1936, the Blaschkas produced 4,300 glass models that represent 780 plant species and over 700 invertebrate species.

Photo 1. *The* Praya cymbiformis *Blaschka model photographed at UW-Madison*

Leopold and Rudolph Blaschka worked out of their home studio based in Dresden, Germany where they created plant and invertebrate models for museums and universities as educational tools to help inform the public. Glass models were used in place of attempting to preserve live invertebrate bodies, as they often quickly broke down and were difficult to accurately study. These models were used for years as teaching aids to diagram the bodies of plant and invertebrate specimens for students and the public.

The work of the Blaschkas can still be found in the impressive collection of flowers present at Harvard University, the Corning Museum of Glass, The Museum of Natural History in Sweden, University of Oxford and a number of other locations (Photos 1-5).

Although there has been heavy research regarding the lives and travels of the Blaschkas and analysis of the complete models themselves, little headway

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Photo 2. *The* Actinophrys sol *Blaschka model photographed at UW Madison*

Photo 3. *Loren Stump viewing the Blaschka models*

Photo 4. *Original UW Blaschka model of* Actinophrys sol*, photo: Ilia Guzei*

Photo 5. *Partial UW re-creation of* Actinophrys sol

has been made in considering how the models were originally constructed. The Blaschkas were intensely secretive about their process and techniques in their work, which has led to an extreme difficulty in understanding how their models may have been constructed.

We were able to fund this project through the aid and assistance of a Brittingham Foundation Grant provided by the UW Zoology Museum which allowed us to invite skilled soft-glass worker Loren Stump to visit UW-Madison for three days to research the variables present in proof-of-concept construction of period appropriate Blaschka models. Our project works to understand how the Blaschkas may have created their work, and to highlight their lifetimes of skill and research in their mastery of model-making. For Loren's visit, we chose to focus on the creation of the *Actinophrys sol* based on the technical limits of our materials and the fact that it contains a variety of hollow and solid forms. We also investigated other components such as glass coated copper wire for jellyfish tentacles, a variety of glass spines, and a glass bulb inside a bulb.

TORCH

In our project, the first variable of research was finding an historically relevant torch to create our models. Unfortunately, little research exists regarding the kinds of torches Rudolph and Leopold Blaschka used to create their work. It is assumed that Rudolph and Leopold each had a bench with one torch, but it is unclear if they had additional torches to work off of as well. We used natural gas and air for our torch at typical house pressure (1/4 psi).

Based on this knowledge, we created a modified torch from a circa 1920's US torch (Photo 6) to conduct our research We replaced the cracked and broken lead tubing on the torch with new copper tubing, to return the torch to a functional state (Photo 7).

Photo 6. *Circa 1920's gas and air torch used for our study*

Photo 7. *Modified torch with replaced copper tubing.*

Photos 8 and 9 show the process of investigating different tips to produce the flames required to create our work. For this project, we needed a fire capable of creating both the larger bubbles and the fine detail work required to create a model. The majority of the first day of Loren's visit was spent investigating options regarding our torch. We went through an intuitive trial and error process to find the best torch tips to achieve the fires we were looking for. The final configuration of torch tips is shown in Photo 10, which gave us the most desirable fires.

In this configuration, we used National torch tips, UW Chemistry machine shop parts, and threaded fittings for our torch. This was the most efficient way for us to achieve our goals regarding this torch in such a short time frame. We were able to work with what we were familiar with to help us achieve our goals more quickly than fabricating completely new parts.

The torch functions through an air feed blown through the copper tubing and designated

Photo 8. *Various torch tips evaluated*

Photo 9. *Final configuration of torch tips*

Photo 10. *Small fire on torch*

Photo 11. *Large fire on torch*

torch tip to a natural gas candle fed through the vertical glass and brass tubes. The shape of each of the openings for gas and air determines the shape and size of the flame as they meet each other.

The Blaschkas would have had a torch with only one respective gas and air feed, but it would function on the same premise as this torch which has three outlets. This allowed us to be much more efficient in our process of testing out different tips

Photos 10 and 11 show the kinds of fires we were able to achieve on our torch. Figure 10 shows the sharp fire we used for more detailed work, and Photo 11 displays the large fire for blowing bubbles and other general work. Photo 12 is an image of Loren working on the modified torch.

While working, we also kept the lights very dim as it made it easier to see the fires, and we eventually added a wind shield to help protect the flames from air currents.

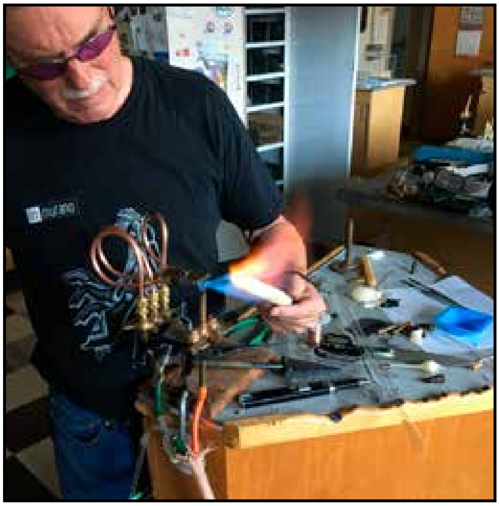

Photo 12. *Loren Stump working on the modified torch*

GLASS

The next variable we investigated for this project was the different kinds of glass we used to create our models. We mostly tested clear glass for this process with the exception of the Lauscha eyeball tubing which was milky-white in color. We wanted a glass that could be formed in a relatively cool fire common to the time period of the Blaschkas.

Table 1 is a chart of the number of the different glasses we tested during Loren's visit. We found that Lauscha soda-lime tubing worked well for blowing bubbles up to 50-55 mm in diameter. Comparatively, the largest bubbles in the UW collection were the jellyfish bodies, measuring 75-80 mm in diameter

After our investigation, the Lauscha eyeball tubing became the most desirable glass we tested. However, this glass is extremely difficult to obtain, and we only had a small amount of it. Photo 13 depicts Tracy working the eyeball glass in the fire on our modified torch.

Manufacturer or type	Glass Type	COE	Form
Sitaki (Japan)	Soda-lime	104	Cullet
	Lead	120	Cullet
Lauscha (Germany)	Soda-lime	104	Tubing
	Eyeball tubing*	?	Tubing
Neon tubing	Soda-lime	92	Tubing
	Lead	92/92	Tubing

Table 1. *Glasses used for evaluation*

*The prosthetic eye tubing was tan/milky white in color and not clear, but was still evaluated for suitability in the flame.

Photo 13. *Tracy Drier working with the Lauscha eyeball glass*

TECHNICAL INVESTIGATION

Once we gained a sense of the kinds of fires we could achieve on our torch and which glasses worked well in the fires, we were ready to begin working on creating models. During Loren's visit, we mainly focused on the creation of the *Actinophrys sol* invertebrate model due to our understanding of the technical limits of the materials with which we were working. We knew that we could make a bubble up to 50-55 mm in diameter, and the *Actinophrys sol* model fit well into this size range and the other techniques we were looking to explore.

Photos 14 and 15 show a portion of our working process for creating the *Actinophrys sol*

Photo 14. *: Tracy Drier creating the body of the* Actinophrys sol *Blaschka invertebrate model*

model. In Photo 14, Tracy Drier can be seen working on creating the large bubble for the main body of the model. Figure 15 shows our working table, including various parts for jellyfish and other invertebrates. There are *Radiolarian, Aulosophaera elegantissima*, jellyfish, and other parts we worked on as well as the *Actinophrys sol* model closer to completion.

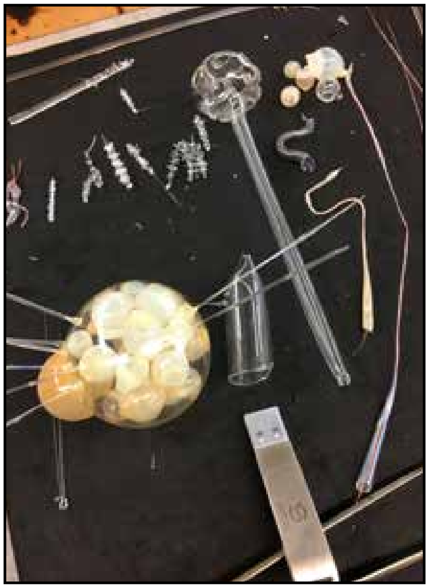

Photo 15. *Variety of UW objects produced*

One of the common technical questions of Blaschka models is how the Blaschkas created glass coated copper wire for their jellyfish tentacles. In our project, we investigated the process of placing the copper wire into a small hollow tube of glass, then heating the glass over the copper wire and carefully pulling the glass coated wire through the fire until the desired length of wire is coated. Photo 16 depicts the process of Tracy pulling the glass coated copper wire through the fire. We found this technique to be very successful for achieving our desired outcome. It is impossible to know whether or not this is the specific technique the Blaschkas used due to their intense secrecy over their processes, but we found it to be an extremely viable possibility for the way they may have done so.

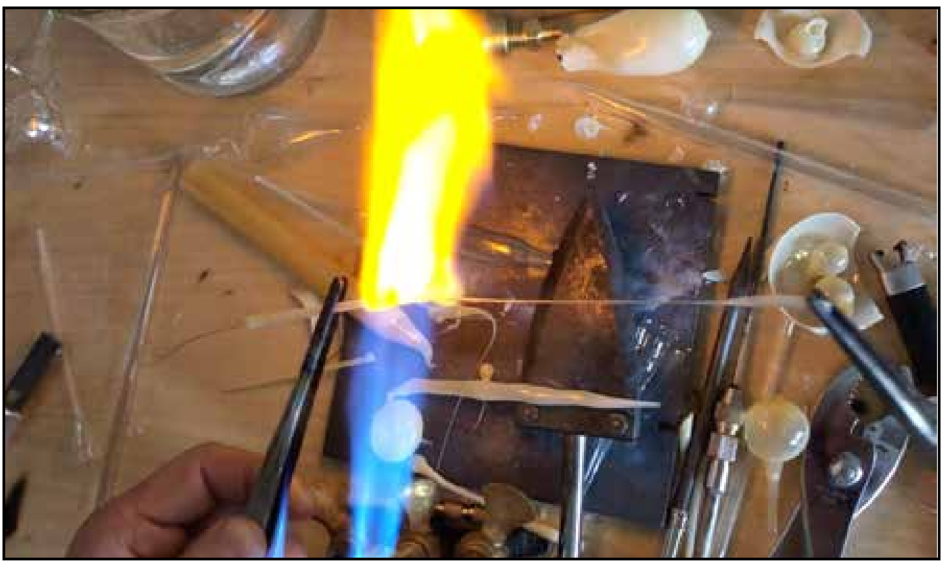

Photo 16. *Process for creating glass-coated copper wire*

OTHER MATERIALS

Part of the power and intricacy that comes with the Blaschka models making them captivating to viewers worldwide is largely due to non-glass processes, such as gluing, painting, and non-glass sculpting with wax, plaster, etc. Photo 17 displays a number of the other materials we obtained outside of glass to create our models, and Table 2 shows an

Photo 17. *Various materials evaluated*

NON-GLASS MATERIALS
Casein
Rabbit Hide Glue
Beeswax
Dammar Wax
Wheat Starch
Hide Glue
Gelatin

Table 2. *List of materials obtained*

itemized list of the specific materials in our toolkit. All of these materials were found in the chemical analysis of the Blaschka models through prior academic research references.

During this portion of the investigation, we mainly focused on the usage of rabbit hide glue found in the chemical analysis of the original Blaschka models. We chose this adhesive mostly due to Loren Stump's previous experience in working with the material. Photo 18 depicts Lauren Aria testing the rabbit hide glue on some of the glass spines for the models.

Photo 18. *Lauren Aria testing hide glue on glass spines*

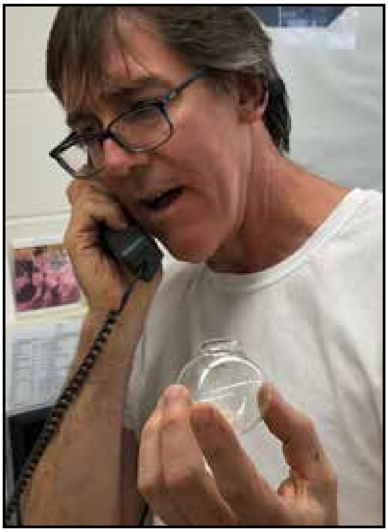

Photo 19. *Tracy Drier allowing the hide glue to dry*

On the *Actinophrys sol* model, we used the rabbit hide glue to adhere the small bubbles to the body of the model, to adhere the spines to the model, and to create the small nodes on each of the spines. Photo 19 displays Tracy beginning to adhere the inner bubbles to the body of the *Actinophrys sol*.

In our final model, it is worth noting that our model has a very glossy, glass-like surface, while the original Blaschka model does not. From references, it is likely that the Blaschkas used a surface treatment on their model such as a wax, gum arabic, or another material to remove the glassy appearance of the model. This care and attention to detail helps provide much of the realism of the original models. Unfortunately, during our short three-day investigation, we did not have the time to study different surface treatments on our model, but this will be a likely project of research in our future.

UPCOMING

We were able to obtain a new glass as a medium of research provided by Aaron Kirchhoff (Strong Force Glass, ND) that he created based off of chemical analysis of Blaschka glass from UW Blaschka shards by the Corning Museum of Glass. In theory, this glass should be very similar to the actual glass the Blaschkas used to create their work, thus helping us get closer to our re-creations of their models. Photos 20 and 21 display the new glass we received from Aaron Kirchhoff. The glass in Photo 20 is purple due to the manganese content which, we believe, was used in the original Blaschka glass to cut the green color of their clear glass due to the lower purity of their ingredients. The glass in Photo 21 has the manganese removed making the glass more clear in color. Aaron Kirchhoff provides a more detailed review of this glass-making process in these *Proceedings*.

Photo 20. *Glass created based off the Corning analysis of UW Blaschka shards*

Photo 21. *Glass created based off the Corning analysis of Blaschka shards, manganese removed*

CONCLUSION

Overall, this project has traversed uncharted territory in the historical research of glassblowing forging a new path that has received a lot of interest but very little actionable research prior to this project. During this three-day visit, we were able to create a proof-of-concept Blaschka model and a number of other components. We were also able to use historically relevant tools, torch, and equipment in order to achieve these goals. There

Photo 22. *Helen Lee (left) and Andrew Bearnot (center) observing Loren Stump working on the torch*

are many more possibilities for us to continue our learning and research now that we have obtained glass based on the chemical analysis of Blaschka shards from the Corning Museum of Glass.

It is exciting to see a room full of very intelligent people who have lifetimes of experience, knowledge, and skill in the field of glass all feeling unfamiliar and out of their element, showing how much room there is to rediscover new techniques and possibilities through this project. As work continues, we will only find more room and possibilities to learn and grow.

Resurrecting A 100 Year Old Glass: Batching a Blaschka Replica Glass Melt Using Data From ICP MS-HR Analysis

by

Aaron Kirchhoff *

ABSTRACT

The University of Wisconsin-Madison has invested resources to learn more about their Blaschka marine invertebrate collection which is housed in the Department of Zoology. The scope of their interest included determining the feasibility of producing replica glass stock for experimentation in the flame using percent composition data from Corning's 2019 ICP high resolution mass spectroscopy analysis (Bakowska et al.)† *of small quantities of Blaschka glass as a guide. Kirchhoff utilized this data with minor colorant modifications to produce two glass batches which very closely approximate that of one specific Blaschka glass sample identified in Corning's study as "Glass #1 Clear-Hollow." Three important glass physical properties were determined from Kirchhoff's glass batch study: working temperature range of the glass in the furnace was found to be 1000ºC to 1250ºC, coefficient of thermal expansion was found to be approximately 108 - 110 x 10^{-7} cm/cm/deg C, and annealing temperature range was determined to be 490ºC - 505ºC.*

Photo 1. *"Glass #1 Clear-Hollow" without arsenic on left, "Glass #1 Clear-Hollow" without arsenic or manganese on right*

INTRODUCTION

The overarching goal of this glass batch melt study is to successfully melt a glass batch that, when complete, replicates the results of the ICP-MS analysis as closely as possible. Successful batch melting becomes a balance between two forces - the planned execution of the process versus the obligation to navigate a broad assortment of inexorable variables which can pull the final composition away from the target. This document intends to characterize the significant number of variables that can affect the accuracy of the melt and then disclose the actual melting process used for this study.

THEORY OF GLASS LIFETIME: FROM FURNACE TO MODEL

Tracing the lifetime of the glass starting in powder and following it to its final form as a

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† Murray Bakowska, Kuenzli Clark, Riesback White, Corning RDC, "Elemental Analysis of Blaschka Marine Invertebrate Glass Models," Presented June 11, 2019, *25th International Congress on Glass/GMOD Archaeometry III*, Boston MA.

biological model, the glass undergoes two distinct complete melting phases. The first phase is done in a glass melting facility where powders and granules of different molecular constitution are combined using heat to create a relatively large quantity of glass. The molten glass from this first phase is processed, formed, and cooled to room temperature into smaller quantities in preparation for transport to a different location and subsequent flamework manipulation in phase two. The second distinct melting phase is carried out when the artist heats the glass in the flame to form it at the bench. In contrast to the first tightly controlled batch melting phase, in the second phase the artist can heat, cool, and reheat a single region of glass many times with different heat intensities and for unknown lengths of time to reach their desired shape. This second phase is relevant because when glass is worked in the flame, its composition changes in response to the intensity of the heat as some of the more volatile compounds vaporize and/or decompose. The fastest change in the glass composition from flameworking is found in the loss of the alkali metal fluxes, including sodium and potassium. In the case of the Blaschka models, and just like any other flameworked glass object of obscure origin, it cannot be known how much total time in the flame or how much heat intensity the glass experienced during the phase two fabrication of the model. The most scientifically accurate method of recreating a flameworked glass model would be to start by creating a batch melt which matches as closely as possible the phase one "virgin glass." Reverse engineering the exact glass constituent weight percentage of the target phase one glass by using phase two sample data presents inherent inaccuracies, in part because it is impossible to know which parts of the glass elements experienced how much heat and subsequent constituent loss, among other variables. What can be said with certainty is that the glass analysis from any flameworked glass model is phase two glass, and therefore is to some degree different than the original batch melt from phase one. Thus, it should be well understood that embarking on recreating a glass batch melt based on data from glass samples that have been manipulated in the flame will inherently render a glass that is to some unknown degree different than the original batch melt that preceded the flame exposure of the glass during the model making. The distance between the two ends of the spectrum of phase one and phase two glass constituent weight percent could range from negligible to significant.

Variables that can affect glass sample accuracy from Blaschka models:

1. Homogeneity in the glass from initial batch melt.
2. Depletion of fluxes and other constituents to varying degrees in discrete regions as the artist reforms the glass in the flame.
3. Artist combination of glasses at the bench; two or more glasses averaged in a sample with the assumption by the researcher that it was one type.

Variables that can affect replica batch melt accuracy:

1. Purity of the precursors and minerals.
2. Inaccuracy and/or precision of the scales.
3. Contamination from the crucible and adulterating the melt.
4. Time spent lingering at or above melting temperature within the melt furnace.
5. Homogeneity of the molten glass when formed to room temperature.
6. Presence of molecular water bound to powders, preventing accurate measurement.

Variables that can affect melting process:

1. Distribution of heat within the melt furnace firebox zones.

2. Ventilation rate of the firebox for necessary gas exchange and glass formation.
3. Heat output of the elements.
4. Speed of ramp up/cool down.
5. Function of controller and thermocouple signal interpretation.

Variables that can affect accuracy of determining an annealing temperature range:
1. Uneven distribution of heat within annealing oven firebox zones.
2. Ability for controller to maintain a given temperature without fluctuation.
3. Function of thermocouple(s) and controller signal interpretation.

PROCEDURE

Purity of the precursors and minerals

The purity of the glass precursors in this study have not been independently analytically established but are considered "functionally pure" for the industries from which they were sourced. For this study, the intent was to get the purest form of the compounds and precursors for a reasonable cost; high-purity reagent grade compounds are always an option but increase the cost of research beyond feasibility for the needs of this study.

According to Bakowska et al., the Blaschka glass identified as "#1 Clear-Hollow" was found to be comprised of ten compounds: aluminum oxide Al_2O_3, arsenic trioxide As_2O_3, calcium oxide CaO, potassium oxide K_2O, manganese oxide MnO, sodium oxide NaO, lead oxide PbO, boron trioxide B_2O_3, silica SiO_2, and zinc oxide ZnO.

Constituents and their precursors were sourced from three industries:

1. Glass industry: silica SiO_2 was from a mine in Oklahoma and is supplied to the art glass batch industry. Alumina Al_2O_3 and boric acid $B_2O_3 \cdot 2H_20$ precursor also came from a supplier for the art glass batch industry.
2. Pharmaceutical industry: calcium carbonate $CaCO_3$ precursor is supplied in relatively high purity for human consumption.
3. Ceramics industry: potassium carbonate K_2CO_3 precursor, sodium carbonate Na_2CO_3 precursor, manganese carbonate $MnCO_3$ precursor, lead carbonate $PbCO_3$ precursor, and zinc oxide ZnO are all common minerals used in clay and glaze making for the ceramics industry. Two distributors in the ceramics industry were utilized to source these compounds.

For safety reasons, arsenic was omitted from both batching processes and also for the safety of anyone who might flamework with the glass. The percent composition was established at 0.004 percent by weight and therefore does not constitute a significant shift in constituent ratios. Furthermore, its function in the melt is that of a fining agent and decolorant, so the absence of such small quantities should not affect the physical properties of the glass such as melting temperature or properties of the glass in its solid form.[1]

MELTING

Constituents were measured and added to a mixing container as very fine powders. Silica was added as small granules, prepared in size specifically for the process of glass melting. The container was agitated in a randomized mixing method to homogenize the powder mixture.

[1] J. E. Shelby, "Introduction to Glass Science and Technology," *The Royal Society of Chemistry* (*Cambridge UK:* 2005): 34.

A high-alumina crucible with 300 mL volume was loaded at room temperature to approximately half full. The half full crucible was placed into the melt furnace at room temperature. The furnace was programmed with a few ramp/soak plateaus and troughs to ultimately reach and hold 1230ºC. At key temperatures and as the volume of the batch receded from melting, batch charges were made to top off the crucible. The entire program was less than 14 hours long.

Homogenization of the melt was done naturally by agitation from gas bubble outgassing, convection within the liquid glass, and molecular diffusiophoresis (Photo 2).

Photo 2. *Melt furnace operating at 1200ºC with crucible of molten glass at center*

FORMING TO ROOM TEMPERATURE

Once the glass had been properly processed in the melt furnace, it was removed by taking gathers on the end of a 9 mm diameter stainless steel rod. Working temperature range was found to be 1000°C – 1250°C, with the most effective gather temperature to be approximately 1230°C. When the gathered glass layers were large enough, the molten bulb was pulled into rods approximately 50 cm long and seven to ten millimeters in diameter. These rods were left to cool naturally to room temperature in open air (Photo 3).

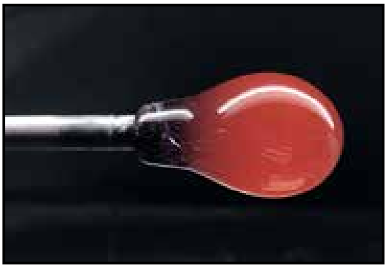

Photo 3. *Gathering glass from the melt furnace on stainless steel rod*

Photo 4. *Strain as seen through a polariscope on un-annealed rods of "Glass #1 Clear-Hollow" at room temperature. This strain can be interpreted by inconsistency in transmission of light through the rods' large dark regions at the core and end of the rods.*

ANNEALING TEMPERATURE RANGE

In the polariscope, a predictably severe strain could be observed in the rods after natural cooling in open air. The absence of this strain was used as a marker for achieving effective strain relief during annealing temperature trials. Tests were done using glass rods about 15 cm long and 8 mm diameter, bridged unsupported between two kiln bricks. The annealer was programmed to ramp up in 45 minutes and soak for five minutes. Trials began at 490°C and proceeded in five-degree increments to 515°C. Strain relief was observed at 490°C and minor slumping began to appear at 515°C (Photo 4).

COLOR VARIANCE

As stated before, the first melt excluded arsenic and at room temperature was a plum color as seen at left in the photograph of the rods on the first page of this presentation. It is well known that arsenic is introduced to a glass melt to function as a dual purpose color blocker and also a fining agent;[2] in the absence of arsenic in the first melt, the manganese imparted a strong plum color. It is the author's assessment that manganese was originally introduced to the batch to function as a decolorant of iron contamination from impure silica; presumably the silica being mined for glass melting 150 to 100 years ago was not as pure as the silica we have access to today and subsequently contained a higher amount of iron contamination. Manganese is known for its capacity to counteract the specific coloring properties of iron contamination in glass,[3] and I surmised from all this that arsenic was secondarily introduced to counteract any purple coloration from excess manganese. Suspecting that the silica used in this study was purer than the silica of yore, the second melt omitted both manganese and arsenic, and the resulting glass was absolutely clear. This supports the theory that the absence of iron contamination in the silica used for this study contributed to an excess of manganese as it was not "consumed" by any iron and also not able to be color blocked by arsenic.

CTE

Coefficient of thermal expansion testing was carried out with samples from the first melt and compared to two glasses of known CTE. Using the common technique at the bench of melting one of each type into a small sphere and pulling into a thin rod 1-2 mm in diameter and 300 mm long, the first melt was found to be close to 108 x 10^{-7} cm/cm/Deg C (Photo 5).

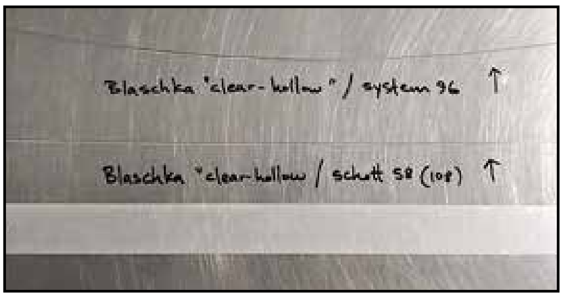

Photo 5. *CTE tests with first melt, using System 96 (CTE of 96 x 10^{-7}) and Schott S8 (CTE of 108 x 10^{-7}) for comparison. Note lack of curvature to the lower glass rod indicating close compatibility.*

ACKNOWLEDGEMENTS

Thanks to Tracy Drier of The University of Wisconsin-Madison and Laura Monahan of The University of Wisconsin-Madison for inviting me to participate in their research, and Erich Moraine of Wild Rose Glass for connecting us, his intellectual contributions, and acting as a very informed resource in discussing all things Blaschka.

Photo credits:

Photo 1 by Tracy Drier, UW Madison, Photos 2-5 by the author.

[2] W.A. Weyl, "Coloured Glasses," *Society of Glass Technology* (Sheffield, England: 1951): 118.

[3] Ibid 121.

Teaching Scientific Glassblowing to Non-Scientific Glassblowers

by

Sally Prasch*

ABSTRACT

Sharing the knowledge of scientific glassblowing helps people in many other fields. In this presentation, I go over a few methods of teaching scientific glassblowing, show examples of projects and ways of working glass safely in the labs and studios.

Photo 1. *Teaching a lathe class at Penland School of Crafts, photo credit Robin Dreyer*

I think all of us have had people asking us to teach them scientific glassblowing. They do not want to become scientific glassblowers but would like to learn more about the process.

Before I start, I would like to talk about a few of my early teachers who helped me so much. I started working with Lloyd Moore in 1970; he was the scientific glassblower at the University of Nebraska and did art and craft shows on the weekends. Lloyd Moore taught me both scientific and artistic glassblowing and taught me how to teach. I use his teaching methods to this day.

In addition, Sylvia Vigiletti and Audrey Handler helped me though my college years and beyond. It is hard being a woman in glass but with their guidance, I kept with it. I think it is important to have diversity among teachers and that includes women. Even now when I teach, women come up to me and let me know that I am their first female instructor and how much they appreciate having a female instructor.

I teach semester long scientific glassblowing classes at the university level and in shorter

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workshops around the world. I would like to share today some of my teaching methods to teach non-scientific glassblowers.

Photo 2. *All school photo at the Penland School of Crafts, photo credit Robin Dreyer*

When I prepare to teach, I start by asking four questions:

Where will I be teaching?

How long is the class?

Whom will I be teaching?

What do I think the students want to take from the class? (This may change after the first meeting with students.)

By asking these questions, I develop a schedule, a base of what I want to teach. I start by writing a syllabus with dates, demonstrations, readings, practice pieces, and for some that need a grade, papers and tests. I started teaching at age 15 and have yet to stick to my original syllabus. As students learn, questions arise and we may go down paths that are off the main syllabus. I am ok with this but always come back to my syllabus. For years, I have averaged 12 – 100 students a month except for COVID time. Then everything went online; so, I learned many other ways to teach. Technology is a wonderful thing and I try to keep up on it and bring it into the classroom.

I think we often forget that not everyone wants to become a scientific glassblower. I check in with my students and adapt the class to meet their individual needs. Many of my students are teachers in other fields.

I try to bring history, math, science, archeology and art into the class. You can easily connect scientific glassblowing to many different fields, providing rich discussions in the classroom. As a teacher, I feel we need to question things to open minds.

I find it very important to know your students. Teaching is not about the teacher, it is all about the student. Learn how they would like their name pronounced, what pronouns they prefer, and where they are from. Listen to what they want to take from the class and try to cover all the bases. Learn how to welcome people in their language. Scientific glassblowing can be challenging, so demonstrate some fun cultural things that can be made of glass. Examples: chopsticks, roosters, pomegranates and so on. Develop some side projects that cover straight and side seals, but that can also be engaging and have meaning to the student.

The students are paying to learn, so give them what they want along with what you feel they should learn. Remember, many students will not have glass as their career path, so make it fun.

One project I use for my MFA or Art History students is to pick an historic painting that has glass depicted. Ask the students to talk about the glass that is in the painting. How is it used? How was it made? Was the glass just made up for the painting? Then have the students try to make the piece.

Depending on where I will be teaching, the syllabus will change. Every glassblowing teaching lab is different. I ask myself what we can do as a class with the torches and glass provided. What tools will be available: hand tools, lathes, cold working equipment? How can I incorporate everything available into my class? How can I make it about scientific glassblowing?

At Pilchuck Glass School, I know what is available there and I can create a basic teaching schedule. Before the first day of class, the Pilchuck staff tour us through the cold, hot, mold, neon, flame, and print shops. On our first class meeting, I see how many students would like to experience the different areas of glass and arrange a way for them to work in each area. At this school there are many other glass classes going on at the same time. After talking with the other instructors, I partner each of my students with a student in another class. They are to make two pieces so they each can have one using techniques from both classes.

When I teach in other countries, I go with the flow, trying my best to learn the ways of the area. When I taught in Japan, they had a strict schedule. Timing was everything. You start on time and end on time. Your words are translated while you are demonstrating; sometimes you have to hold hot glass longer so the translation can be completed. It was hard for me to keep things to the minute. When I taught at the Niijima Glass School, I really liked that bath time was on the schedule. Before dinner, we would all go to the bathhouse and

Photo 3. *George Kennard and Sally Prasch teaching at Salem Community College, photo credit Kristin Deady*

relax a bit. The best part of teaching outside the country is trying all the different foods. It is not just about glass.

Scientific glassblowing can be incorporated into all aspects of glassmaking. We can do ring seals in the hot shop. Maybe take some different colors of neon tubing, straight seal them together, then with your blow hose keeping pressure, pour hot glass over the neon tubing. When teaching neon you can bring in all kinds of scientific glassblowing techniques, history and vacuum technology. Incorporating scientific glassblowing techniques into other areas of glass is endless.

I feel that having the students make an exact replica of what you demonstrated does have some merit. However, what really makes a class interesting for both the student and teacher is seeing how techniques can be applied in different ways. I may start with everyone using the same glass technique. Maybe I will demonstrate a ring seal, show different ways it can be made and used and why. I have everyone make a condenser. Next, I ask them to take the techniques they have learned and design something different.

By the end of any of my classes, I find students taking the scientific glass techniques in many different directions; I encourage this and love seeing what people create.

We now have many glass schools around the world and I would like to encourage everyone here to bring your scientific glassblowing skills to others. If you are thinking about applying to teach at schools, give them a bio that can be easily vetted. Give them your history of the schools where you have previously taught. Titles of classes, what the classes covered, date and images of your work. Be clear and timely when listing what materials you will need for class. Make it easy for the school and it will get around that you are not only a good teacher but play by their rules. All these schools talk with each other and they know who is who in the glass world, who can be relied on to be honest and a dependable instructor.

After over 50 years of teaching, I sometimes wonder what it is all about? Perhaps it is not what is being taught or what is being learned. It is about the space created between the student and teacher, the trust that we find in each other.

Thank you,
Sally

Photo 4. *Teaching bench work, Penland School of Crafts, photo credit Robin Dryer*

Photo 4. *Happy student, University of Vermont, photo credit Sally Prasch*

Using Time-Series Flow Measurements to Analyze Oxygen Usage

by

Dennis Kornbluh*

ABSTRACT

This paper explains the benefits of maintaining an historical record of minute-to-minute oxygen flow rates. It shows how time-series graphs reveal oxygen consumption patterns, and how these patterns may be correlated with specific activities and events. It explains how a summary of total oxygen usage by week or by month can help to reconcile gas company bills, or plan for the implementation of a new oxygen solution, such as transitioning from compressed cylinders to liquid oxygen (LOX) or an oxygen generator. A scenario is described that illustrates how the use of time-series measurements increases the accuracy of oxygen usage predictions.

INTRODUCTION

Oxygen is a significant cost for many applications, from aquaculture to torchwork and scientific glass shops to veterinary clinics and hospitals. Oxygen prices rose significantly during the pandemic,[1] and prices remain "sticky" even now in the spring of 2023.[2]

With an expensive commodity such as oxygen, the cost of waste adds up quickly. For example, a three L/min line leak will blow off approximately 213 K tanks[3] per year at a cost of $7-8K.[4]

There are ways to economize on oxygen, e.g. by using less (e.g. finding and preventing leaks, training users to economize), purchasing an oxygen generator, or switching from compressed cylinders to LOX dewars or bulk LOX. However, before you choose an alternative, it is important to have a good understanding of your current usage which is likely to change over time. This may happen for a variety of reasons such as seasonal business trends and special projects. The more you know about your usage patterns, the more accurately you can budget.

Gas company bills are a source of information that reveals the volume of oxygen that was purchased over a period of time. However, there are two issues with this source:

1. The bills will not shed much light on waste. For instance, it would be practically impossible to determine if you have a line leak by looking at monthly volume.

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[1] Reuters reported in May 2020 that the cost of medical oxygen had risen by as much as 50% in some countries due to increased demand and supply chain disruptions. *The Economic Times* reported in April 2021 that the cost of medical oxygen in India had increased by more than 3-4 times due to the surge in COVID-19 cases. *The Guardian* reported in April 2021 that the cost of medical oxygen in Nepal had increased by up to 800% due to the surge in COVID-19 cases. *The Straits Times* reported in April 2021 that the cost of medical oxygen in Malaysia had increased by as much as 40% due to the COVID-19 pandemic.

[2] The unit cost of delivered oxygen can be difficult to parse out of a complicated invoice. There are many factors, such as compressed vs. liquid, distance of delivery, tank rental vs. stationary platform. Anecdotally, users of oxygen in the aquaculture, glass, and veterinary industries are purchasing oxygen generators such as HVO systems specifically because delivered oxygen continues to go up in price.

[3] A K-tank (aka H-tank) contains about 7400 liters of oxygen at a pressure of about 2200 psig. This calculation assumes a cost of $45 per K-tank.

[4] A K-tank is a compressed oxygen cylinder that typically contains 261 CF/7400L @ 2200 psi. A K-tank is equivalent to an H-tank in volume and pressure.

2. The gas company might not be properly recording the number of tanks you use, perhaps because of administrative errors or faulty measurement devices. If you are not keeping an independent record of volume, you will not know whether your gas company bills are accurate.

To get a more precise view of usage, it is necessary to measure your oxygen flow rate at regular, sub-minute intervals, over a span of weeks or months. To reconcile oxygen bills, you must also have independent knowledge of the total volume of oxygen consumed over the billing period.

FLOW MEASUREMENT DEVICES

Velocity flow meters and mass flow sensors are commonly used to measure gas flow rates. A velocity flow meter provides a point-in-time reading, i.e., the current flow rate. Some flow sensors are capable of storing a limited amount of data in the device for periodic download.

A recent alternative is a mass flow sensor that is able to store flow measurements in the cloud for instantaneous analysis and automated notification when flow rates exceed expected norms.

1. Velocity Flow Meter

A velocity flow meter (aka "rotameter") measures the flow rate of gas by changing the height of a "float" (silver ball) in a graduated cylinder to indicate the approximate flow rate, typically in Standard Cubic Feet per Hour (SCFH) or Standard Liters per Minute (SLPM). You can also use a flow meter to set the flow to a desired rate (Figure 1).

Figure 1

For the purpose of recording flow measurements over time, a flow meter has several drawbacks:

- If you want to know what the flow rate was in the past, you need to make regular observations and record them manually. If you want sub-minute measurements, that is practically impossible to accomplish without automation.
- Flow meter accuracy ranges from ±5% to ±10% whereas mass flow sensor accuracy is typically ±0.5% to ±2%.
- If the regulator pressure does not match the pressure for which the flow meter was designed, its measurements will be even less accurate.

On a velocity flow meter, the float may be viewed from different angles which makes it difficult to take consistent readings. However, as a rough gauge of the flow rate, or to set the flow to an approximate rate limit, a velocity flow meter can be a useful tool.

2. Mass Flow Sensor

A mass flow sensor (MFS) is an electronic device that provides accurate measurements of mass and volumetric gas flow rates. These devices use a hot wire mass airflow sensor to measure the volume of gas entering the device. Its operating principle is similar to a hot wire anemometer which determines air velocity. For details, see the box below.

Measurements are collected and converted to digital form, then stored, either in the device's local memory, or by communicating over a network to another storage device. Some devices support a USB interface, enabling data to be downloaded to a memory stick. Others use RS-232 or RS-485 serial interfaces and must be connected to a receiving device that is designed to collect such data. For specific details about the options available, consult the device documentation for the flow device you are considering.

Mass flow sensor products that store data on a USB memory stick or that transmit data over serial lines require technical skills to download, process, and format the collected data. This can be challenging for day-to-day use.

How a Mass Flow Sensor Works

A wire, similar to a toaster wire, is suspended within the airflow. By applying a constant voltage across the wire, it is heated. As the wire's temperature increases, so does its electrical resistance, thereby altering the electrical current flowing through the circuit, in accordance with Ohm's law.

As air passes over the wire, it cools the wire, subsequently reducing its resistance. As a result, more current flows through the circuit, since the supply voltage remains constant. The wire's temperature continues to rise until the resistance reaches equilibrium. The variation in current, whether an increase or decrease, corresponds to the mass of air passing the wire. An integrated electronic circuit converts this measurement into a voltage, which is translated to a flow rate.[5]

Keep in mind that mass flow sensors are designed with a set of capabilities, such as the maximum flow rate and maximum pressure. For example, if your line pressure is 50 psig and your flow rate can go as high as 100 L/min, ensure that the MFS device you choose can support those characteristics.

CLOUD-CONNECTED MASS FLOW SENSOR

The HVO® Oxygen Tracker is a mass flow sensor that provides a convenient alternative to labor-intensive and technically challenging flow devices that require data management. By storing flow measurements in the cloud every 10 seconds, the Oxygen Tracker prevents users from having to manually collect, store, and process data for viewing. Users with an active cloud subscription can access near real-time flow data displayed in a time-series graph on any web browser or mobile device.

The Oxygen Tracker is able to measure flow rates as small as 0.1 L/min and as large as 300 L/min with line pressures up to 100 psig. It can operate in environments where the temperature is 0 to 50°C (32 to 122°F). At 21.1°C (70°F) and 14.7 psia (1 atm), the flow accuracy of the mass flow sensor is ±2% of the reading or 0.05 SLPM, whichever is greater.[6]

ANALYSIS OF GRAPH PATTERNS

Visualizing time-series flow measurements is key to understanding how oxygen is being used in a given setting. Using an Oxygen Tracker, flow measurements were taken in a glass studio[7] over a 12 hour period. The resulting graph is shown on the next page (Figure 2):

[5] Wikipedia: https://en.wikipedia.org/wiki/Mass_flow_sensor. Accessed May 15, 2023.

[6] You will see references to psia (atmospheric pressure) and psig (gauge pressure). Any gas container that is isolated from the atmosphere, whether in a gas line or a sealed tank, will be measured in psig.

[7] Stoked Glass of Bridgeport, CT is the glass studio that provided some of the information for this paper.

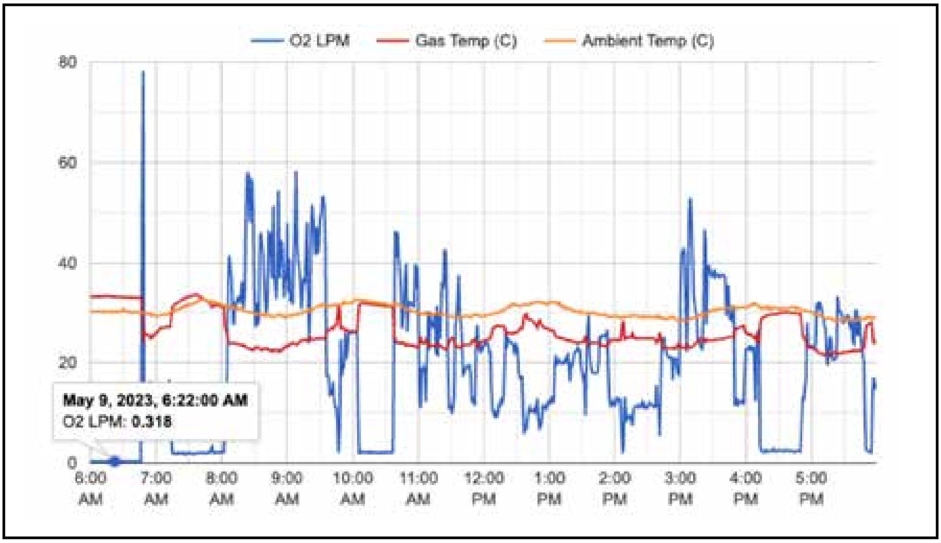

Figure 2

From the graph above, we can make the following observations:

- There was a flow rate of 0.318 L/min at 6:22AM, which is prior to the start of the work day. This is most likely due to a small leak somewhere in the studio.
- Just before 7AM, a ball valve was opened that permits the lines in the studio to be filled with oxygen. This caused a spike to almost 80 L/min.
- There are variations in the flow rate throughout the work day, with a maximum flow rate of approximately 58 L/min. The average flow rate appears to be roughly 30 L/min.
- During the sample period, an oxygen generating system capable of producing 60 L/min would be able to keep pace with demand during peak intervals, and a 30-40 L/min system might actually be sufficient, given that stored oxygen provides the buffer needed during periods of high usage.

Longer sample periods may make it possible to more accurately estimate oxygen usage.

While the glass studio flow graph illustrates a chaotic usage pattern, some applications have more static flow rates. The graph shown in Figure 3 reflects oxygen consumption in an aquaculture operation. During a 6 hour sample period, there is a constant flow of oxygen to a series of fish tanks, so the L/min graph line is nearly flat.

In an aquaculture setting, oxygen gas is converted to dissolved oxygen (DO) so that fish can breathe. According to Henry's Law[8] the temperature of the water has an inverse relationship to the solubility of oxygen. Thus, the higher the water temperature, the less dissolved oxygen the water can hold. That is why large fish, which require more oxygen than smaller fish, are struggling to survive in natural settings as global temperatures rise (Figure 3, *next page*).

Based on the data in Figure 3, one might be tempted to conclude that a flow rate of 10-12 L/min would be sufficient for this application. In reality, the flow rate must be adjusted

[8] Wikipedia: https://en.wikipedia.org/wiki/Henry%27s law. Accessed May 15, 2023.

according to a variety of factors, such as water temperature, fish breed, stage of life (fry, fingerling, adult), and even feeding schedules since the metabolic rate of fish increases significantly during feeding.

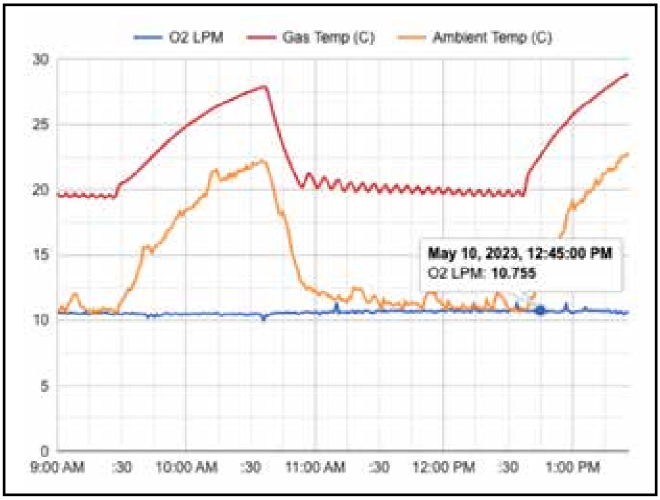

Figure 3

Assumptions about oxygen usage based on a small sample could lead to a significant budget miscalculation. Indeed, the aquaculture operation from which this graph was obtained has since adjusted their constant flow rate to 15 L/min due to rising spring temperatures. Operations managers must periodically measure the DO that is present in their tanks and make adjustments to the oxygen flow rate in order to achieve the desired levels. With a means to measure the actual volume of oxygen used over time, one is able to create an accurate forecast of the required oxygen volume.

For this reason, the Oxygen Tracker maintains a count of the total volume of oxygen used since the counter was last reset.[9] With an up-to-date cloud subscription, up to a year[10] of flow measurements are maintained in cloud storage. The Seeing Eye™ cloud service sends a weekly usage email report, a sample of which is shown in Figure 4 below:

Oxygen Tracker Weekly Usage Report (2023)

<CUSTOMER NAME> Oxygen Tracker with id: 10000000abcdef01

Total for week 15: 18,847.092 Liters / 2.62 K or H tanks.
Total for week 16: 69,197 Liters / 9.61 K or H tanks.
Total for week 17: 103,310 Liters / 14.35 K or H tanks.
Total for week 18 (current): 80,406 Liters / 11.17 K or H tanks.

Grand total: 271,760.092 Liters / 37.7 K or H tanks

Figure 4. *Weekly oxygen volume report*

There are several benefits to having detailed data for flow and cumulative volume. First, knowing your precise oxygen consumption over time takes the guesswork out of budgeting. It also makes it possible to determine the economics of alternative oxygen sources. For

[9] The Oxygen Tracker's touch screen user interface enables authorized users to reset the counter to zero at any time.
[10] Longer storage durations can be arranged, if required.

example, above a certain volume,[11] compressed oxygen cylinders become more expensive per unit of delivered oxygen than LOX dewars. At an even higher threshold, it may be more cost-effective to invest in the installation of a permanent LOX tank. In many cases, an oxygen generator might be more economical. Knowing your oxygen requirements in detail makes it possible to confidently calculate the potential savings from using alternative oxygen sources.

SCENARIO: A GLASS STUDIO

In this section, we will analyze the oxygen used at a Connecticut-based glass studio.[7] We will calculate the annual cost of oxygen based on monthly gas bills. For comparison, we will use measurements collected from a cloud-enabled mass flow sensor to compare predictions about oxygen volume to see how these predictions aid the studio in budgeting.

NOTE: It is also possible to estimate oxygen usage based on the characteristics of individual torches found in the studio. However, in a large studio, this is rather more complicated, due to the number and types of torches commonly used. Actual measurements are preferable to calculations that rely on assumptions.

1. What the gas bills reveal

In 2022, Stoked Glass was purchasing 230L liquid Dewars at the rate of approximately one per week at a cost $320 per tank. Thus, they were paying about $320 x 52 = $16,640 per year for oxygen. One of the challenges they experienced was ensuring that there was enough oxygen. Since their oxygen consumption was inconsistent, there were times when they would run out unexpectedly. For unscheduled deliveries, it was necessary to wait three to five days before oxygen would be delivered. In these circumstances, the shop had to shut down, resulting in significant losses in production and revenue.

In mid-2022, the local oxygen supplier was acquired by AirGas, and prices immediately went up. This led to the glass studio's decision to purchase an oxygen generator.

Figure 5

The gas bills reveal how much oxygen is being purchased by week, month, and year, and the cost in those time frames. However, they cannot be used to determine how much oxygen is wasted due to off-gassing, line leaks, or inefficient usage. Nor can they use them to correlate the approximate cost of oxygen for individual projects. More granular usage information is needed to gain these types of insights which are an aid to economize.

2. What the Oxygen Tracker reveals

At the end of December 2022, an Oxygen Tracker was installed at Stoked Glass. After a few days, they were able to look at graphs that show a profile of the specific oxygen flow rates they experience throughout the day. The graph on the next page shows a 96 hour period, which provides some insight into daily usage patterns:

[11]Determining when an alternative oxygen source is more cost-effective than bottled or bulk oxygen depends on a variety of factors such as the regional cost of oxygen refills, whether tanks are owned or rented, delivery fees (which are based on the distance from the gas supplier), whether deliveries are scheduled or ad-hoc, whether weekend or holiday delivery is needed, and HazMat fees.

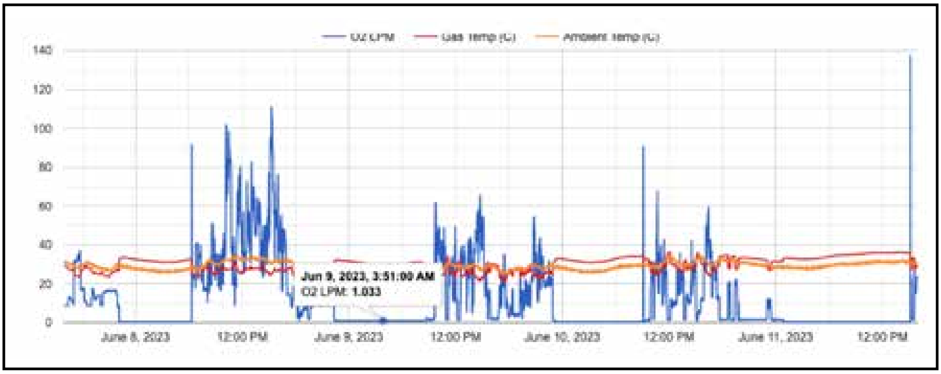

Figure 6. *A time-series graph showing four days of oxygen flow rates*

From the graph above, we begin to understand what a typical day[12] looks like in terms of expected flow rates. Here are a few insights we have gained:

- More oxygen was consumed on June 8 than in the next three days.
- Work started at 9am EDT on June 8, 11am EDT on June 9, and 1pm EDT on June 10.
- At the end of the day on June 8, someone forgot to turn off the ball valve that releases oxygen to the studio gas lines. We know this because 1) there was no spike in the flow rate the morning of June 9 indicating the opening of the ball valve, and 2) there was a leak of just over a liter per minute for about 12 hours which is greater than the usual leak of about 0.3 LPM.
- The maximum flow rate reached 110 L/min, but flow rates from 40-80 L/min were more typical.
- The average flow rate over this brief period was approximately 40 L/min.
- Coupled with the knowledge of who was in the shop on a given day and time, one might identify prodigious users of oxygen – not to point fingers, but perhaps as an opportunity to train more efficient techniques.

That is quite a few valuable insights from a single graph. Visualization of flow data is an excellent way to understand the utilization of this valuable resource. Having a year's worth of data could enable managers to budget more effectively, as well as to be able to correlate projects with oxygen cost to better account for the shop's own costs.

CONCLUSIONS

- Analog flow measurement devices provide point-in-time readings, which are of limited usefulness for making accurate forecasts.
- Some digital flow measurement devices are able to save historical readings locally or transmit them to a database. However, data processing is needed to produce graphs and other kinds of reports, which is challenging for small organizations.
- Having easy access to granular oxygen flow rate data can facilitate more effective and more economical management of oxygen resources.

[12]Note that the graph in Figure 6 shows times in PDT whereas the studio is located in the Eastern time zone.

2023 Technical Posters

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Ampule Transfer Device for Oxygen-Sensitive Materials

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One-Page Poster

Tracy Drier and Lauren Aria

The Unfortunate Sharpie

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2023 Technical Demonstrations

Patrick DeFlorio – *Yankee Glassblower, Inc.*
5C Collets for Glassblowing

Hideaki Hashimoto & Riku Hashimoto – *Tokyo Seisakusho Manufacturing, Inc.*
Japanese Style Jacketed 500 ml Flask

James Hodgson – *Kansas State University*
One Fabrication Technique for a Larger Scale Blood Feeder

Kyle Meyer – *The Procter and Gamble Co.*
Salon Cup Scrub

Erich Moraine – *Wild Rose Glass*
Build a Protractor on your Lathe Spindle for Accurate Rotation Angles While Working

Victor Nunn – *Nunn Better Glass*
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