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Asking the Right Questions Lets You Make the Right Vacuum System

by
Gary Coyne*

ABSTRACT

A vacuum system can be a simple collection of stopcocks attached to a single tube, a bench top unit designed for a single function, or a large floor unit that can be adapted to a wide variety of uses and functions. Because of the potential variability of a glass vacuum system, it is critical for the glassblower to know exactly what the researcher expects and plans to do with the vacuum system that he wants to have made. Because of the wide potential variations for a vacuum line, it behooves the glassblower to ask a series of questions to help narrow down the design of the vacuum system. This paper is a collection of those questions that will help the glassblower get started. In addition, there are some design and construction tips that will help avoid some inherent problems often associated with vacuum systems.

PART 1: THE QUESTIONS

It is very common to have a situation where someone comes into a glass shop and hands the glassblower a drawing for a piece of apparatus that includes a standard taper joint but no identification of what size joint (and probably no indication as to whether it is an inner or outer joint). When the customer is asked for added information, the response is often: "Well, the usual size." This gets quite a bit messier when the customer asks for a vacuum line and we ask "what kind" and the response is "Well, the usual kind." In over 40 years as a glassblower, I have no idea what a usual kind of vacuum line is.

A vacuum line can be something as simple as a bunch of stopcocks attached to a single tube (Image 1).

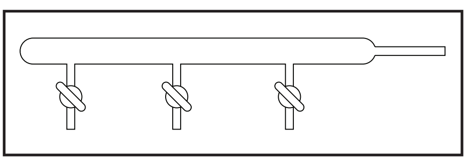

Image 1: *The simplest manifold*

It could also be a desktop system designed for a single purpose (Image 2).

Or it could be a complex self-standing line designed to deal with a variety of intended chemistry-in-progress and unknown chemistry for the future (Image 3).

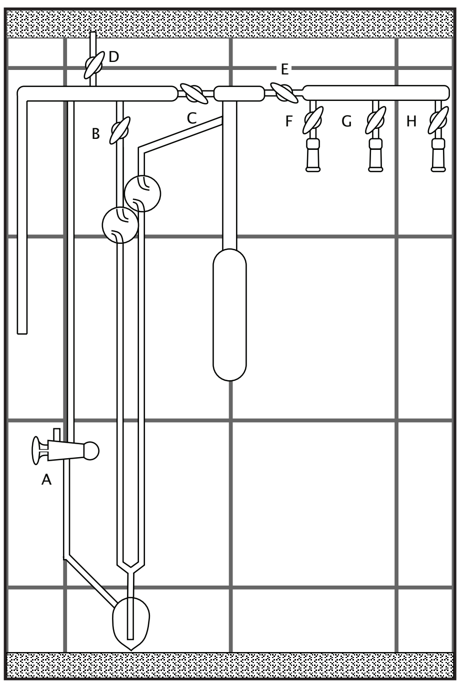

Image 2: *A simple desktop vacuum line*

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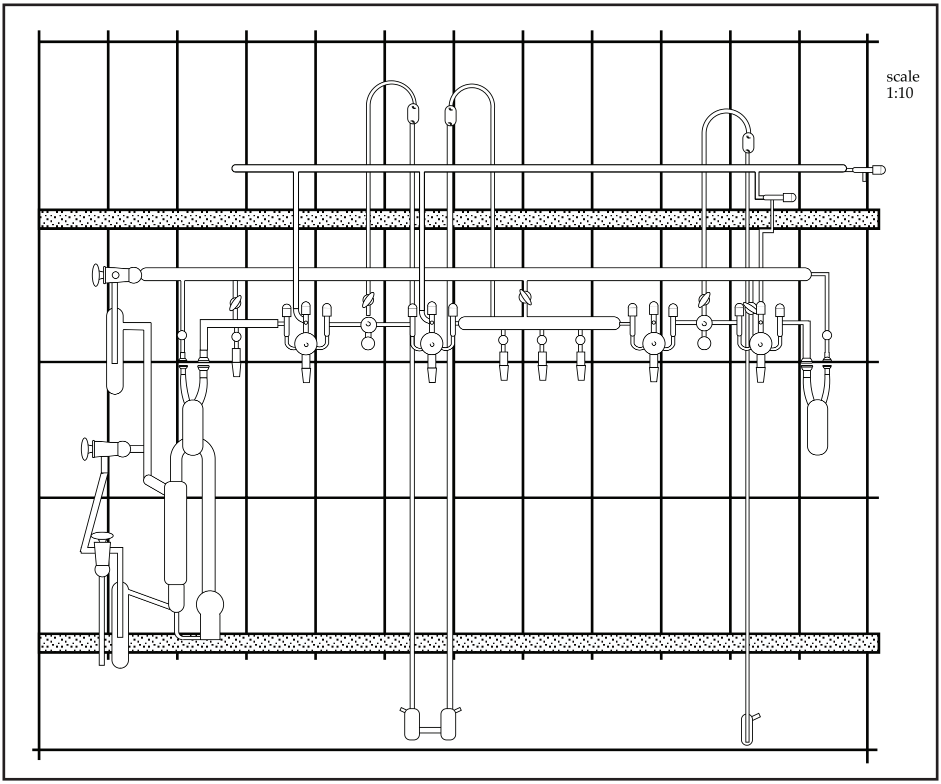

Image 3: *A complex free-standing vacuum line*

Because of that potential variation, the glassblower is advised to ask the customer a series of questions to help narrow down what they want and expect to do with this vacuum line.

In a best case scenario, the first question should always be "Is there an existing vacuum line you have seen around here that you want to duplicate." If the answer is "Yes," the glassblower should then ask if there is "anything you would like different about that line or could you use that line as is?" The key here is for the glassblower to have the customer do some mind experiments to make sure that this vacuum line has what is necessary for them to do their chemistry. The time for any alterations in this existing vacuum line for the new line should be determined before construction begins.

The one probable vacuum line that the customer is likely to ask for "just like that one" is the Schlenk line as Schlenk lines tend to be fairly consistent in design. Variations tend to be limited in the number of stations on the line and/or the type of connector to their Schlenk flasks. The value of the Schlenk line is that it allows the researcher to do chemistry requiring an ultra-high vacuum level of oxygen content but at atmospheric pressures. That is, a lot of chemistry requires work to be done in an oxygen-free environment (Image 4).

Achieving that low level of oxygen can be done in several ways. For many years, the most common approach was to simply evacuate the system to an ultra-high vacuum state. The problem with this is that this requires a lot of extra equipment (which increases the cost of the line) and a significantly more complicated vacuum line.

Image 4: *The Schlenk line*

Alternatively, the minimum Schlenk line requires only a good quality mechanical pump and a vapor trap. Any extra components (e.g., gauges, extra pumps, etc.) are typically not needed. Any variations on a standard vacuum line or Schlenk line can be covered in a series of seven questions that should be asked before any work is started. The exact order of these questions is mostly irrelevant but all seven should be asked.

So, here are the seven questions:

Question 1: Will the vacuum line be installed in a fume hood or will it be free-standing?

The purpose of this is that anything that goes into a fume hood will be constrained by the internal dimensions of the fume hood. This also tells the glassblower that any assembly

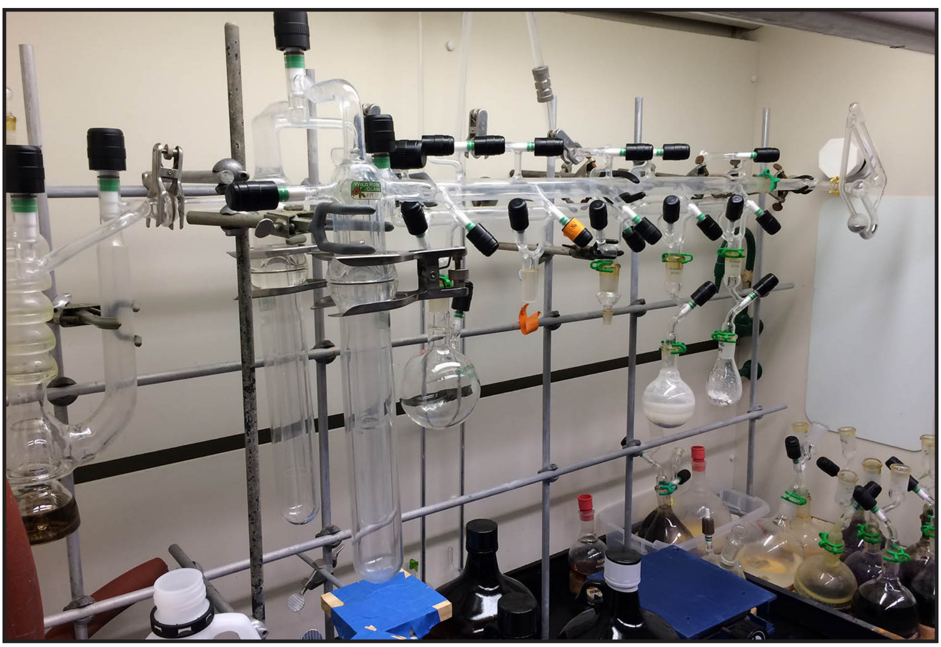

Image 5: *Vacuum line in fume hood*

of the vacuum line will be done within the confines of the fume hood; that means limited physical access. In addition, any design functionality to assist the researcher's access will be strongly appreciated. For example, placing the traps in an easily accessible location is better than placing them in the back. Also consider that not all users will be tall or short but both may require access (Image 5).

If the vacuum line is a tabletop or floor-standing unit, many of the access and size limitations are no longer an issue. In addition, this means that any repair and/or alterations are going to be much easier for the glassblower. If the line will be on a table, then the one-sided access is still a limitation. Free floor-standing provides the most access (Image 6).

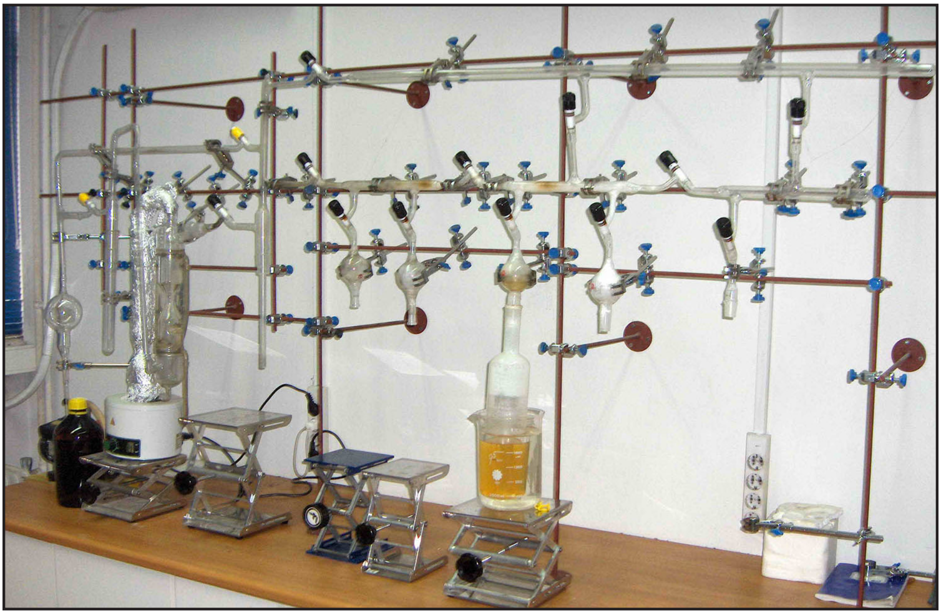

Image 6: *A free-standing vacuum line*

Question 2a: Do you need a low, high, or ultra-high vacuum system?

First some quick definitions:

	torr	Pump type
Low	< 10	Peristaltic, Mechanical
High	≈ 10^{-3}	Mechanical (+ trapping)
Ultra-high	≈ 10^{-6}	Cryo, Turbo, Diff

If their needs are low vacuum, chances are they are pumping on condensers to decrease the boiling point and/or assisting the collection of vapors in a trap. As such, a second question to add to this one should be:

Question 2b: Will this be used as a dynamic or a static vacuum system?

A dynamic vacuum system means that the user is always pumping because the stopcock and/or valves are typically open in use. A static vacuum system means that the user plans on closing the stopcocks or valves and expects the vacuum to remain. This lets the glassblower know what kind of removable joints might be needed as well as what kind of stopcocks might be best for the system.

Question 2c: Will the process and/or use be mostly wet or dry?

This lets the glassblower know if he or she needs to account for lots of vapors, or little or no vapors. In addition, it provides information on what kind of traps might be best and how big the traps might be.

Question 2d: If wet, what are the solvents being collected (water, hydrocarbons, ?)?

If water is all that is going to be collected, simple rubber (Buna-N) O-rings are sufficient but if the system will be processing halogenated hydrocarbons, halogen compounds, etc., the system needs to use Viton O-rings. If the system will be collecting aldehydes, ketones, ammonia, acetates, etc., then the more expensive Kalrez® O-rings might be required.

Question 3a: What kind of pumping system do they want or plan to use?

If it is a low vacuum system, they might be using a peristaltic pump. These are slow and do not need much maintenance. Alternatively they may want a low performance mechanical pump that will be helping to remove vapors from a rotary evaporator. Again, this means things are simple.

Question 3b: What kind of pumping system do they want or plan to use?

If it is a high vacuum system, then all they need is a good mechanical pump and the vacuum system will need some traps. However, it is good to know if they plan on using a dry or wet mechanical pump. If they are using an oil pump but their vacuum system is not generating any significant amount of vapor, they may need liquid nitrogen traps to prevent back streaming of mechanical pump oils. If a dry pump is used and the system is not used to collect liquids from the system, then there is less need of a full trapping system.

Image 7: *A cryo pump*

Question 3c: What kind of pumping system do they want or plan to use?

If they want an ultra-high vacuum system, then they need a secondary pumping system. This can either be a cryo pump (Image 7), a turbo pump (Image 8) or a diffusion pump. Admittedly, the most likely secondary pumping system attached to a glass vacuum system is the diffusion pump.

Note: if there is a secondary pump system, it is strongly recommended that a cold trap of some kind be placed in between the mechanical pump and the secondary pump to prevent the mechanical pump oils from

Image 8: *A turbo pump*

back streaming into the secondary pump. If the user has an old mercury pump, this is absolutely essential.

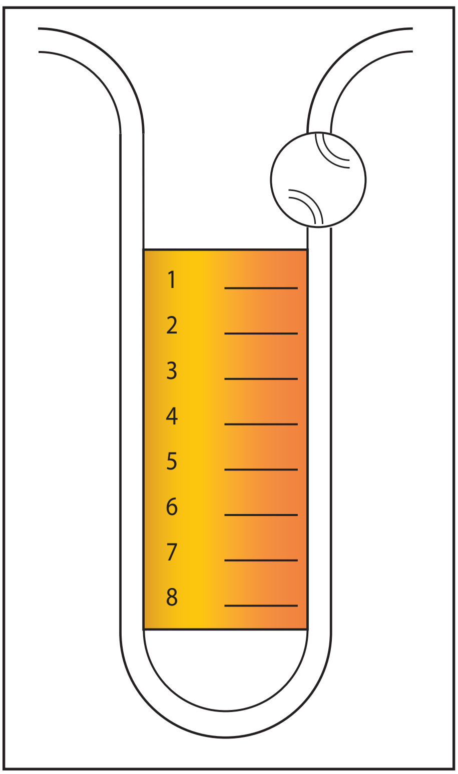

Image 10: *The manometer gauge*

Image 9: *A diffusion pump*

Question 4a: What kind of low vacuum gauge do they want?

Admittedly, there is not all that much need for a vacuum gauge if they want a low vacuum system. Nonetheless, a simple manometer will provide some level of measurement. If the facility allows mercury, such a manometer can be small enough to put in a fume hood. Oil manometers have to be taller and are much slower due to oil adhesion on the glass. It is always a good idea to put a trap on a manometer between the liquid and your system (Image 10).

Question 4b: What kind of high vacuum gauge do they want?

However, once they get into high vacuum, some type of gauge is strongly recommended. This is for knowing what their current vacuum is, for quantifying, and it is a useful tool for tracking down leaks in the system. In addition, by observing the day-to-day vacuum capabilities of the system, the gauges can help follow maintenance and the "health" of the system.

The typical high vacuum gauges are the thermocouple gauge (Image 11) and the Pirani gauge (Image 12).

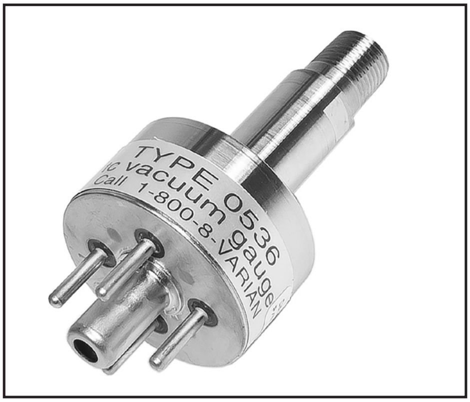

Image 11: *The thermocouple gauge*

Image 12: *The Pirani gauge*

The selection of which to use is typically done by the user and the glassblower just needs to make it happen.

Question 4c: What kind of ultra-high vacuum gauge do they want?

Because of the dynamics and physics of ultra-high vacuum, there is a need to know if one is at 10^{-4}, 10^{-5}, or 10^{-6} torr vacuum. The only way to know this is by using either of the more common ultra-high vacuum gauges: the hot cathode ion gauge (Image 13) or the cold cathode ion gauge (Image 14).

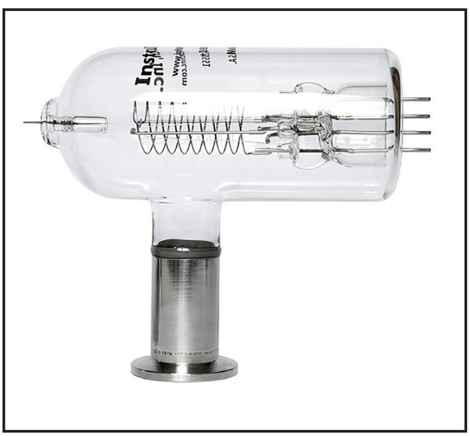

Image 13: *The hot cathode gauge*

Image 14: *The cold cathode gauge*

Like the thermocouple or Pirani gauges, much of the desire of one over the other is personal and typically based on what the researcher is accustomed to using. The glassblower simply needs to attach what the researcher wants.

Question 5: What kind of stopcocks/valves does the researcher want/need?

There are basically four different options, the Teflon®, glass, and high-vacuum glass stopcocks, and rotary valve (Image 15).

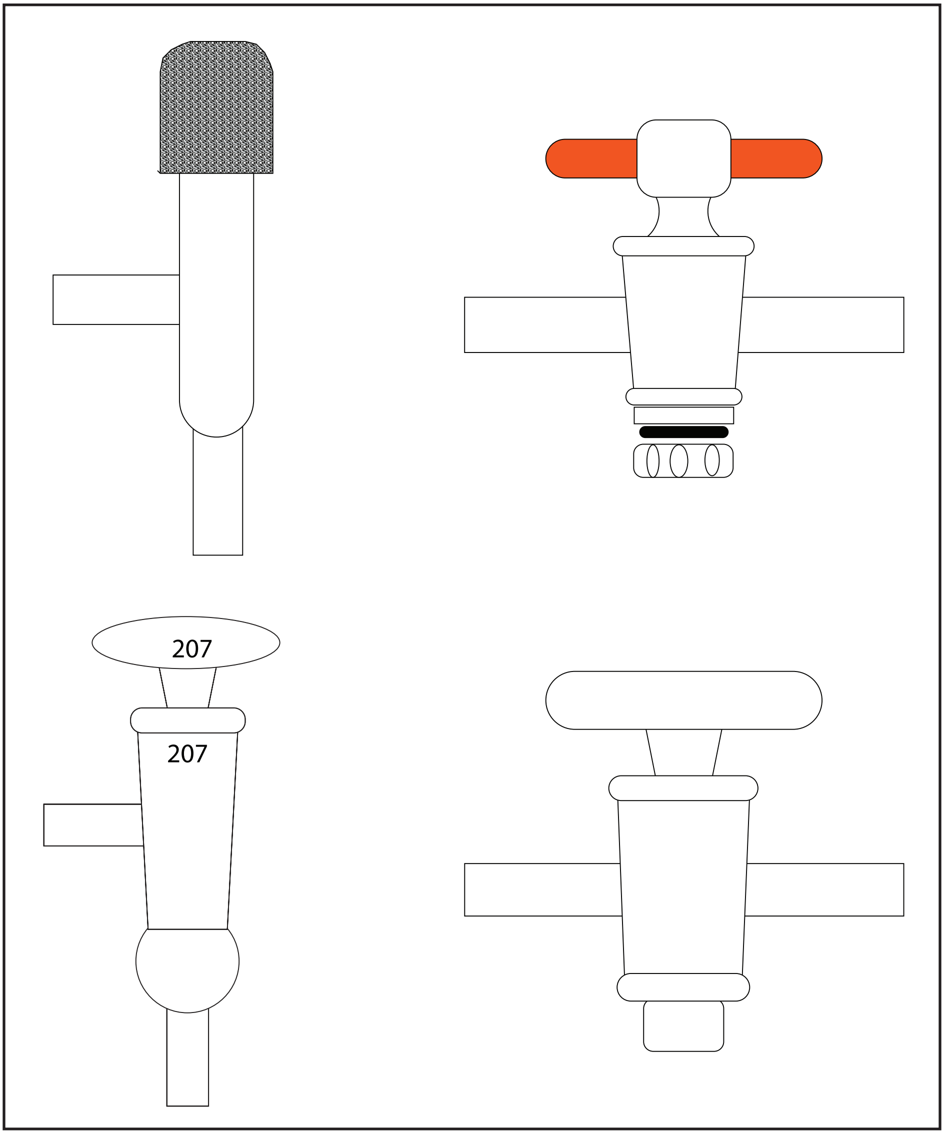

Image 15: *The four different types of stopcocks/valves*

The Teflon® stopcock can be used for a low vacuum system, especially if the system will only be used dynamically. The Teflon® stopcocks can be used on Schlenk apparatus components such as Schlenk flasks if, and only if, the materials being studied are not terribly sensitive to oxygen and the Schlenk flask will not be placed in a freezer. Since Teflon® contracts considerably more than glass, leakage is almost guaranteed.

The glass stopcock is suitable for all Schlenk line component pieces as long as the line is not also being used for ultra-high vacuum chemistry. Standard glass stopcocks by themselves should not be used for ultra-high vacuum use.

The ultra-high vacuum stopcocks can be used for any kind of vacuum system, even if the system is only a high vacuum system. Ultra-high vacuum stopcocks should be used any time there is a need to maintain a static vacuum. Standard glass stopcocks cannot be relied upon to maintain a static vacuum. Ultra-high vacuum stopcocks always have a unique number placed on the barrel and plug to match the two together as the final grind of these stopcocks were done as a matched set. If the wrong plug goes in the wrong barrel, the stopcock's sealing may fail and thus prevent the user from getting the vacuum their system should be able to achieve. It is always a good idea to review this bit of information with the researcher and their assistants at any opportunity.

The rotary valve can be used on any kind of vacuum system. Besides their ability to be used on any kind of system as well as dynamic or static systems, they require no grease. The biggest limitation of these valves are users who close the valve, then tighten the valve a bit more "just to make sure." Repeated extra tightening will typically flatten the closing O-ring causing failure in the valve. In addition, if the rotary valve has very thin screw threads, extra tightening can cause the threads to be stripped. Like the numbers on high-vacuum glass stopcocks, these issues should be reviewed with the customer.

Question 6: How will samples be attached to the system?

This is an easy question to overlook but there are a variety of ways this can be done and it is easy to combine them (mix and match) to provide alternatives on the same system. Simply, one can use any of the three standard glass connectors: the standard taper joint, the O-ring joint, the ball and socket joint (strongly recommend using the O-ring version of this joint), or a simple hose connection (Image 16).

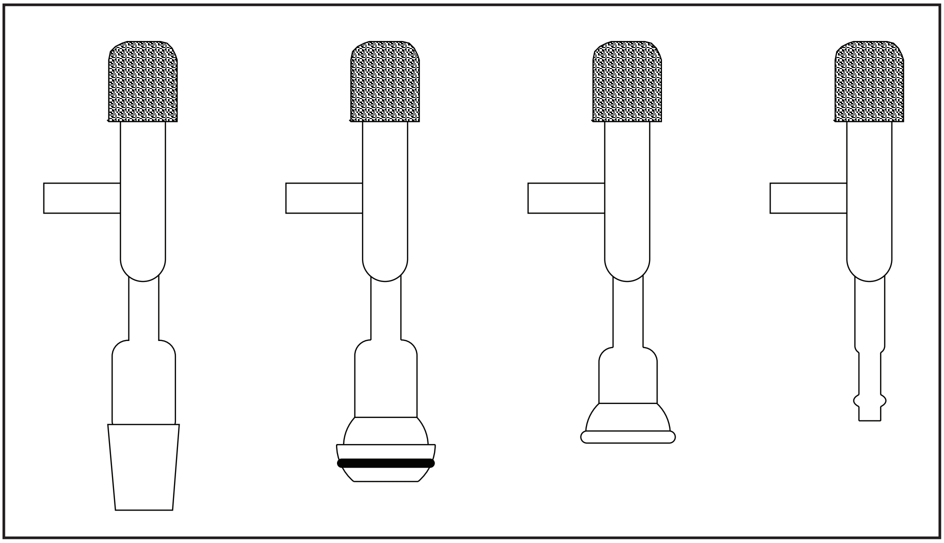

Image 16: *Various ways to attach items to the vacuum line*

Question #7: How does the researcher plan on cleaning the system?

As vacuum systems are used, they become dirty. When there is limited air in a system, the ability for dirt and contamination to travel to far reaches of the system is pretty amazing. If one looks back at the first image in this paper, that vacuum line is very difficult to clean because one can only do so by bringing liquids into the system, shake them around and shake them out. On the other hand, a closed end is not likely to have a leak.

So, the question is: should the glassblower provide some sealable opening to allow the user to shove a bottlebrush or the like down into the line for cleaning, and if so, what is the best type?

There are four options here: one, as stated, is to leave it as a closed end. This cannot leak but is very hard to effectively clean. Alternatively, use a standard taper joint; while this will provide the best seal possible, the problem and the reality is that this joint will be removed very rarely. If the researcher used an organic grease, that grease will become old and hard, and a hot-air heat gun will likely be needed to separate the two. If the researcher used silicon grease, the joint will very likely start to leak in three to six months after some or all of the soluble component in silicon grease has evaporated. In addition, the more the soluble component has left the joint, the more difficult it will be to remove the standard taper joint member with a heat gun or any other mechanism. There is no resolution for this and the joint is likely going to require being cut off and replaced.

O-ring joints are an excellent approach, but if they also provide the access for the trap system, it is very difficult to align the trap perfectly so that the O-ring properly seals. It only requires a very minor tweak to create a leak in an O-ring joint.

A standard ball and socket joint would be good but they are not sufficiently leak-tight for a static vacuum system or an ultra-high vacuum system. On the other hand, O-ring ball and socket joints are very well suited for this type of use. Be sure to get the polished socket joints to mate with the ball joint, and it can be a tad helpful if an extremely small amount of organic grease is applied to the O-ring prior to closing. Do not use silicon grease for this purpose (Image 17).

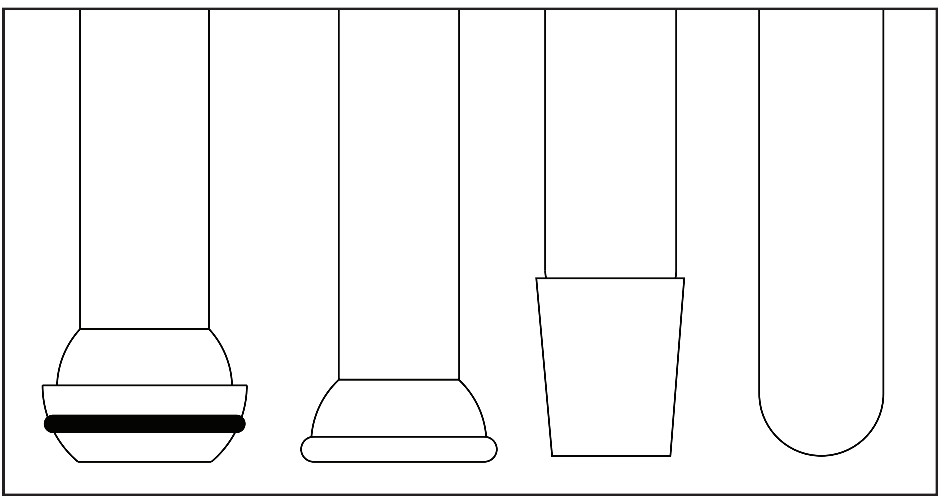

Image 17: *Access to vacuum line via a removable joint*

PART 2: CONSTRUCTION TIPS

The following are some construction tips that can help make the life of the glassblower and the researcher a bit nicer and result in fewer issues.

Example 1: Using the vertical bars for attaching finger clamps

When attaching a vacuum system (or its component pieces), always install the clamps and finger clamps on the vertical bars for supporting the line and any additional pieces (e.g., bubblers, etc.) Image 18.

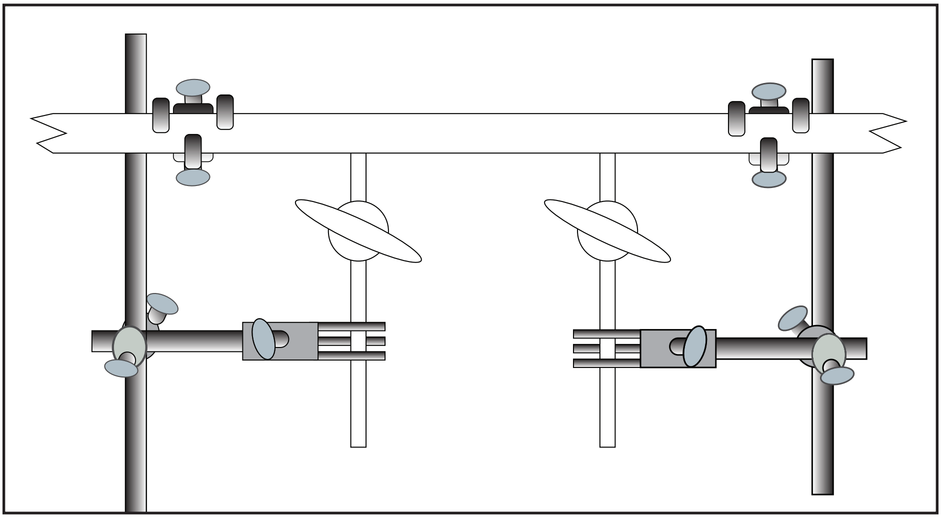

Image 18: *Use the vertical bars to attach the vacuum items to the rack*

The reason for this is if one uses the horizontal bars, it does not take much of an effort for the thumbscrew of the clamp to drift. This will cause the bar assembly to simply rotate out of horizontal which in turn will cause anything that the clamp is supporting to come down crashing into whatever is below (Image 19).

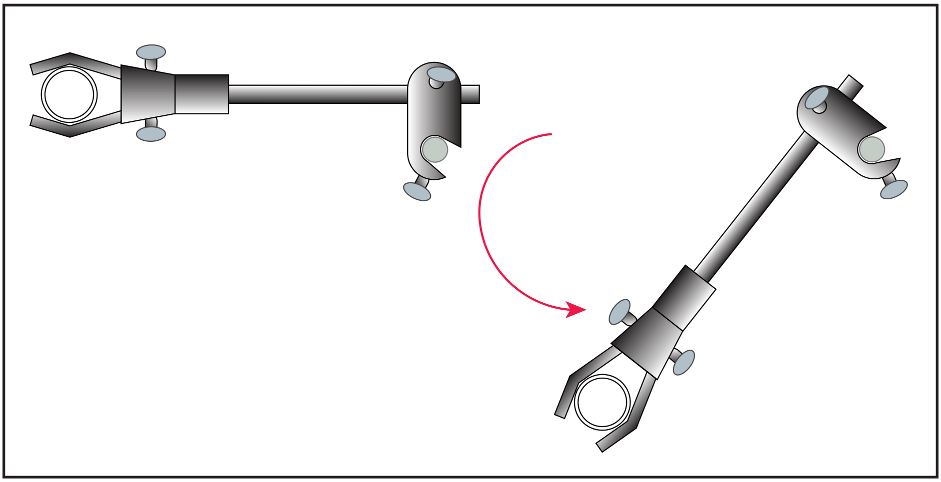

Image 19: *Problems with using the horizontal bars to attach items to the rack*

Example 2: Install Traps to face the right way

Traps are almost always installed facing the wrong way. This is often because the path of the system to the trap then to the pump visually is more logical than the other way around. However, there is a big problem with this during use, especially if the vacuum system creates a lot of vapors (Image 20).

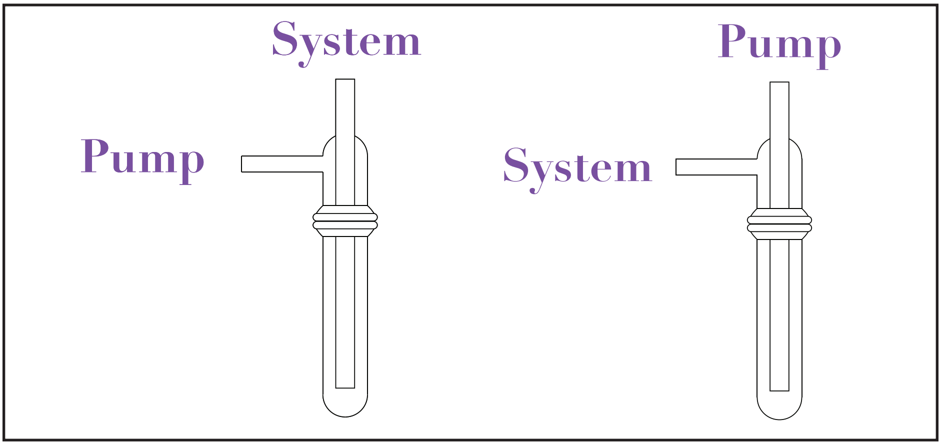

Image 20: *The two ways to attach a trap to a vacuum line*

The problem can easily be seen once the traps have been placed within liquid nitrogen and vapors start to collect. In the traps where the system is attached to the inner ring-seal tube, the vapor's ice collects in the inner tube. It often does not take much time for this to close off, completely sealing off any throughput of gases.

Alternatively, if the system is attached to the trap's side, vapors collect on the inside of the removable trap bottom. It is extremely unlikely to close off throughput on the trap bottom regardless of how long the system sits. In addition, if the glassblower provides two bottoms for each trap, the user can start with the first trap bottom. Then, as conditions warrant, vent the trap, remove the bottom to evaporate in the fume hood while placing the second bottom on the trap, and start up work with minimal down time (Image 21).

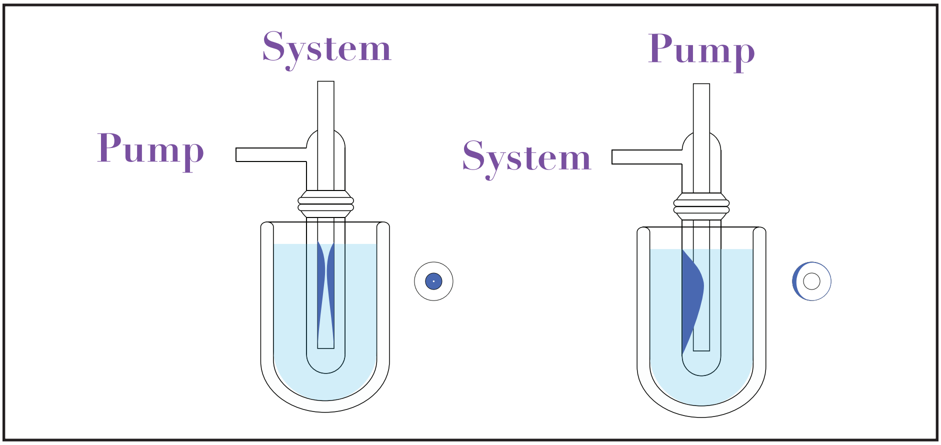

Image 21: *This is why the way you hook things up makes a difference*

Example 3: Add a vapor trap after the pump

One area that people often ignore or do not fully consider is that the vapors leaving the mechanical pump may not be all that healthy. As such, letting them exhaust directly into the lab is not recommended. It is best to connect a large diameter hose from the pump's exhaust tube to a fume hood. It is also wise to keep in mind that these vapors have been under pressure (within the pump) and will condense as they leave their high-pressure environment. This is where placing a vapor trap after the pump is a good idea.

These traps do not have to have any complications and do not even need a ring seal. The side tube might have a slight upward bend in which to help liquids drain as shown in the image below. In due course as the system is used, the researcher will see a film develop on the inside that only gets heavier over time. The only limitation is that once the collected materials start to get too close to the side tube, one needs to remove the trap by cutting the tubing off of the trap with a razor blade, clean it out and put it back in position (Image 22). Do not try to pull the trap off the tubing as it will not easily come off and may break due to the force applied to try to remove the trap.

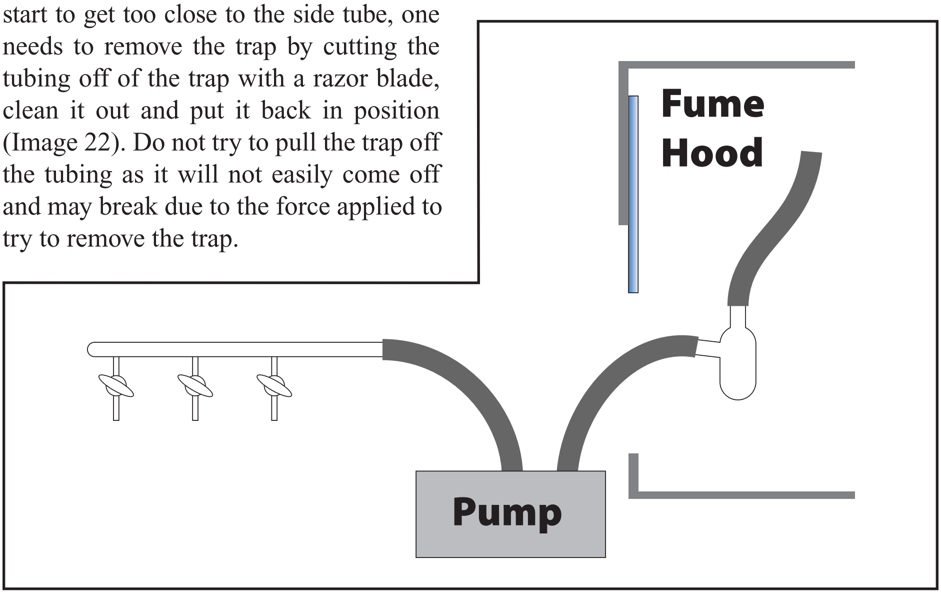

Image 22: *The exhaust trap*

FINAL THOUGHTS

Creating simple or complex vacuum systems does not mean the burden of confusion is suddenly on your shoulders. Rather, everything is simplified if the project is approached by a methodical, even approach. If the range of possible alternate options is brought to a reasonable level by asking the right questions, then the rest of the project is considerably simplified.

Simply, asking the correct questions means the customer will get what they need with the least amount of anguish on the glassblower's part.

Additionally, if the glassblower places the results of their questions onto the work order, it will provide a good verification and backup for all work done. Work orders can be considered contracts. Once the work order is created, have the customer review and sign it. Then, if the glassblower uses 19/22-inner joints for the customer to attach their flasks because that is what the work order states but they "meant" 14/20-inner, the customer pays for any alterations. If the work order stated 14/20-inner and the glassblower uses 19/22-inner, that is the glassblower's fault.

Continuous Improvement

by

Michael A. Menconi*

ABSTRACT

The lean manufacturing techniques and principles of Six-Sigma and Kaizen, when applied in the glass shop, can help achieve a competitive edge in the marketplace.

INTRODUCTION

Manufacturing technical glass requires a combination of knowledge, innovation and technique. While there are many challenges such as defeating variation and staying within engineering tolerance, understanding the history of continuous improvement stands out as a valuable commitment.

The general idea of Continuous Improvement is an ongoing effort to improve products, services and processes.

One way to become more efficient in manufacturing is to combine elements from a quality system and a lean manufacturing system. The methods in this technical paper have components from both a quality system and a lean system. The results are consistent and clear that both systems will increase quality and reduce variation.

This technical paper will examine the history of Continuous Improvement and include an application for the glass shop for the benefit of The American Scientific Glassblowers Society. This plan includes lean manufacturing techniques and added controls for variation.

A BRIEF HISTORY – CONTINUOUS IMPROVEMENT

The American Society for Quality defines Continuous Improvement as *"…an ongoing effort to improve products, services or processes. These efforts can seek incremental improvement over time or breakthrough improvement all at once."* Like any other business seeking to improve with each day, technical glass manufacturing can also benefit from Continuous Improvement. Continuous Improvement is the purposeful effort to improve daily.

The history of Continuous Improvement can be traced back to initiatives implemented in several companies in the 1800s where management encouraged employee-driven improvements. Incentive programs were set in place to reward employees who brought about positive changes in the organization.[1] There are three key events that helped to shape the development of Continuous Improvement: the Ford Motor Company, Toyota manufacturing team, and events of the Second World War.

In 1913, Henry Ford was the first to integrate an entire production process.[2] At Highland Park, MI, he married consistently interchangeable parts with standard work and moving conveyance to create what he called flow production. The public grasped this in the dramatic form of the moving assembly line, but from the standpoint of the manufacturing engineer, the breakthroughs actually went much further.

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[1] N. Bhuiyan, & A. Baghel, "An Overview of Continuous Improvement: From the Past to the Present," *The Emerald Research Register* 43.5 (2005): 761-771.

[2] J. P. Womack, *The Machine that Changed the World: The Story of Lean Production–Toyota's Secret Weapon in the Global Car Wars That is Revolutionizing World Industry* (New York: Free Press, 2007).

Shortly thereafter, the Toyota manufacturing team of Kiichiro Toyoda and Taiichi Ohno examined ways to reduce the cost of production. As a result, Toyota team discovered that a series of simple innovations might make it more possible to provide both continuity in process flow and a wider variety in product offerings. From this point, Toyota team revisited Ford's original thinking and invented the Toyota Production System.

During the Second World War, the United States government set up the "Training Within Industry" service to enhance industrial output on a national scale. This service included job method training which was a program designed to educate supervisors on the importance and techniques of Continuous Improvement methods. The Training Within Industry program was introduced in Japan by the United States forces present after the end of the Second World War.[3]

TOYOTA PRODUCTION SYSTEM – THE BIRTH OF LEAN MANUFACTURING

Born in Dalian, China in 1912, Taiichi Ohno is considered to be the father of the Toyota Production System which became Lean Manufacturing in the United States. He devised the Seven Wastes as part of this system. He wrote several books about the system, including *Toyota Production System: Beyond Large-Scale Production.*[4]

This system shifted the focus of the manufacturing engineer from individual machines and their utilization to the flow of the product through the total process. Toyota concluded that it would be possible to obtain low cost, high variety, high quality, and rapid throughput times to respond to changing customer desires by applying the following principles:

- right-size machines for the actual volume needed
- introduce self-monitoring machines to ensure quality
- locate the machines according to process sequence
- pioneer quick setups so each machine could make small volumes of many part numbers
- have each process step notify the previous step of its current needs for materials

An added bonus was that information management could be made much simpler and more accurate.

In 1943, Taiichi Ohno joined the Toyota motor company. Ohno had worked as a shop-floor supervisor in the engine manufacturing shop of the plant, and gradually rose through the ranks to become an executive.

A key step in Lean Manufacturing and the Toyota Production System is the identification of steps that add value and those that do not. By classifying all the process activities into these two categories, it is then possible to start actions for improving the former and eliminating the latter. Some of these definitions may seem rather 'idealist' but this tough definition is seen as important to the effectiveness of this key step. Once value-adding work (actual work) has been separated from waste, then waste can be subdivided into 'needs to be done (auxiliary work) but non-value adding' waste and pure waste. The clear identification of 'non-value adding work', as distinct from waste or work, is critical to identifying the assumptions and beliefs behind the current work process and to challenging them in due course.

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[3] D. A. Dinero, *Training Within Industry: The Foundation of Lean* (New York: Productivity Press, 2005).

[4] T. Ōhno, *Toyota Production System: Beyond Large-scale Production* (Cambridge, MA: Productivity Press, 1988).

TOYOTA PRODUCTION SYSTEM – SEVEN WASTES

An expression "Learning to see" came from developing the ability to see waste where it was not perceived before. Many have sought to develop this ability by traveling to Japan and visiting Toyota manufacturing to compare the difference between their operation and one that has been under Continuous Improvement for thirty years under the Toyota Production System.[5]

Taiichi Ohno was instrumental in developing the way to identify waste, with his "Seven Wastes" model. Shown in Figure 1.

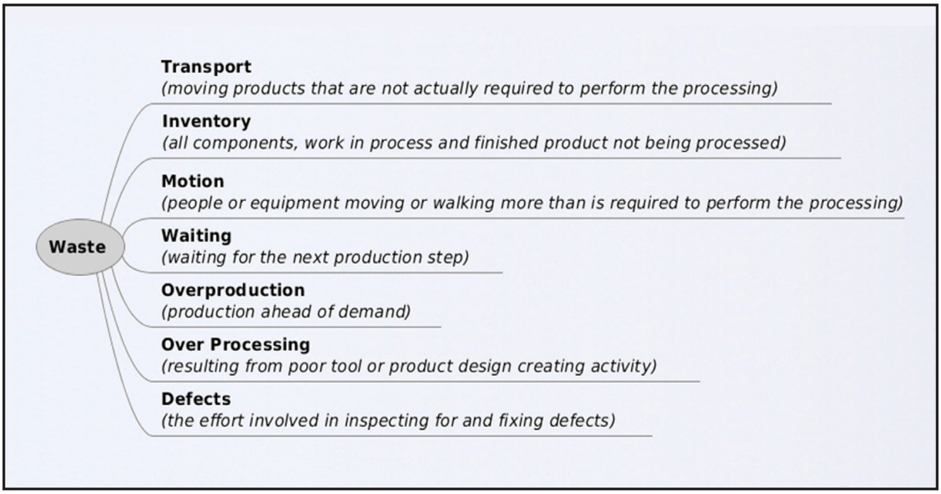

Figure 1. *"Seven Wastes" model*

His model of the seven wastes identifies resources that are commonly wasted. Toyota's Chief Engineer Taiichi Ohno identified these wastes in part of the Toyota Production System.

TRANSPORTATION

Each time a product is moved, it is at risk of being damaged, lost, delayed, etc. as well as being a cost for no added value. Transportation does not make any transformation to the product that the consumer is willing to pay for.

INVENTORY

In the form of raw materials, work-in-progress (WIP), or finished goods, represents a capital outlay that has not yet produced an income either by the producer or for the consumer. Any of these three items not being actively processed to add value is waste.

MOTION

In contrast to transportation, which refers to damage to products and transaction costs associated with moving them, motion refers to the damage that the production process inflicts on the entity that creates the product. This damage can be either over time (wear and tear for equipment and repetitive strain injuries for workers) or during discrete events (accidents that damage equipment and/or injure workers).

[5] S. Shingō, *A Study of the Toyota Production System from an Industrial Engineering Viewpoint* (New York: Productivity Press, 2005).

WAITING

Whenever goods are not in transport or being processed, they are waiting. In traditional processes, a large part of an individual product's life is spent waiting to be worked on.

OVER-PROCESSING

Over-processing occurs any time more work is done on a piece other than what is required by the customer. This also includes using components that are more precise, complex, of a higher quality or more expensive than absolutely required. (Traditional notion of waste, as exemplified by scrap that often results from poor product or process design.[7]

OVER-PRODUCTION

Over-production occurs when more products are produced than is required at that time by your customers. One common practice that leads to this waste is the production of large batches, as often consumer needs change over the long times large batches require. Over-production is considered the worst waste because it hides and/or generates all the others. Over-production leads to excess inventory, which then requires the expenditure of resources on storage space and preservation, activities that do not benefit the customer.

DEFECTS

Whenever defects occur, extra costs are incurred reworking the part, rescheduling production, etc. This results in labor costs, more time in the "Work-in-progress." Defects in practice can sometimes double the cost of one single product. This should not be passed on to the consumer and should be taken as a loss.

KAIZEN

Kaizen is a process that was founded by Masaaki Imai, the Chairman and founder of the Cambridge Corporation, an international management consulting and executive recruiting firm. He developed the Kaizen process to improve work flow. Imai named his process Kaizen because in Japanese, the word means "for improvement" or "change for the best."[6]

Figure 2. *The Kaizen process*

Imai (1986) acknowledged that Kaizen starts with detection of needs and problem definition:

> *The starting point for improvement is to recognize the need. This comes from recognition of a problem. If no problem is recognized, there is no recognition of the need for improvement. Complacency is the arch enemy of Kaizen.*[7]

[6] M. Imai, *Kaizen (Ky'zen), the Key to Japan's Competitive Success* (New York: Random House Business Division, 1986).

[7] Imai Masaaki, *Kaizen (Ky'zen), the Key to Japan's Competitive Success* (1986) p. 9, cited in *Total Quality Handbook* (1990): 32.

While past Continuous Improvement initiatives reflected the use of various principles related to work improvement, modern-day Continuous Improvement is associated with organized and comprehensive methodologies. These Continuous Improvement programs, in which typically the overall organization, or a large part of it, is involved in change, are also more popularly associated with the introduction of Total Quality Management which also gained leverage in Japan thanks to W. Edwards Deming.[8]

Plan, Do, Study, Act

Masaaki Imai stated, "Japanese executives recast the work of W. Edwards Deming from the 1950 JUSE seminar into the Plan-Do-Check-Act (PDCA) cycle. Building the PDCA cycle based off Deming's JUSE seminars of 1950."[9]

The "Plan, Do, Study, Act" (PDSA) Cycle is a systematic series of steps developed by W. Edwards Deming for gaining valuable learning and knowledge for the continual improvement of a product or process. These four steps are repeated over and over as part of a never-ending cycle of continual improvement.

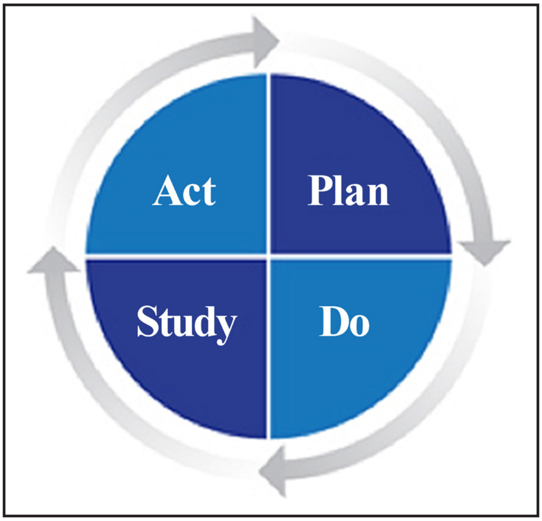

Figure 3. *The Deming Wheel, or Deming Cycle*

Plan – Identify a goal or purpose, formulate a theory, define success metrics and put a plan into action.

Do – the components of the plan are implemented, such as making a product.

Study – outcomes are monitored to test the validity of the plan for signs of progress and success, or problems and areas for improvement.

Act – Close the cycle, integrating the learning generated by the entire process, which can be used to adjust the goal, change methods or even reformulate a theory altogether.

Six Sigma Methodologies – DMAIC

Inspired by Deming's Plan-Do-Study/Check-Act Cycle, Six Sigma projects follow two project methodologies. These methodologies, composed of five phases each, bear the acronyms DMAIC and DMADV.[10]

There are two Six Sigma sub-methodologies: DMAIC and DMADV. The Six Sigma DMAIC process (define, measure, analyze, improve, control) is an improvement system for existing processes falling below specification and looking for incremental improve-

[8] W. E Deming, *Out of the Crisis* (Cambridge, MA: MIT Press, 2000).

[9] M. Imai, *Kaizen: The Key to Japan's Competitive Success* (New York: Random House, 1986): page 60.

[10] T. Pyzdek, *Six Sigma Handbook* (2014).

ment. The Six Sigma DMADV process (define, measure, analyze, design, verify) is an improvement system used to develop new processes or products at Six Sigma quality levels. To clarify the difference, DMAIC is used for projects aimed at improving an existing process. DMADV, on the other hand, is used for projects aimed at creating new product or process designs.

Lean management and Six Sigma are two concepts that share similar methodologies and tools. Both concepts are of Japanese origin, but they are two different programs. Lean management is focused on eliminating waste and ensuring swift process flow, while Six Sigma's focus is on eliminating defects and reducing variability.

Figure 4. *Six Sigma DMAIC phases*

- ***Define*** the system, the voice of the customer and their requirements, and the specific project goals.
- ***Measure*** key aspects of the current process and collect relevant data; calculate the 'as-is' Process Capability.
- ***Analyze*** the data to investigate and verify cause-and-effect relationships. Determine what the relationships are, and attempt to ensure that all factors have been considered. Seek out the root cause of the defect under investigation.
- ***Improve*** or optimize the current process based upon data analysis using techniques such as design of experiments and standard work to create a new, future state process. Set up pilot runs to establish process capability.
- ***Control*** the future state process to ensure that any deviations from the target are corrected before they result in defects. Implement control systems such as statistical process control, production boards, and visual workplaces. Continuously monitor the process.

Six Sigma Methodologies – DMADV

Six Sigma Methodologies can also be employed if a current process requires more than just incremental improvement. It is also used for projects aimed at creating new product or process designs known as DFSS ("**D**esign **F**or **S**ix **S**igma").

Figure 5. *Six Sigma DMADV phrases*

- ***D**efine* design goals that are consistent with customer demands and the enterprise strategy.
- ***M**easure* and identify CTQs (characteristics that are **C**ritical **T**o **Q**uality), measure product capabilities and production process capability, and measure risks.
- ***A**nalyze* to develop and design alternatives.
- ***D**esign* an improved alternative, best suited per analysis in the previous step.
- ***V**erify* the design, set up pilot runs, implement the production process and hand it over to the process owner(s).

APPLICATION

This methodology for technical glass manufacturing is simple and straightforward. By taking time to clean, set up equipment properly, and gathering only the necessary amount of tools and supplies per operation are only some of opportunities for improvement. Inspired by the fundamentals of Continuous Improvement, this is a continuous improvement practice that is based on the Deming Cycle, Kaizen, and includes Lean Work Flow. Implementing this plan requires consistency, self-discipline and practice.

PLAN

The plan of a lathe operator is to hopefully increase quality while reducing product variation. Taking time to wipe down your bench and organize your tools is a value-added daily activity that will improve the quality of your work.

Tools used in the fire will decay and leave behind excess particles that contaminate the work station and supplies, and can impair the function of the product line. Clean glass is vital to producing a quality product. Just as a chef starts with quality ingredients, it is essential for a lathe operator to start with clean glass.

> *"You don't have to cook fancy or complicated masterpieces – just good food from fresh ingredients."*– Julia Child

Starting with clean glass is critical to the production of electronic glass. Implementing and maintaining an ultrasonic wash station is costly. Hydrofluoric acid (HF) has been used in industrial glass manufacturing for years and does wonders for cleaning. However, it is extremely costly to install and maintain an EPA approved ventilated acid room. Never use HF before completing the proper trainings!

An inexpensive and effective glass cleaning method is a simple two-step process:

1. Use a cotton wiper and deionized water to remove dust.
2. Use a synthetic wiper and ethanol to break down water and remove residue.

Keeping your work station clean and organized before you start working will improve the quality and final result of your work.

DO

A simple way to understand a lean work flow is to apply the same rules from the "Sometimes, Always, Never" rule for wearing a suit coat within Figure 5. It is also an easy way to remember how to organize the tools and supplies of your lean work station to increase productivity and reduce waste.

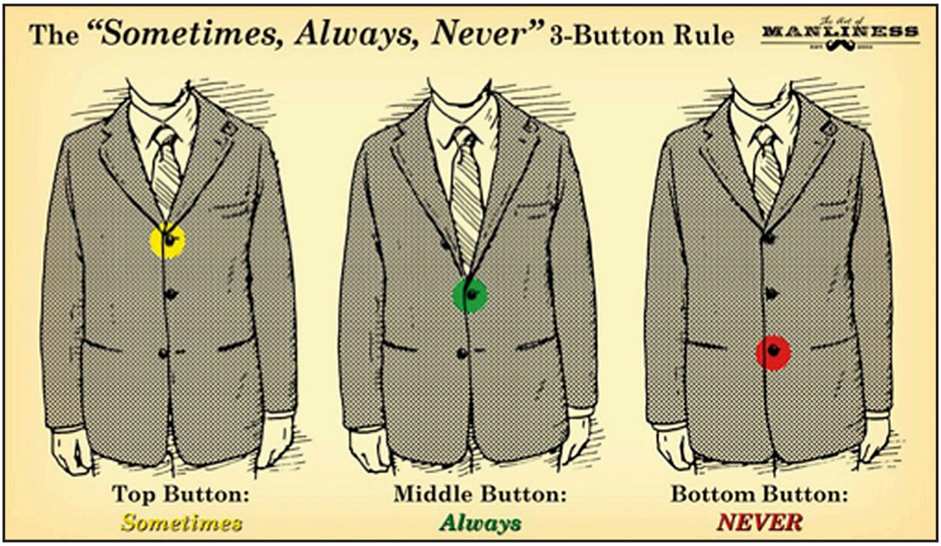

Figure 6. *Sometimes, Always, Never — the art of Manliness*

SOMETIMES

Do not keep tools and supplies at the work station that are only used sometimes. A nearby locker or shelving unit for these is ideal, as pulling more tools or raw materials than required is waste.

ALWAYS

Keep at the workstation tools and supplies for only the current projects. This will reduce the movement required to work.

NEVER

Tools and supplies that are no longer in use or no longer required should be either sold or scrapped. This is excess inventory that could be used to obtain either new tools or increase floor/shelf space.

STUDY

This can be as easy as looking at what you have made and reflecting on the process or you can inspect a complete product line for quality and variation.

Setting up a non-quality parameter for quality control on completed goods is ideal for producing quality products. When the final product is measured or inspected, a final decision can be made based on fulfilling criteria and tolerances.

A quality logbook can be a simple checklist of columns created to identify criteria, and rows are created to verify each item or product. For each product, set your goals or criteria in place for quality and verify that engineering tolerances are met. A well-lit inspection table is a good area to inspect and measure glass.

In the event that a product cannot be salvaged with a reasonable amount of time/effort, it should be scrapped immediately. Keeping a log of scrapped goods is an important task because it directly impacts your costs/profitability.

It is important to identify problems. If a problem re-occurs, adjustments or calibrations can be made at this point to prevent future occurrences and you will have a record for Kaizen.

ACT

Kaizen encourages you to implement changes that are potentially or currently affecting the quality of your work. This is simply done by creating two columns on each page of a notebook: title the first column: *Problem* and the second column: *Solution*. At any point in the day, note any problems you are experiencing that affect the process or quality of your work.

> "*In Kaizen you do not need to have an immediate solution for a problem, as the starting point for improvement is to recognize the need. This comes from recognition of a problem. If no problem is recognized, there is no recognition of the need for improvement*." – Masaaki Imai

CONCLUSION

Through practice, I have discovered that Continuous Improvement is important to include in the running plan of any quality facility. Applying Continuous Improvement methods will directly impact the value and quality of any manufacturing company. This technical paper was written for members of The American Scientific Glassblowers Society to better understand the history and value of Continuous Improvement.

ACKNOWLEDGEMENTS

I would like to formally thank The American Scientific Glassblowers Society for allowing me an opportunity to present this technical paper during the 2016 Symposium. Additionally, I would like to thank Erich Moraine and Nate Stelton: Erich encouraged me to write this paper and Nate helped with editing. Thank you both.

Freeboard – The Key to Floating Your Seven-foot Glass Boat Down the River

By

Michael T. Hengler*

ABSTRACT

"Freeboard – The Key to Floating Your Seven-foot Glass Boat Down the River" is a technical analysis and documentary of the making of a seven-foot glass boat, its engineering, design, failure, and success.

PROLOGUE

I envisioned a boat made of lava rock floating down a glowing red molten river of liquid lava, I just had to figure out how to make it happen. The idea was of interest because I was attending graduate school at the University of Hawaii-Manoa where lava, land, culture and commodity all blur into one. The stigma you may have heard, if you have visited the Hawaiian island chain, is that you should not take rocks from the island – it will bring bad juju. The irony is that the rock is not only taken, it is sold by local business people of the island within the islands and back to the mainland of the United States. To advance my pursuit in using the lava rock as an artistic medium, I had to first verify if in fact it was taboo to take all rock.

The reality, after working with native Hawaiians, professors of Hawaiian studies, archeologists, and practitioners, is that the cinder (a rubble-like lava erupted from cinder cone volcanos) is not considered taboo to take or use; it is actually believed to be the vomit of Pele (the goddess of fire and the creator of the islands in Hawaiian belief). The stigma about removing rocks arose from Haoles (non-native Hawaiians) taking sacred rocks from Heiaus (sacred Hawaiian temples).

Many times, by many people who were authorities on the matter, I was given permission to use the cinder. I now had to figure out how to shape and mold the material to an artistic end. I had envisioned and tried using traditional off-hand glassblowing methods. I tried this by making a crucible from clay, adding the cinder rock to the crucible, bringing it up to 1000°F in an annealer, then gloved the crucible into a pre-warmed gloryhole. I then brought the glory hole up to around 2400°F to liquefy the lava rock, and used the glory hole to both gather the lava out of the crucible as well as to reheat it.

The problem was not so much the formation of the rock, but rather the annealing of it. The making process was awkward but familiar: the rock body had no plasticity but was still malleable and moldable. I was able to form it into basic boat shapes, but, after annealing, the boat had separated into shards. Another way had to be developed.

Working with a professor of Geophysics at the University of Hawaii-Manoa, I was able to obtain the makeup of the cinder from the Big Island of Hawaii. Using this composition, I worked with a professor of ceramics to develop a thermal glaze. The glaze functioned to hold the cinder rock together by mixing the glaze with the cinder and firing it to a temperature that would vitrify the glaze and function to hold the cinder rock in its determined form.

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The tests went well. Soon I had developed a fleet of six lava boats that I planned to bring back to the active lava flows of the Big Island. The idea was not only to break up the economic ecology (that was the cinder bagged and sold) by removing it from that cycle, but also to return the rock to its place of origin, honoring the initial and largely disseminated belief that the rock should remain where it was found. This idea, on a metaphorical level, was a parallel between the volcanic process and us as humans: the lava rises from the earth, navigates its path until its energy is expended, after which it becomes one with the earth again; humans too rise up from the same elemental makeup of the earth, we ambulate until our energy is expended, then return to the earth (Figure 1).

Figure 1. *Lava boats*

My girlfriend at the time, who is now my wife, and I (bless her patient and supportive soul!) moved to the Big Island and rented a rustic house (read: shack) with catchment water and a shabby sometimes-functioning-solar-powered-system in the last habitable subdivision which had been twice covered by the East Rift Zone lava flows. By day, the landscape smoked with sulfur dioxide (Figure 2). By night the hills glowed red from active lava (Figure 3).

Figure 2. *Kalapana days*

Figure 3. *Kalapana nights*

We managed to hike, arduously, through some situations so dangerous that my heart quickens still thinking of it now, and return those boats back to the active lava flows. The culmination of this effort was exhibited in a gallery as a 24’x18’ projection of the video footage of the boats floating down the lava rivers. The gallery space was black, but for the red glow of the footage. The floor of the gallery was covered in the cinder one would traverse on the Big Island. The crunch and instability of the gallery visitors' footing along with the darkness, projected imagery, and 10' lava boat installed in the gallery space that lifted towards the video footage created a sense of unease and eerie wonderment (Figure 4). This artwork earned an unanimous vote from my Thesis Committee to award me a Masters of Fine Arts degree. It was in the overlap of this thesis project that I began to visualize boats made of other materials that could take me on uncommon voyages.

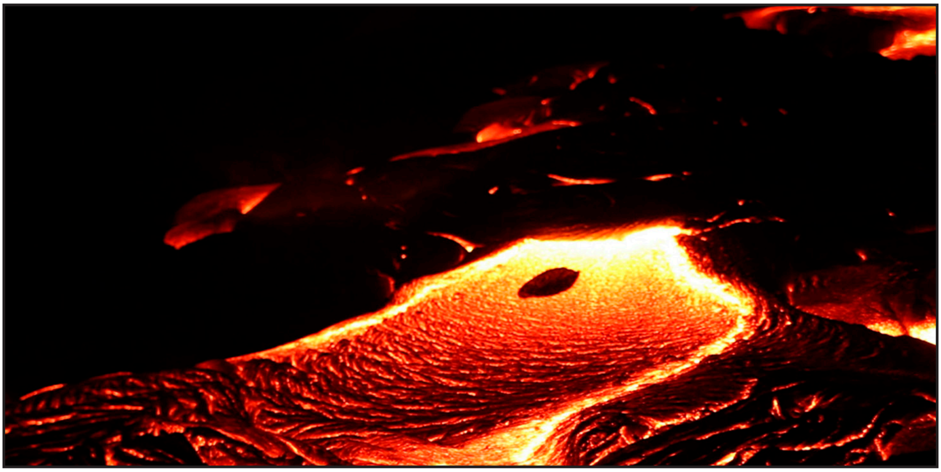


Figure 4. *Lava boat's voyage*

BOAT OF GLASS

I had a vision of me navigating the brackish waters of the Maurice River with nothing obstructing my vision of the watery world below my body but a thin line of clear glass in the shape of a dory drift boat. I hoped to push the craft forward with a clear glass paddle, each stroke striding me closer to Delaware Bay, and the Atlantic Ocean. I would attempt to create this work at the Creative Glass Center of America (CGCA) at Wheaton Arts, where I applied for and received a three-month Fellowship. I wanted to build a boat of glass big enough to hold a human and a glass paddle to propel it. I proposed that, if the craft proved sufficiently buoyant, I would take it to the waters for a maiden voyage. The task was to figure out how to technically accomplish this.

LOST WAX

My first attempt at a glass boat was three feet long, which was one third of what I projected I would make at full scale (Figure 5). I decided to work in the lost wax method. I built a dory-inspired hull out of victory brown microcrystalline wax. I cut the form in half to minimize the weight and size of the invested form, attached the sprue system, added the casting cup, invested the form and reinforced it with expanded steel, and steamed out the wax (Figure 6). Even cut in half, the invested mold had to be forklifted into the kiln (Figure 7).

I slowly brought the annealer up to a little above the softening point of Spruce Pine Batch (around 1250°F) both to burn off the water in the mold, and so that the mold and oven were hot enough to assist the hot glass billets to flow down and into the mold. I made the billets by gathering glass from the furnace, formed the glass in the shape of the casting cup, and added them to the casting cup to flow into and to fill the mold.

Figure 5. *Wax boat*

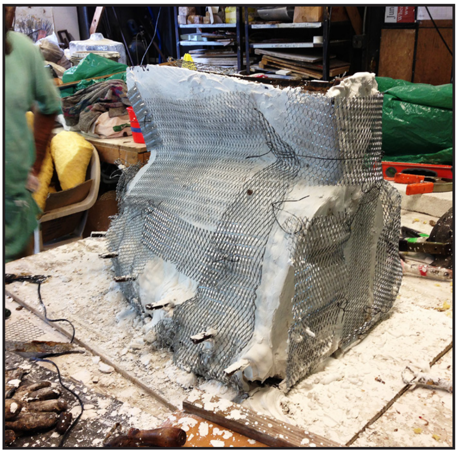


Figure 6. *Half boat invested*

Figure 7. *Into the oven*

The result of this process was not very successful. The mold should have been cast a little thicker and been better reinforced with the expanded steel; part of the mold broke out during the process of adding the billets. Not only was the mold technically flawed, the annealing was as well – the boat was cracked after it was divested.

More than the technical issues just described, I feared that this process rendered too much inconsistency in the wall thickness of the boat. This consideration was of utmost importance to me in the event that I would successfully make a boat big enough, and buoyant enough to float me, because the consistency of the boat's wall thickness would ensure even annealing and less of a chance of breakage. All things considered, I decided to abandon this process and explore other working methods.

SHEET GLASS BUILDING

CGCA had a small supply of four foot by eight foot sheets of glass around the facility which I was given permission to use. I saw the sheet glass as a modular unit from which I could attempt to construct a boat. The early prototypes seemed promising: fast and easy to build. When I began to test them for buoyancy, they showed less promise. The first model had essentially no freeboard – the water line was level with the top of the boat (Figure 8). I manipulated the design by lengthening the height of the boat's walls. This resulted in extra freeboard and was encouraging enough that I decided to scale up the size of the boat so that I could utilize the full eight feet of the sheet glass. In the process of trying to move one of the full sheets of glass, it cracked and split into jagged shards, in my hands! I took that as a sign to acknowledge the fragility of this glass, and that its construction as a single quarter inch sheet was not safe to pursue.

Figure 8. *Sheet glass prototypes*

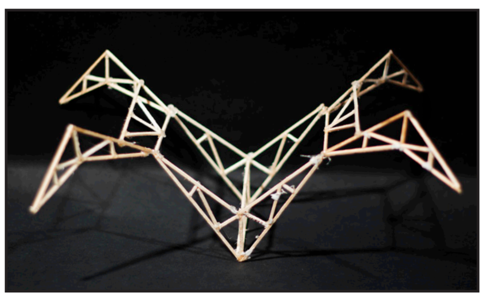


Figure 9. *Skeletal frame*

Not quite ready to abandon this method of building, I was curious to see if I could build a skeletal structure to house and reinforce the sheet glass boat (Figure 9). I worked up some designs and had a local architect who was a friend of CGCA render them in CAD to gain a better idea of how this might all come together (Figure 10). Although the design showed promise for added buoyancy by adding glass floats to four outreaching arms of the skeletal structure as well as a way to protect and reinforce the glass, I did not like the effect – there was too much stuff other than the boat. I wanted to keep true to my minimal aesthetic and the integrity of the work as a simple and small division between me and the waterline. After many design variations, I decided to abandon this method of working as well.

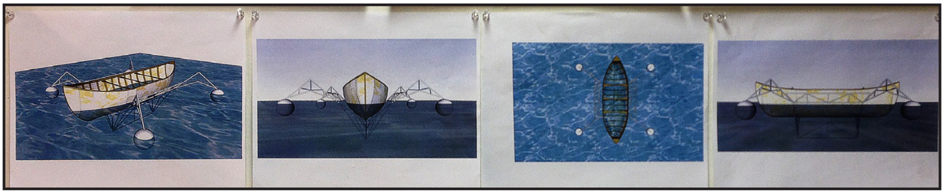


Figure 10. *Skeletal frame designs*

INTERLUDE

Around this time of the Fellowship, my now fiancé and I had to fly back to Hawaii for our wedding we had planned prior to being informed that I was awarded the Fellowship at CGCA (Figure 11). We met our incoming family on Oahu, had a lovely ceremony, and then were off to our honeymoon in… New Jersey?! Certainly less glamorous than a wedding on Oahu, but hey, Hawaii is a tough act to follow, and who does not love Jersey (Figure 12)?

Figure 11. *Wedding on Oahu*

Figure 12. *Honeymoon in New Jersey*

FUSED SHEET GLASS HULL

With renewed vigor, I returned to the task of building a human-sized glass boat. The prototyping started out small at eight inches long and only two sheets of quarter inch sheet glass fused together (Figure 13). I suspected that fusing sheets of glass together (a process whereby the glass is heated hot enough so that the separate sheets become liquid, stick together, and become one unit) would be safer and stronger because I could stack the quarter inch sheets to find a balance between buoyancy and structural stability, and maintain an even wall thickness throughout the vessel.

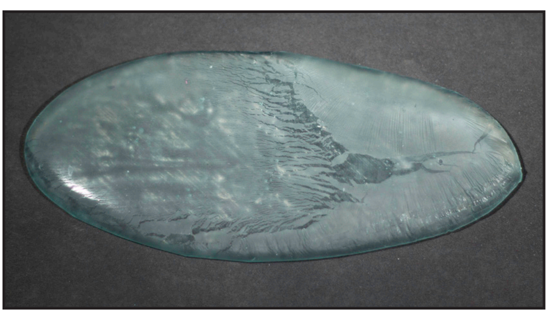
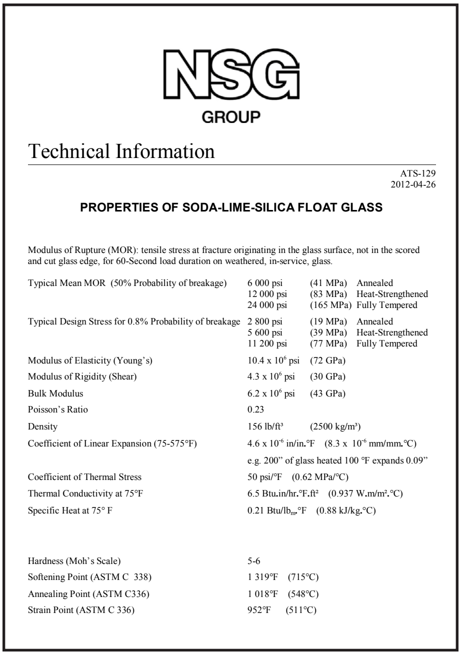


Figure 13. *Fused test one*

I used Pilkington's (a sheet glass manufacturer) numbers (Figure 14) for the softening point (1319°F), annealing point (1018°F), and strain point (952°F) of their sheet



NSG GROUP

Technical Information

ATS-129
2012-04-26

PROPERTIES OF SODA-LIME-SILICA FLOAT GLASS

Modulus of Rupture (MOR): tensile stress at fracture originating in the glass surface, not in the scored and cut glass edge, for 60-Second load duration on weathered, in-service, glass.

Typical Mean MOR (50% Probability of breakage)	6 000 psi	(41 MPa)	Annealed
	12 000 psi	(83 MPa)	Heat-Strengthened
	24 000 psi	(165 MPa)	Fully Tempered
Typical Design Stress for 0.8% Probability of breakage	2 800 psi	(19 MPa)	Annealed
	5 600 psi	(39 MPa)	Heat-Strengthened
	11 200 psi	(77 MPa)	Fully Tempered
Modulus of Elasticity (Young's)	10.4 x 10^6 psi	(72 GPa)	
Modulus of Rigidity (Shear)	4.3 x 10^6 psi	(30 GPa)	
Bulk Modulus	6.2 x 10^6 psi	(43 GPa)	
Poisson's Ratio	0.23		
Density	156 lb/ft^3	(2500 kg/m^3)	
Coefficient of Linear Expansion (75-575°F)	4.6 x 10^{-6} in/in.°F (8.3 x 10^{-6} mm/mm.°C)		
	e.g. 200" of glass heated 100 °F expands 0.09"		
Coefficient of Thermal Stress	50 psi/°F (0.62 MPa/°C)		
Thermal Conductivity at 75°F	6.5 Btu.in/hr.°F.ft^2 (0.937 W.m/m^2.°C)		
Specific Heat at 75° F	0.21 Btu/lb_m.°F (0.88 kJ/kg.°C)		
Hardness (Moh's Scale)	5-6		
Softening Point (ASTM C 338)	1 319°F (715°C)		
Annealing Point (ASTM C336)	1 018°F (548°C)		
Strain Point (ASTM C 336)	952°F (511°C)		

Figure 14. *Pilkington's Temperature Chart*

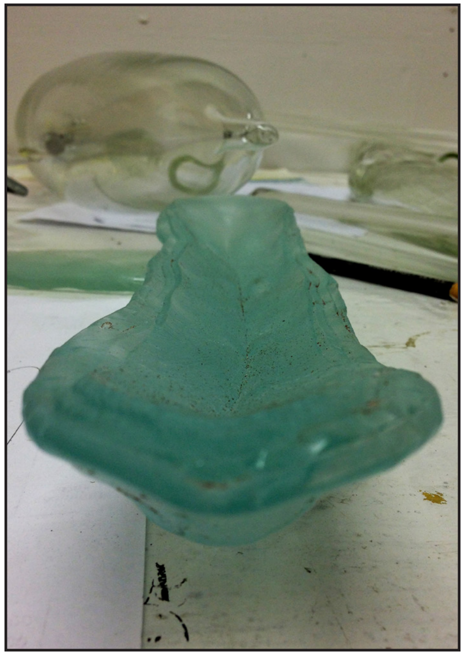


Figure 15. *Fused test two*

glass.[1] The second fusing test was 14 inches long and used three quarter-inch sheets of glass that were fused together (Figure 15). The fused glass came out of the oven annealed, so I attempted to slump it over a sand and bentonite clay form that I prepared in the shape of a boat hull. By placing the flat and fused sheet glass over the top of the clay and sand mixture, and heating it up in the oven to its softening point, I was able to get the glass to droop down into the hollow of the mold and render a basic boat hull shape. The three sheets of glass were too thick for the amount of surface area I was working with, but it gave me hope and a better idea of proportions for the next test.

I moved the scale up to four feet in length on the next two tests. The first one was three sheets thick, and the second was four. Both fusings went well and showed very little devitrification. I held the temperature of the oven at just below the softening point so that all of the glass was ready to bond molecularly. Then, just a small bump in temperature allowed the glass to fuse together with very few bubble traps between sheets.

I then tried to slump these fused sheets; the first of these two attempts did not go well. The glass did not have anything to hold it in place over the top of the mold, so the sheet glass slumped and slid down into the mold itself. Attempting to correct for this on the second four-foot slump, I cut the sheet glass so that the edges extended over the outer perimeter of the mold, thinking that, as the glass slumped into the mold, the edges around the mold would also slump over the outer rim of the mold and hold the glass back from sliding down and into the mold. The effort worked, but left excess glass around the upper portion of the boat which added unnecessary mass and created an imbalance in the boat's weight distribution (Figures 16 and 17).

[1] NSG Group, Technical Information Sheet–Properties of Soda-Lime-Silica Float Glass, ATS-129, 2012-02-265.

Figure 16. *Fused test three*

Figure 17. *Fused test four*

Although the previous tests were not perfect, I felt confident enough to scale up the form again. The biggest oven the CGCA facility owned allowed me to make a boat that would be seven-feet long. I kept with the decision to use four quarter-inch sheets. The seven-foot sheets were an inch thick once fused prior to the slumping process. I decided to fuse copper wire between the sheet glass so that I could connect the wire to the brick mold over which I would slump the glass in order to hold the glass in place (Figure 18). This idea allowed me to avoid the weight gain and imbalance of the prior four-foot test.

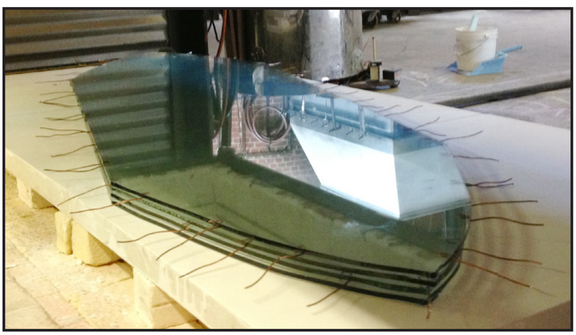


Figure 18. *Seven-foot fuse prep with copper*

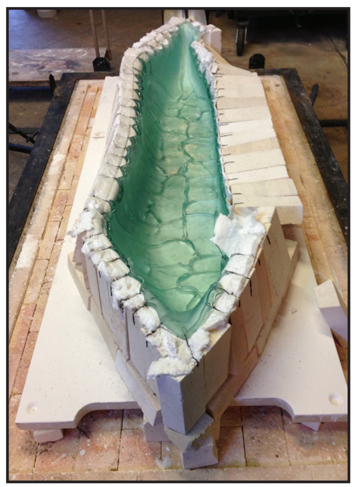


Figure 19. *Slump result*

The problems inherent with scaling up became quickly apparent in the first slump. I stapled the copper wire that I fused between the sheets of glass to the brick mold, as intended. The result was that the copper held the glass to the brick, mostly, but also ripped the brick down with it into the void of the mold during the slump (Figure 19). This seemed to have an easy remedy: I just had to connect the vertical bricks of the mold to the horizontal ones beneath them… and successfully fuse another seven-foot boat form.

The effort to fuse another seven-foot boat proved to be much more difficult than my first experience. The second attempt cracked on the way up to fusing temperature because I rushed through a very simple step: fully cook off any residual moisture in the kiln shelves present from the kiln shelf primer (Figure 20). I rushed through this step because I was running out of time – the residency was coming to an end. My haste to speed up the process was actually costing me time. I pressed on.

Figure 20. *Cracked fuse*

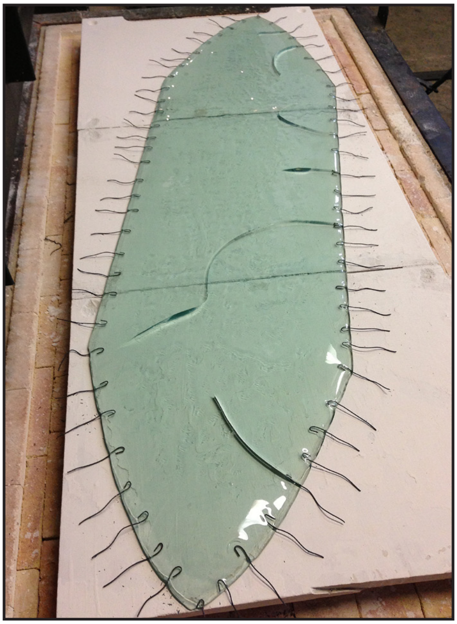


Figure 21. *Annealing Cracks*

The next fuse attempt looked great, except for the stress cracks that ran from the copper wires that I had fused into the glass (Figure 21). Copper has a similar coefficient of expansion as glass and should not have caused cracking. I attributed the cracks to me crashing the annealer's temperature from fusing temperature at 1450°F to annealing temperature at 1030°F. The rest of the annealing cycle's duration was consistent with the thickness of the glass.

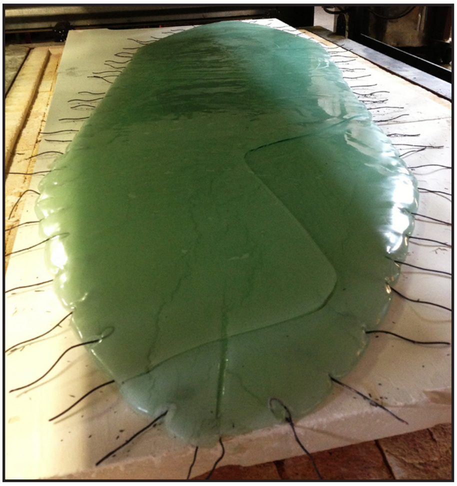


Figure 22. *Devitrification and cracks*

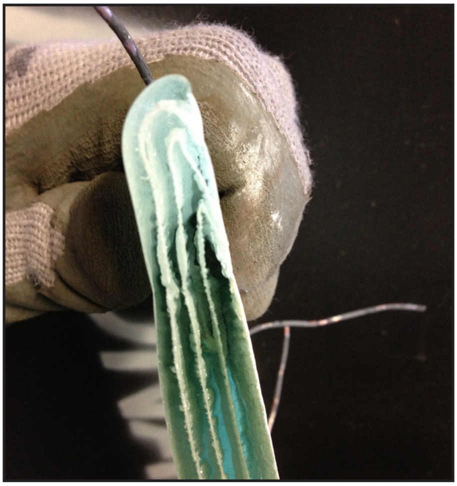


Figure 23. *Cross-section of fusing*

The cracks in this fusing attempt were superficial, so I decided to try to refuse it. They may have been superficial, and this effort may have worked, but the glass devitrified severely in the re-fuse. The result was opaque glass with new cracks that ran in different directions, inconsistent with the prior orientation of the copper wire placement (Figure 22). In examining the cross sections of the fusing, there was significant crystallization both on the surface of the glass but also between the layers of glass (Figure 23).

SECOND INTERLUDE

It was time to start the next attempt, but I had now officially run out of time as a Fellow at CGCA. I had previously set up an internship to work with Mike Souza (Figure 24) at Princeton University to understudy his expertise at scientific glassworking, as well as an internship with Paul Stankard (Figure 24) to understudy his expertise in the field of glass encasements. I was able to appeal to Hank Adam's sympathies (the Director of CGCA) and get an extension to continue working on this project. I worked weekdays with Mike or Paul, and would drive back to CGCA on the weekends to continue my effort at this glass boat.

Figure 24. *Mike Souza*

Figure 25. *Internship with Paul Stankard (right)*

LAST CHANCE

I had enough time left to attempt one more fuse and slump. I took it slowly and considered prior mistakes, trying to correct for them and improve aspects of my design to render a better result. I began with the copper wire system. I had previously been bending the copper wire to form a hook shape on one end of the wire. The hook was the part of the wire that was then fused between the glass sheets. I then just stapled that wire to the brick. This design had issues in the first slump: the hooks were ripped out of the glass from the weight and molten state of the glass. This time, instead, I made two prong v-hooks (Figure 26). The design was supposed to help divide some of the weight that pulled on each hook by distributing the pull of the slumping glass over two points rather than one.

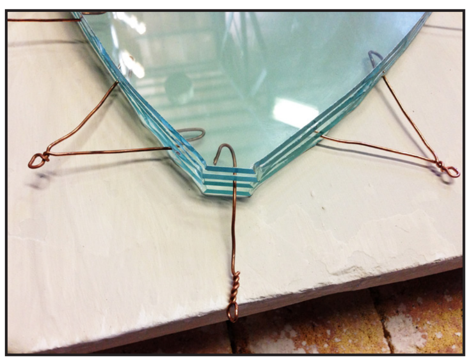


Figure 26. *Revised hook system*

I also increased the hold time at the annealing and strain temperature in the annealing cycle, and avoided crashing the temperature of the annealer from fusing temperature to annealing temperature. That practice is usually done to prevent devitrification from forming in the glass, but it did not seem to be a problem. Rather, the problem was the cracking, so that took precedence. I applied these modifications and the fuse went beautifully (Figure 27). I was now ready to try my last slump attempt. I had already made myself a two sided kayak-style paddle out of glass in the event that I got to this point. Whether I could put it to use would be determined shortly (Figure 28).

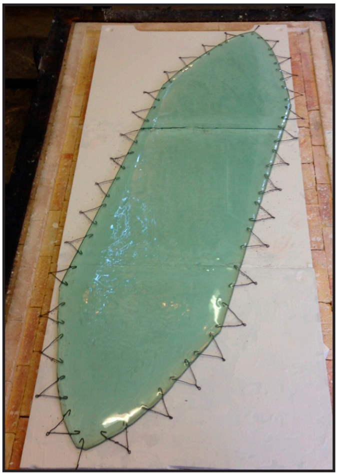


Figure 27. *Final fuse*

Figure 28. *Glass paddle*

I did not alter the mold design from the first slump attempt: the alterations I implemented were in the way I tensioned the glass on the top of the mold's bricks. On the back of each of the v-hooks that were fused in the glass was a ring through which I was able to run stainless steel wire. I threaded the wire through the ring of a v-loop on one side of the boat, ran the wire under the kiln shelf, and tied it off to another v-loop ring directly opposite the first. In this way, the more the boat pulled down, the more it held itself tight to its original position above the mold. Running the stainless wire under the kiln shelf also helped disperse the weight from the vertical bricks of the slumping mold. As an added step, I also stapled the vertical bricks of the mold to the horizontal ones beneath it. The result looked like something out of Gulliver's Travels (Figures 29 & 30).

Figure 29. *Tensioned fusing*

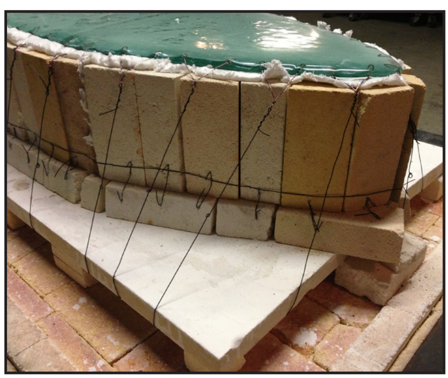


Figure 30. *Detail*

Everything was in place and seemed ready to slump. The alterations I made proved to correct my previous mistakes – I had successfully slumped a seven-foot glass boat (Figure 31)! This was all very exciting, but I could not help wanting to test the craft's buoyancy. I wanted to see if my voyage 20 miles down the Maurice River, into Delaware Bay and out to the great Atlantic Ocean was going to be possible.

I had previously worked with another friend of CGCA who is an engineer in order to determine the amount of surface area I needed to keep me and the boat afloat. I used these numbers to determine the measurements of my craft once I began to work at the seven-foot length. He came into the studio for the occasion to see how we fared. We forklifted the boat from the oven to a foam padded cart which we used to roll the boat to the campus pond.

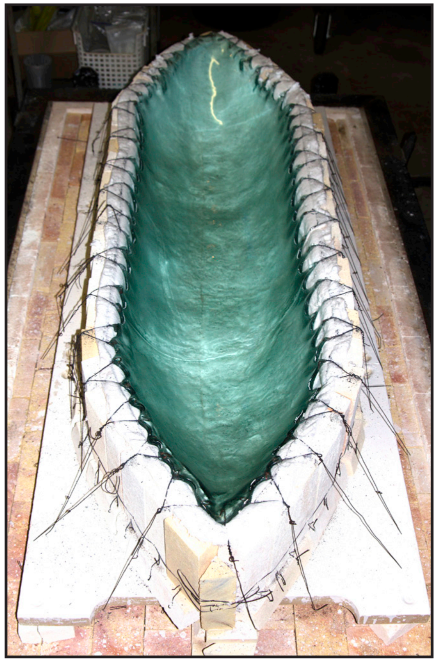


Figure 31. *Fused boat*

EPILOGUE

The moment of truth left us scratching our heads trying to figure out what went wrong in the equation. With about 10-20 pounds of pressure, the boat would begin to submerge beneath the water line (Figure 32). I lost about three inches of freeboard because of the way the boat slumped in relation to the copper hooks. It did make, however, very aesthetically pleasing u-shaped undulations along the sides of the boat. We may never know if those three inches would have made the difference in enabling me and this boat to attempt this voyage.

Figure 32. *Fused boat*

It is empirical speculation that leads me to believe that my ability to recount this story is a direct result of the boat's inability to provide me the necessary freeboard to float the river. The closer I came to rendering a successful glass boat, the more that the lesson I had learned, by way of the broken shards of sheet glass, sliced at my better judgement to float the river. I had fears of going hard aground and sinking, but not before slicing a femoral artery; I intended to wear Kevlar chaps as a preventive measure, if the freeboard was plentiful enough. I am, on some level, grateful that I did not have to determine if the chaps were necessary, or not.

Conversely, I am quite sad that I did not get the chance to experience the water in the almost absence of a boat. I wanted to see the clear thin line of the glass disappear into the interface of the water. I wanted to ride the edge between two worlds on a journey that defied good sense and rationale but challenged the confluence of poetry and art, just to see what it would look like. I still imagine it as a would-have-been mini epic chapter in my life: a journey only possible by letting go of better judgement to make room for beauty through danger and daring.

In any event, the engineer took me and my newly-wedded wife down the Maurice River on his more traditional boat to close our time in New Jersey (Figure 33). Looking past the pink horizon, to where the sun meets the dusk of the universe, I could not help but feel that everything was as it should be. We were still all traveling through this world in our vessels, seeking the best destination for our moments in time; that is a realization visible without the need to look through a lens of glass. The world still provided a path to pleasure combining dissimilar worlds in order to achieve new perspectives and new pathways.

Figure 33. *Maurice River*

British Society of Scientific Glassblowers Exam Syllabus and Competitions

by

Lee Mulholland[*]

ABSRACT

This will be an outline of the BSSG examination syllabus and competition programme as well as the role that the "Board of Examiners" plays in both. It will be presented in three parts, starting with the BOE and then moving on to the exam syllabus and competitions.

BOARD OF EXAMINERS

The Board of Examiners has, over the past 40 years, developed a series of Basic Training Courses. It is not intended that these courses should, in themselves, make up a craft apprenticeship but rather to provide a series of progressive basic training courses in bench lamp work (3 syllabi), hand lamp work (one syllabus) and lathe glass working (2 syllabi) in such a manner as to enable, by selection, varied personal requirements to be met. These courses can be used to advantage as 'in company' training courses.

BSSG exams have taken place in the UK as well as in Northern Ireland, New Zealand, Australia and South Africa. These exams are conducted by BSSG appointed examiners, Master Glassblowers or Society Fellows by appointment of the Examination Secretary of BOE. There have also been candidates from India, Jamaica, UAE and Nigeria (and soon Norway) taking exams in host workshops in the UK.

BOE have also been actively involved with Verre du Lycée Dorian (Paris school, Scientific Glassblowing Department) to encourage and assist with more international placements of their successful students. Currently we have been assisting a Quartz company in Malta to deliver an in-house training program to improve the level of skill of its workforce with BSSG accredited certification for staff members undertaking the program. To date there have been over 250 BSSG examinations taken.

As the Society offers no official training courses or facilities, anyone wishing to take any or all of the exams must first purchase a syllabus and work through the contents with the help of their employer or training facility. Then when they feel ready, they can apply to take their exam. The BSSG will always be happy to help those from overseas who wish to take an exam or find a venue in the UK to do so. The workshop here, at the University of Southampton will have hosted an exam for Elijah Aller from the University of Oslo by the time you read this. On the day of the exam, one of the BOE appointed examiners (two examiners need to attend the final exam) will arrive at the venue to oversee the examination process and mark the examinee's work at the end of the day.

EXAMINATION SYLLABUS

The BSSG exam syllabus is broken down into seven separate exams. These are,

1. Introduction To Elementary Scientific Glassblowing
2. Handburner Glassworking
3. Bench Glassblowing Stage One
4. Bench Glassblowing Stage Two

[*] Glassblowing Workshop, School of Chemistry, University of Southampton, Highfield, Southampton, Hampshire, SO19 7RD, UK. Email: Lrm1@soton.ac.uk.

5. Lathe-Working Stage One
6. Lathe-Working Stage Two
7. Certificate of Competence

INTRODUCTION TO ELEMENTARY SCIENTIFIC GLASSBLOWING

A beginner's course. The syllabus has been arranged to provide a simple basic training for technicians and scientists wishing to acquire a useful elementary expertise as an addition to other laboratory skills.

Also, when applied with emphasis on basic manipulative skills, this syllabus provides a progressive and interesting starting point for the apprentice glassblower.

Practical examination: 3 hours

Pass standards: Pass 50%
Credit 70%
Distinction 85%

Figure 1 is one of the drawings from the exam.

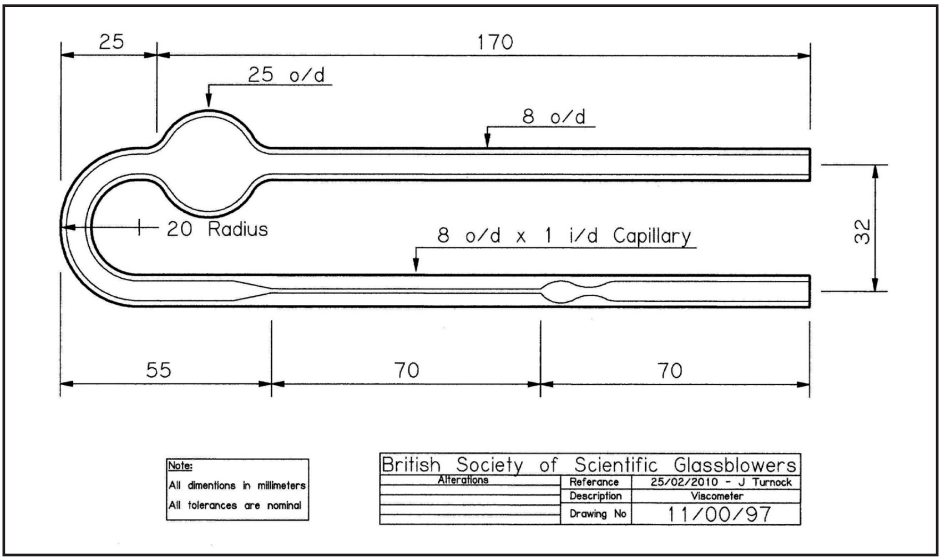


Figure 1. *Viscometer from "Introduction to Elementary Scientific Glassblowing*

HANDBURNER GLASSWORKING

This syllabus may be taught in conjunction with the Elementary syllabus on which to some small degree it is dependent; a combination of both will provide a much improved scope of simple basic techniques considered adequate to meet the needs of most technicians and scientists.

This course is also an essential preliminary to Lathe Glass Working

Practical examination: 3 hours

Pass standards: Pass 50%
Credit 70%
Distinction 85%

SCIENTIFIC GLASSBLOWING STAGE ONE

Practical bench lamp work with a little theory. A progressive continuation and broadening of the work covered in the Elementary syllabus.

Practical examination with a short written paper: 5 hours

Pass standards: Pass practical 55% + written 50%
Credit practical 70% + written 60%
Distinction practical 85% + written 70%

These pass standards are the same for the next three exams.

SCIENTIFIC GLASSBLOWING STAGE TWO

Practical bench lamp work with a little theory. A progressive continuation of the work covered in Stage One syllabus and a broadening of techniques.

Practical examination with a short written paper: 5 hours

LATHE GLASSWORKING STAGE ONE

A basic course for beginners covering the first principles of glass manipulation using a glassworking lathe. Some theory is included as well as lathe care and maintenance.

Practical examination with a short written paper: 4 ½ hours

ADVANCED LATHE GLASSWORKING

Further development of Lathe Glassworking. This syllabus includes work of an appreciatively higher standard than Lathe Glassworking Stage One. Some theory is included.

Practical examination with a short written paper: 4 ½ hours

Figure 2 is one of the drawings from the exam.

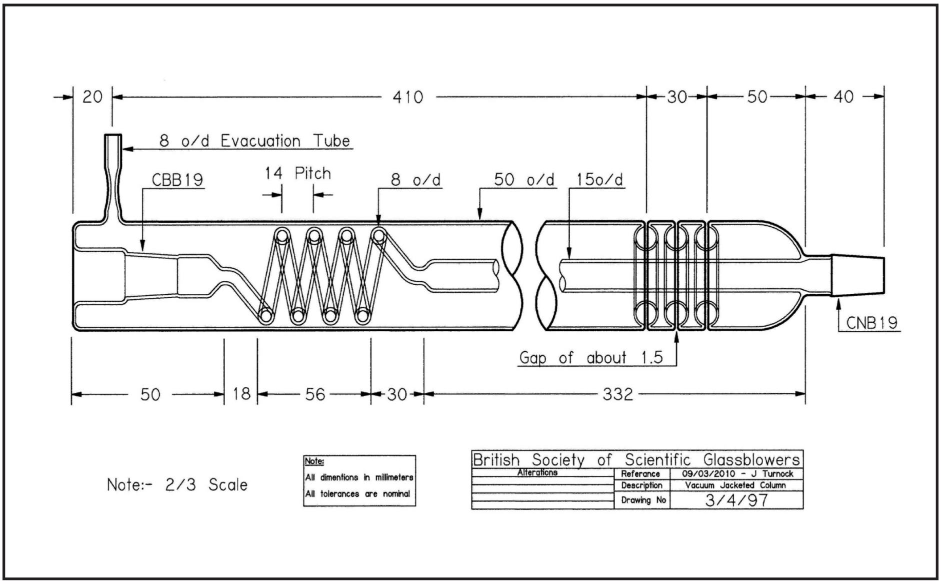


Figure 2. *Vacuum Jacketed Column from "Lathe Glassworking Stage 2"*

STANDARD OF COMPETENCE

The Standard of Competence is accepted by the BSSG as qualification for Full Membership of the Society and application for full membership is implicit in the examination application form.

The practical work includes operations of a higher standard than Scientific Glassblowing Stage Two syllabus. However, the sizes of tubing to be manipulated remain quite reasonable, although some experience is desirable in handling longer lengths of tube and heavier pieces of apparatus. Some lathe work is included, but not appreciably higher in standard than Lathe Glassworking Stage One syllabus. The written paper is of a higher standard and of greater breadth than the combined courses and includes a few of the more common techniques. The standard of the examination pass mark is higher than the normal course examinations.

The Standard of Competence provides a useful terminal course for full-time glassblowing students dependent mainly on short courses to advance their knowledge of basic manipulative skills. Also, the examination may be used as a proficiency standard – a standard of competence.

Practical examination with short written paper: 6 hours

Pass standards: Pass practical 60% + written 55%
Credit practical 70% + written 60%
Distinction practical 85% + written 70%

Figure 3 is one of the drawings from the exam.

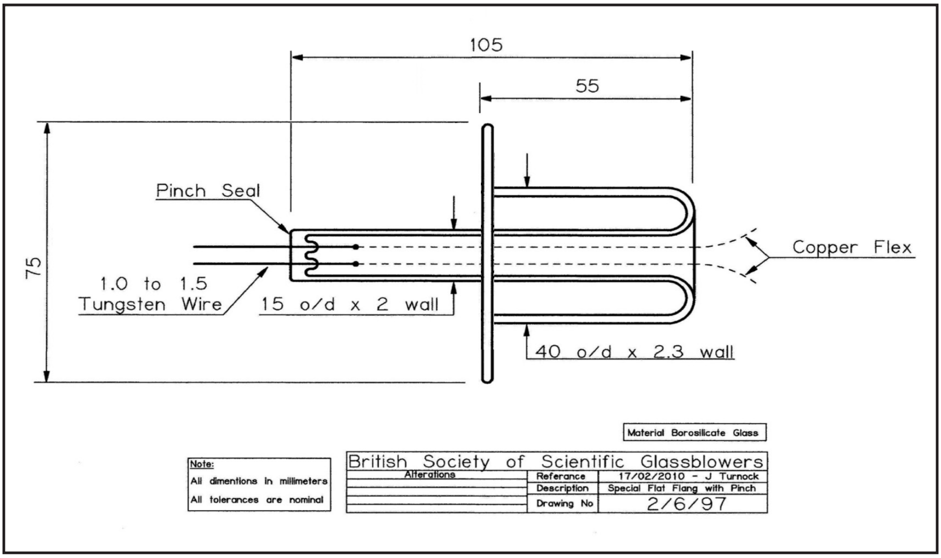


Figure 3. *Special Flat Flange With Pinch from "Standard of Competence"*

PRICE LIST

Syllabus pack – Elementary to Competence: £425.00

NB. Examination Syllabus packs can only be purchased by BSSG members.

UK based Examination fees.

BSSG Members: £250 per examiner per day

Non-members: £300 per examiner per day

Overseas Examination Fees

BSSG Members: £75 per examiner per day, payable to BSSG Office

NB. All costs incurred to facilitate an examiner's attendance should be agreed upon with the examiner and independently met ahead of the examination date.

Non-members: £120 per examiner per day, payable to BSSG Office

NB. All costs incurred to facilitate an examiner's attendance should be agreed upon with the examiner and independently met ahead of the examination date.

Elementary – Maximum permissible number of candidates sitting the examination on one occasion: 10 candidates.

Handburner – Maximum permissible number of candidates sitting the examination on one occasion: 6 candidates.

Stage One Bench – Maximum permissible number of candidates sitting the examination on one occasion: 8 candidates.

Stage two Bench – Maximum permissible number of candidates sitting the examination on one occasion: 8 candidates.

Lathe One – Maximum permissible number of candidates sitting the examination on one occasion (equipment availability permitting): 4 candidates.

Advanced Lathe – Maximum permissible number of candidates sitting the examination on one occasion (equipment availability permitting): 4 candidates.

Standard of Competence – Maximum permissible number of candidates sitting the examination on one occasion: 4 candidates NB. **Two Examiners required**

ANNUAL GLASSBLOWING COMPETITIONS

The Board of Examiners is also responsible for the running and judging of the four scientific and one artistic glassblowing competitions that are held each year, with the winners being awarded their trophies and cash prizes at the symposium "annual dinner" (Figure 4).

Figure 4. *Trophy Table and Competition Entries 2013*

The competitions and their entry requirements are as follows :

AD WOOD CUP

This is open to any "Trainee" member with up to three years' experience. The entry must be made up of one "set piece" (to be set by the BOE each year) and one "free piece." Both pieces must be made without the use of a lathe

HAMPSHIRE TROPHY

Open to any member with up to seven years' experience. The entry must be made up of one "set piece" and one "free piece," both to be made without the aid of a lathe.

SILICA CUP

Open to any member. The only restriction on design, method or machinery used is that the piece must be made from quartz.

QUICKFIT CUP

Open to any member, with no restriction on design, method or machinery used.

DAVID FLACK AWARD

This is an artistic competition open to any member. All entries are to be displayed at the symposium with the winner decided by a secret vote by all attendees and companions, with the winner announced at the "annual dinner."

BIBLIOGRAPHY

BSSG Exam Syllabus

Plastic Safety Coating of Laboratory Glassware

By
Philip R. Surdam*

ABSTRACT

Plastic safety coating of borosilicate glassware is the process described in the following paper. It allows you to increase the safety of your laboratory glassware by coating it with a co-polymer powder that is chemically bonded to the surface and provides added protection. The coating prevents abrasions that can lead to glassware failure, it is resistant to nearly any solvent or acid, and it has a slip-resistant surface for improved handling.

The coating increases durability to glassware while under pressure and vacuum to reduce the hazard of propelled fragments of glass should an item rupture. The contents are also contained by the plastic coating for easy cleanup.

INTRODUCTION

Plastic safety coating of laboratory glassware is a process which allows the containment of materials within borosilicate laboratory glassware in case of breakage. This process thus maintains the structural integrity of plastic coated (borosilicate glass) items in laboratory conditions such as rotary evaporation and certain types of high-performance liquid chromatography (HPLC)—although not limited to these two fields of study. Nearly any (size allowable) Pyrex®/borosilicate item can be plastic coated using the Chemglass (or other) process to achieve the same goal. At Chemglass we can plastic coat up to a 40 gallon carboy, or a 50 L round bottom flask.

The benefits of plastic coating are as follows:

- Increase safety in the laboratory
- Reduced hazards of pressurized glassware
- Resistance to chemical attack
- Help to contain or prevent spills
- Transparency with UV absorption[1]

The main difference (besides cosmetic) between the processes of different companies and institutions is the maximum temperature rating of the plastic safety coating.

At Chemglass, our maximum temperature rating is 60° Celsius (or 108° Fahrenheit) on our original process. We also offer a blue tint for use on our Mobile Phase HPLC Cap Systems (CG-1167-Series). The blue tint helps to identify a coated vs. a non-coated bottle—another benefit to this line is the higher temperature rating of 121° Celsius or 217° Fahrenheit.[2]

PLASTIC COATING PROCESS

Materials: Glas-Lok® Plastic Coat powder, Teflon® tape, silicone tape, aluminum holders,

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* Chemglass Life Sciences Inc., 3800 N. Mill Road Vineland, New Jersey 08360. Email: phil@chemglass.com.

[1] *Glas-Lok® Product Fact Sheet: PFS Thermo-Plastic Powder Coatings*, 3400 West 7th, Big Spring Texas, 79720.

[2] *Chemglass Catalog 2000* (Chemglass Life Sciences, 2000), "Plastic Coating," pg. XIV.

air lined holding tank for plastic powder, Wilt or Trent Oven; 9KW, 3 Phase 240V. X-Acto® knife. grinding bench/1200 grit emery

Step 1: Prepare an oven with either no fan, or the fan turned off. Pre-heat to 420°F. 400° is the recommended temperature, but the extra 20° compensates for heat loss when opening the door (Photos 1 & 2).

Photo 1

Photo 2

Step 2: While the oven heats up, prepare the glassware by readying the holder: adding, removing Teflon® tape to fit the neck. Insert holder into neck, secure with silicone tape (Photos 3-9).

Photo 3

Photo 4

Photo 5 **Photo 6**

Photo 7 **Photo 8**

Step 3: Windex/clean item (Photo 10).

Photo 9

Photo 10

Step 4: Place item in oven for heating: 15 minutes (Photos 11, 12, 13).

Photo 11

Photo 12

Photo 13

Step 5: Turn on the air to the fluid bed of the powder tank to give the plastic powder its buoyancy. Stir the plastic powder in the tank to prepare to dip the item in the plastic powder (Photos 14, 15, 16).

Photo 14

Photo 15

Photo 16

Step 6: (Kevlar) Glove up and remove the item from the oven; dip in the plastic powder (Photos 17, 18).

Photo 17

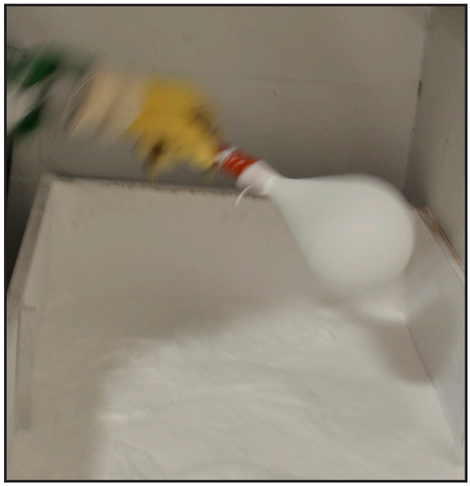

Photo 18

Step 7: Return item to the oven for baking: 10 minutes (Photos 19, 20).

Photo 19

Photo 20

Step 8: Remove item from the oven, place on cooling tray (Photos 21, 22). (Item can be returned to oven if coating is uneven, dimpled, or cloudy.)

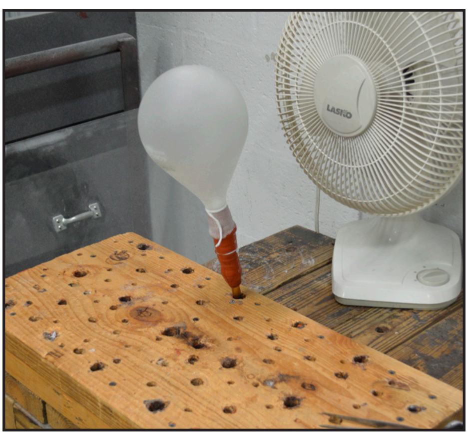

Photo 21

Photo 22

Step 9: Remove silicone and Teflon® tape, use X-Acto® knife for accuracy (Photos 23, 24, 25).

Photo 23

Photo 24

Photo 25

View of finished product (Photos 26, 27, 28)

Photo 26

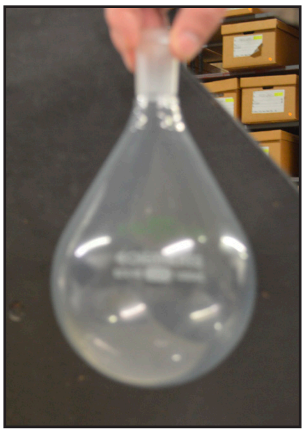

Photo 27

Photo 28

Step 10: Touch up grind using 1200 grit emery and wash (Photos 29, 30).

(Optional depending on availability, but recommended, as the process can leave melted plastic baked into the grind leading to possible leaks under vacuum.)

Photo 29

Photo 30

CONCLUSION

There is no better way to protect your chromatographic column, flask, bump trap, or any other scientific glassware than with plastic safety coating. The co-polymer coating is chemically bonded to the glass surface and provides added protection to your glassware. The plastic coating prevents abrasions that can lead to glassware failure; it is resistant to almost any solvent or acid, and it has a slip-resistant surface for improved handling.[3]

The coating also adds strength to glassware while under pressure to reduce the hazard of propelled fragments of glass should the item rupture. The contents are also contained by the plastic coating for easy cleanup. Sufficiently clear and colorless, plastic coating permits observation into the glassware.[3]

Plastic safety coating of borosilicate laboratory glassware has become a staple of the laboratory supply industry and a fixture in our catalog and day-to-day operations at Chemglass Life Sciences for over 23 years. We list several catalog items with the plastic coat option. Chemglass offers the service for any (size allowable) item in our catalog or as an additional charge to any (size allowable) custom/special item that we may quote.

CREDITS

Thanks to Brad Weir who performed the plastic coat shots (and who runs that Department), and Rick Munyan who did the grinding shots (and who runs that Department).

I wish to thank Mr. Robert Quinn, who developed the Plastic Coating process for Chemglass Life Sciences in 1993 that we still employ to this day and particularly his widow Mrs. Dorinda Quinn, whose strength to go on after losing her husband and both of her sons (two of my best friends). She is an inspiration to all who may lose hope in those darker moments of the human experience. I hope and pray that the years remaining to her are blessed with an ease of grace that she has brought to so many.

Thanks are also due to Alan Durham who runs production for the Surdam family at Chemglass, Tony Mavilla who runs operations, and Amador Roman who has taken over many of the day-to-day duties concerning Lehr/Annealing and Decorating operations as I finally make the move into management.

Also I would like to thank my Father, Walter E. Surdam, and my Grandfather, Walter P. Surdam, two men without whose hard work, dedication to family, and foresight in business, I would neither be writing these words nor walking this Earth.

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[3] Chemglass Life Sciences Inc., Section on: "Mobile Phase HPLC Systems" http://www.chemglass.com/product_view.asp?pnr=CG-1167.

Precision Vacuum-formed Liquid Microjet Fabrication

by

Christopher J. Miller*

ABSTRACT

Precision nozzles capable of producing jets with diameters ranging from 10-500 micrometers (μm) were fabricated for research in molecular beam scattering experiments at the University of Wisconsin-Madison. A borosilicate tube was sleeved over an EDM graphite mandrel, and then heated, and formed under constant vacuum. The mandrels were formed using a standard CNC lathe, and could be shaped to produce any nozzle or vessel with an arbitrary size and monotonically decreasing interior geometry. In order to achieve jet diameters below 500 μm, mandrels with slightly shorter tips were inserted into the nozzle and secured before carefully heating, pulling, and shaping the final taper to the desired specifications. The final exit port diameter was manipulated using a Bunsen burner and characterized using a Dino-Lite edge AM4515T8 optical digital microscope.

INTRODUCTION

While modern scientific techniques have made significant advancements in the understanding of bulk properties of liquids and gasses, a complete picture of molecular dynamics at the surface of the gas-liquid interface has proven to be difficult to probe experimentally. One scheme that has been particularly effective involves scattering of a gaseous beam of particles off the surface of a liquid in a vacuum chamber equipped with mass spectrometer. The data collected from the spectrometer is used to produce an energy distribution of the molecules that can provide useful insight into their interaction. Although these molecular beam scattering experiments utilize a large variety of reaction schemes, most fall into two main categories with distinct experimental setups involving either high, or low vapor pressure liquids. The extremely low pressures involved in these experiments produces a high rate of evaporation in all liquids relative to their rate of evaporation at standard pressures. When trying to understand the gas-liquid interaction at the surface of a liquid, the interaction between the gaseous beam of particles, entering or leaving the jet, and the evaporation of liquid from the surface constitutes a gas-gas interaction. This interaction results in undesirable noise that is difficult to separate from the data representing the signal of the gas-liquid surface interaction.

For very low vapor pressure liquids, this evaporative noise is minimal and corresponds to such a small percent of the total signal that data acquisition is not significantly hindered. Correspondingly, these types of liquids have proven to be relatively easy to study by scattering a gaseous beam of particles off a disk that is continuously coated by rotation through a liquid reservoir. However, when the liquid of interest has a particularly high vapor pressure, a different experimental setup is required in order to effectively reduce the noise in the detected signal. The most common way to minimize evaporative noise is to reduce the surface area of the highly volatile liquid by introducing it into the vacuum chamber using a precision liquid microjet as shown in **Figure 1.**

A liquid microjet is a specialized nozzle or apparatus that is used to produce a fine jet stream of aerosol particles with a sub 100 μm sized jet diameter. While these microjets can be manufactured using a variety of methods and materials, borosilicate and quartz

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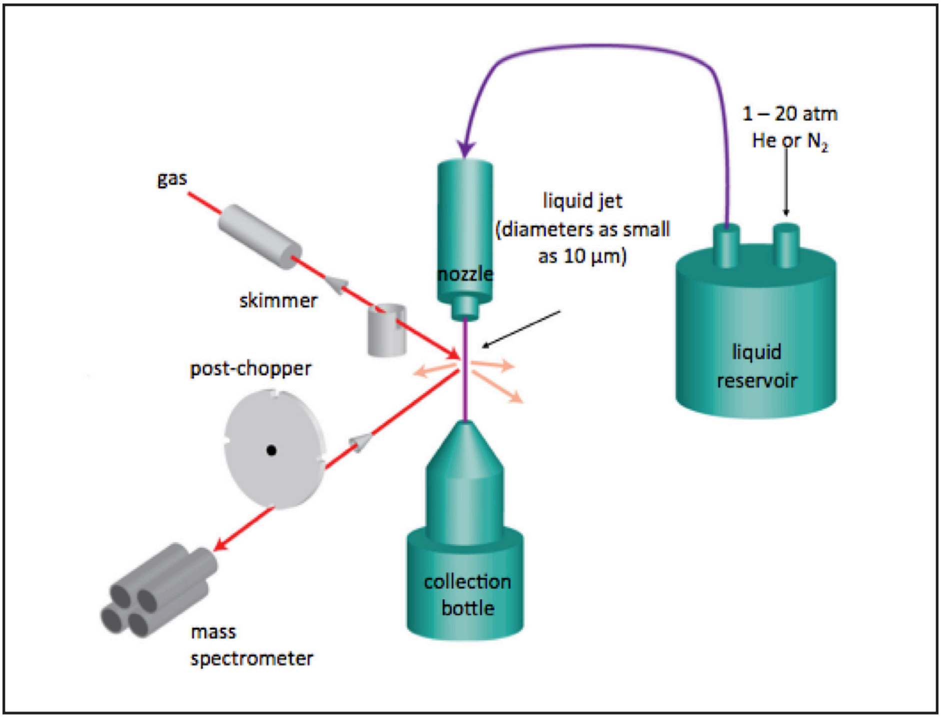


Figure 1. *High vapor pressure beam scattering experiments with liquid introduced into the vacuum chamber via a liquid microjet*

jets have gained particular interest due to their superior chemical inertness under a wide range of reaction conditions. In order to effectively reduce the evaporative noise in the jet, the exit hole diameter of the jet has been found experimentally to range anywhere from 2-100 µm, depending on the particular volatility of the liquid of interest.

While CO_2 lasers as well as capillary tubes have been utilized to achieve consistent exit port diameters at this level of precision, implementation of each method comes with its own unique disadvantages. Glass capillary tubing is manufactured to a very high tolerance with inner wall diameters ranging from 1 mm all the way down to 2 µm. These tubes can be used as is; however, in order to implement these tubes effectively, enormous backing pressures must be used to produce jets with the desired velocity. The major drawback of this technique is that experiments become increasingly cumbersome and dangerous as the radius of the exit port is reduced.

By gradually reducing the diameter of the tube down to the diameter of the exit port, the desired surface area reduction can be achieved with much lower backing pressures. One method that has been implemented to achieve this characteristic involves introducing a precise hole in a pre-made sealed nozzle using a laser. Since glass absorbs strongly in the infrared spectrum, CO_2 lasers have been utilized in order to produce consistent exit port diameters as small as 2 µm. Although this is perhaps the best method for creating exit ports smaller than 100 µm, this technique requires very expensive optics tables and becomes unrealistically expensive and time consuming when producing nozzles at a scale appropriate for regular laboratory use.

Therefore a cheap, efficient, and consistent method of liquid microjet production is essential in order to more easily facilitate molecular beam scattering experiments involving high vapor pressure liquids. In this paper, a method of vacuum formed borosilicate liquid microjet fabrication is proposed and analyzed after implementation in various molecular beam scattering experiments.

METHODS

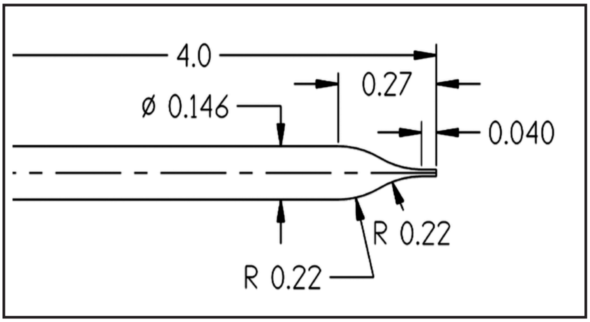
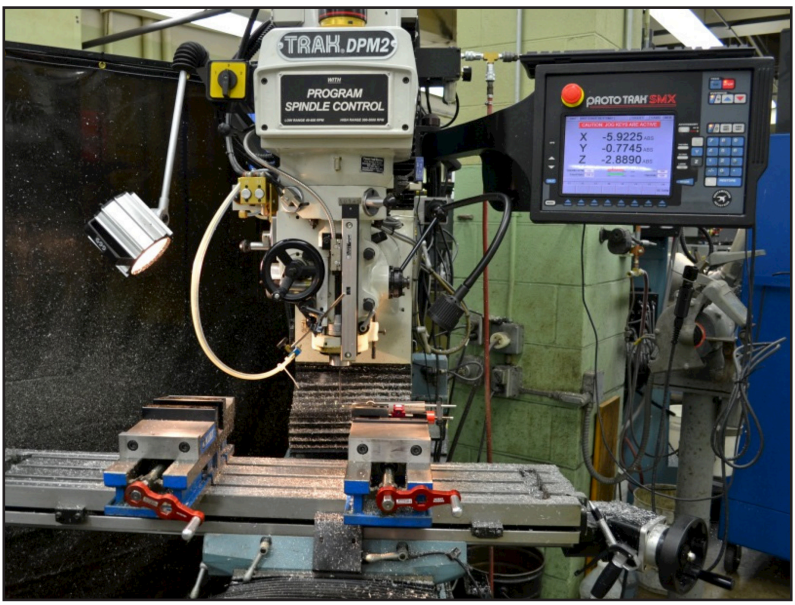


Figure 2: *The mandrels tapered from 3.7 millimeters to a small linear 500 µm section and were designed using equations derived to produce jets approaching laminar flow*[1]

A detailed CAD drawing of the "negative" of the desired shape of the final mandrel or vessel, is created and loaded into the CAD program as shown in **Figure 2.**

Special attention is required in order to ensure the large linear section of the mandrel tapers vary slightly from the large end to the tip; this ensures that the mandrel can be removed from the nozzle after forming. A ¼" graphite mandrel composed of EDM graphite is then inserted into a CNC lathe and machined to program specification as shown in Figures 3 and 4.



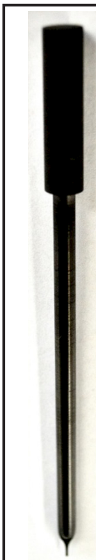


Figure 4

Figure 3: *CNC lathe used to produce EDM graphite mandrel*

Figure 4: *EDM graphite mandrel after tooling*

[1] R.D. Reitz &, F.V. Bracco, "On the Dependence of the Spray Angle and Other Spray Parameters on Nozzle Design and Operating Conditions," *Society of Automotive Engineers* Technical Paper 790494, 1979.

The mandrel is prepared for vacuum forming by dipping in Aquadag® solution and subsequently dried in a cool bushy flame. The mandrel and tube are chucked up in the lathe and a mechanical vacuum pump is connected to the tube. The tube is outfitted with a small bumper in order to fit a standard ¼” Ultra-Torr fitting. The tube is then sleeved over the mandrel, heated, and vacuum-formed to produce the desired shape as shown in Figures 5 and 6.

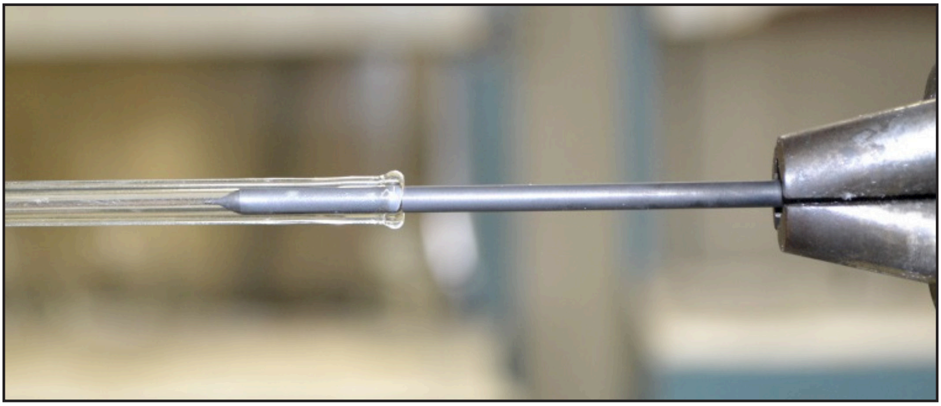


Figure 5: *The vacuum is attached to the tube on the left and is running while the tube is sleeved over the mandrel, heated, and formed*

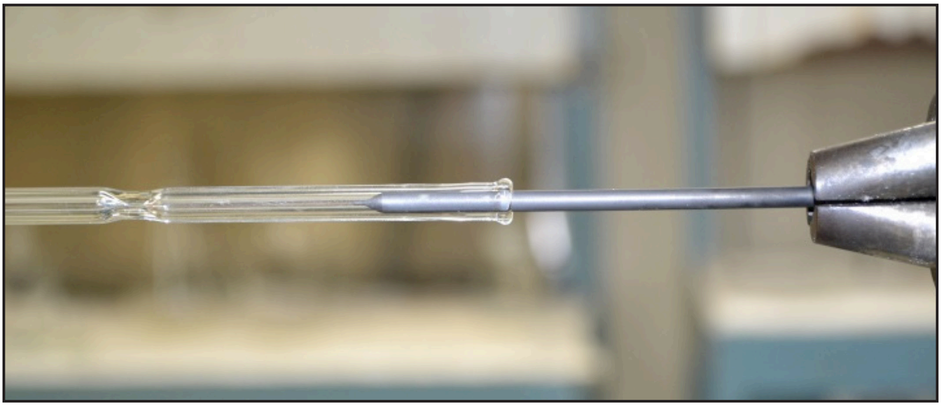


Figure 6: *Removing the mandrel from tube after vacuum forming process*

Care must be taken during heating and forming in order to prevent sealing the tube to the mandrel. The tube is removed from the lathe and connected to a compressed air line with an in-line 2 μm filter. While under constant internal air pressure, the tube is then cut as close to the taper as possible, so that the interior geometry is continuously decreasing. The air line and nozzle must be kept extremely clean during this process in order to prevent clogging of the nozzle.

In this case, due to the material properties of the particular EDM graphite used, the small linear section on the mandrel could not be machined smaller than 500 μm. The tube could be cut at this point to produce very reliable and consistent nozzles with 500 μm exit ports. In order to produce nozzles with exit ports smaller then 500 μm, mandrels with shorter tips were inserted into the nozzle and secured while the tip was heated, condensed, and pulled to the approximate desired size as shown in Figure 7.

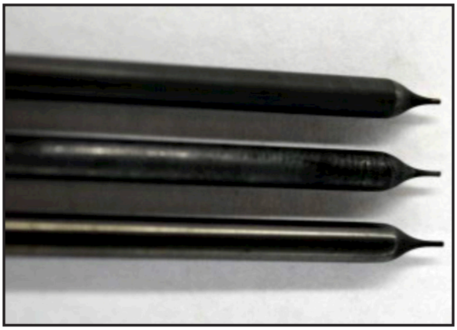


Figure 7: *Working set of tip-finishing mandrels with lengths increasing from top to bottom*

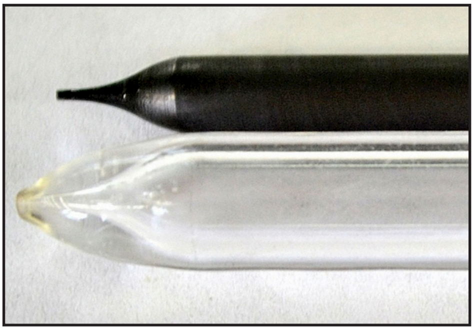


Figure 8: *Nozzle and mandrel after tip has been condensed and pulled during finishing process*

This process allowed the majority of the nozzle geometry to remain consistent and unaltered while the tip was manipulated during the finishing process as shown in Figure 8.

With good eyes, a 1 mm section of the tip can be condensed, pulled, and tapered visually from 500 µm down to about 100 µm. Further finishing work is done using a Bunsen burner, which can be carefully used to reduce the exit port to the desired size with a tolerance of ~5 µm as shown in Figure 9.

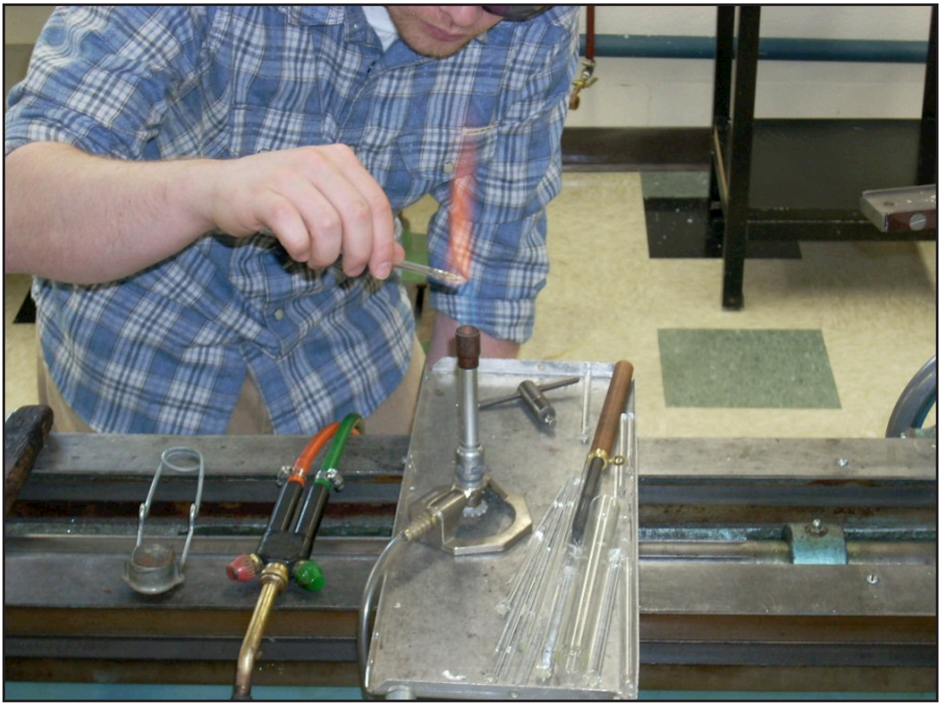


Figure 9. *The tip is heated for approximately 30 seconds in the Bunsen burner until the exit port condenses slightly*

The exit port diameter is measured using a Dino-Lite Edge AM4515T8 optical digital microscope as shown in Figures 10 and 11.

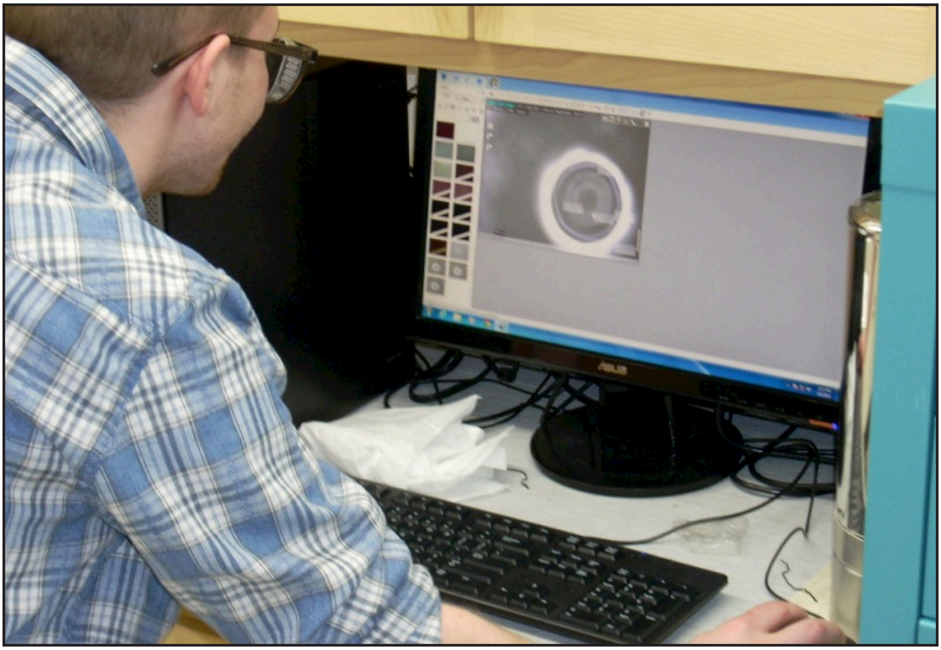


Figure 10: *Computer interface for Dino-Lite Edge AM4515T8 optical digital microscope*

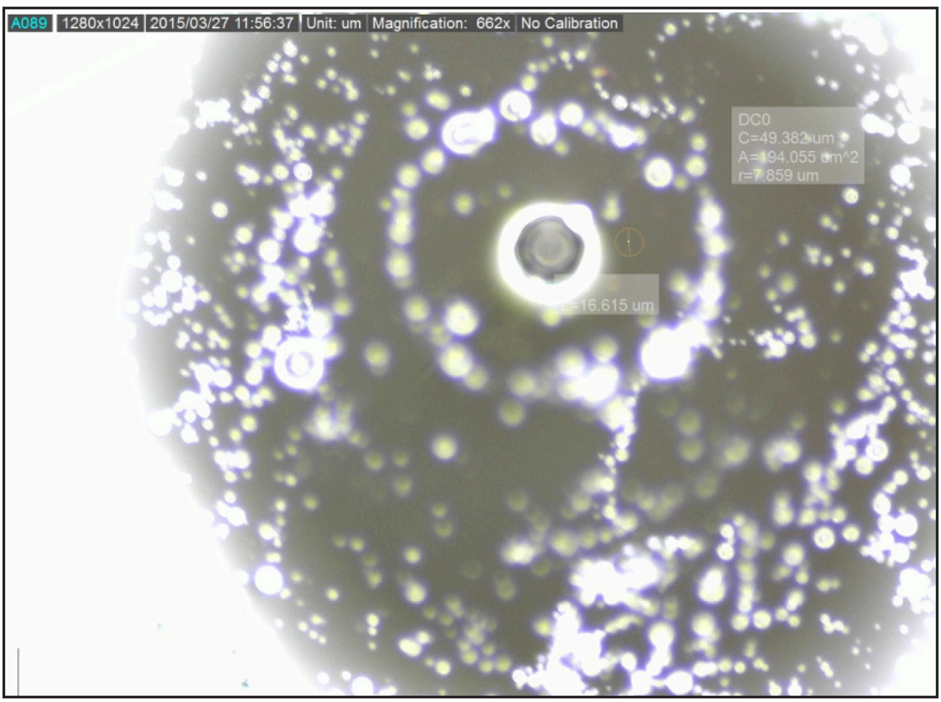


Figure 11: *Image of 15 μm exit port captured with the Dino-Lite Edge AM4515T8 optical digital microscope*

RESULTS/DISCUSSION

A variety of methods were conceived and implemented in an attempt to create an ideal borosilicate microjet fabrication scheme. Of the three methods that produced nozzles capable of yielding experimentally viable results, the vacuum forming method is conceptually the most promising. The other two methods are detailed in appendixes I and II. These methods were abandoned because they were unable to provide the required control over the final nozzle geometry and exit port diameter, and produced nozzles with varying shapes and jet characteristics.

The ability of the vacuum forming method to mold all of the nozzles around one common mandrel at least partially resolved these issues. Unfortunately, the material properties of the EDM graphite used hindered the ability of their tips to be machined smaller than 500 μm while maintaining the desired geometry. This introduced some uncertainty and inconsistency in the final nozzle since the nozzle tips must be heated and manipulated to create exit ports smaller than 500 μm. With careful practice and good eyes, pulling and condensing the tips can become a relatively consistent process. However, the human element still remains the largest contributor to uncertainty in this process. Fire polishing during the finishing process also introduced some uncertainty in the final section of the tips. This still remains an important step because it eliminates undesirable roughness that would otherwise impede the jet's ability to approach laminar flow.

With a more advanced machine shop, mandrels could be easily machined with tips as small as 100 μm allowing minimal distortion of the taper during the finishing process. This method could be also improved by precisely cutting or grinding open the tip, and subsequently polishing with hydrofluoric acid to produce exit ports with a crisp smooth edge.

CONCLUSION

The vacuum forming method proposed is a consistent and reliable fabrication scheme capable of producing nozzles with superior symmetry and reproducibility. This process could be adapted to produce vessels with an arbitrary size and very precise interior specifications. The main limitation is that the vessel interior must be monotonically decreasing from one end to the other so that the mandrel can be removed after forming.

ACKNOWLEDGMENTS

I am grateful to the National Science Foundation for funding these studies. I would like to thank Tracy Drier and all members of the Nathanson research group for their help and support.

APPENDIX I

A 5.5 mm outer diameter (o.d.) capillary tube with an inner diameter (i.d.) of 500 μm is placed in the chuck of a glass lathe, and sealed to a glass rod that is held by the opposite chuck on the lathe. A heat gradient is applied to a small section of the tube by careful heating and pressurizing to a relatively constant internal pressure via a blow tube attached to the open end of the capillary tube. The lathe chucks are moved slightly apart in the horizontal direction so the outer diameter of the tube remains constant while a tapered inner diameter ranging from 500 μm to 2.9 mm with a length of (10-19 mm) is simultaneously produced.

The end of the capillary tube with the larger interior diameter is then blown open and "wiped" clean to prepare the tube for a reliable vacuum seal. A 6.49 mm o.d. borosilicate tube with a wall thickness of 1.15 mm is blown open, wiped clean, and fused to the larger open end of the prepared capillary tube. This seal is worked so that that the resulting o.d. is less than 6.49 mm.

The tube is removed from the lathe and connected to a compressed air line with an inline 2 µm filter. While constant internal air pressure is being applied, the tube is then cut as close to the taper as possible such that the exit porthole has the same diameter as the original inner diameter of the capillary tube. While air pressure is still being applied, the edge of the capillary tube adjacent to the exit hole is then rotated against a rotating wet belt sander producing a bevel with an angle of about 60 degrees that begins at the exit port. It is important that after grinding, there should be a feathered edge between the taper and the ground diameter, and the end of the tube is such that the o.d. is approximately the i.d. of the capillary tube (500 µm). The feathered orifice of the microjet is cleaned by spraying it with Millipore water, and then removed from the air pressure line and allowed to dry.

Once dry, the tip of the jet is heated in a low temperature Bunsen burner flame for about 30 seconds to one minute depending on specific flame conditions. The glass at the tip condenses causing a decrease in the diameter of the exit port opening which can be readily measured using a Dino-Lite Edge AM4515T8 optical digital microscope. This process is repeated until the exit porthole has the desired diameter. Care must be taken to prevent heat penetration in the glass in order to preserve internal symmetry

APPENDIX II

A 6.49 mm tube is heated, condensed and pulled until the interior tapers to a micrometer-sized channel at the end. The tube is removed from the lathe and connected to a compressed air line with an in-line 2 µm filter. While constant internal air pressure is being applied, the tube is cut as close to the taper as possible such that the interior geometry is continuously decreasing. The tip is then successively ground, fire polished, and measured with a Dino-Lite Edge AM4515T8 optical digital microscope until the desired exit port diameter is achieved.

Tips For Transitioning Between Different Types of Glass

by

Corina Guerra,* Erin Mayberry and Grant Mayberry*****

ABSTRACT

This paper is a collaboration between three glassblowers with different technical backgrounds and skills and a combined 23 years of working glass. Each has written about their personal experience with the medium.

INTRODUCTION

The three of us wanted to write a paper that would be useful to anyone currently working glass regardless of skill level. Between us, we have over 23 years combined of broadly varied glass working experience. When transitioning from working one type of glass to another, it is important to note that while some inherent properties of glass are present, each type of glass has different 'rules' for successful application. The following paper reflects what was learned during different transitional experiences. We hope it benefits you.

PART I – CORINA GUERRA

After working with glass for the last eight years, I have picked up a lot of helpful tricks and techniques. I worked primarily with soft glass in the hot shop for most of that time. While studying glass at Alfred University, I also dabbled in bending and filling leaded glass tubing with neon. I first tried flame working with borosilicate when I was in my Senior year at Alfred; however, I did not really learn to work with borosilicate until I started studying scientific glass techniques at Salem Community College. I am fortunate that my background in the hot shop and neon have helped me grasp several concepts while learning to work borosilicate, though some habits I learned from the hot shop have hindered my ability to work on the torch.

My classes in neon helped with my ability to recognize and replicate a good seal when sealing two borosilicate tubes together, whether it is a side seal or a straight seal. When working with leaded tubing in neon, it is the of the utmost importance to make sure that your electrode-to-tubing seals as well as seals between the parts of the sign can withstand vacuum pressure; you cannot complete the bombarding process if you have leaks in your seals.

My background in the hot shop has made it easy for me to work efficiently in the flame shop. When working in the hot shop, it is important to plan your steps and perform each step as quickly as possible. This is because when you sit down to work, you only have a few crucial moments to do what you need to do before your glass is too cool to work with and it takes a decent amount of time in front of the glory hole to heat your glass to proper working temperature. This ability to plan ahead and use my heats effectively has increased my ability to work quicker in the flame shop; this has particularly helped me at my job in scientific glass production. I have also learned that while it is helpful to have your glass very hot while working with it, it is not always beneficial to do so when

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working with borosilicate. For example, when flaring the glass it is important to not get your glass very hot, but only just hot enough to move slightly. In the hot shop, it is best to have your glass as hot as possible because your tools will cool your glass down quickly. I have a greater understanding of how gravity affects the movement of glass since gravity is a key component in how you work with glass in the hot shop. I have found that it is not quite as important while working borosilicate - perhaps that is because I work mostly on a lathe these days.

Although my background with hot glass and neon has drastically helped me while learning to work borosilicate glass, there are some technical concepts I have found difficult to grasp. My main struggle has been having two axes to keep on center as opposed to one. I learned to use my hands together on one side of the glass to create a seamless revolution of the pipe or puntil in the hot shop; when one hand can no longer turn, the other takes over. In the flame shop, it is crucial to turn both hands independently from each other, but consistently the same as each other. It has been difficult for me to work on blown vessels on the torch as a result of this two axis conundrum. This issue is easily fixed by using a lathe because the lathe will always turn each axis consistently and in sync.

Another thing I have struggled with while working with borosilicate is using color and color application. There are only two ways you can change the way a color looks while working in the hot shop. One way of changing the color is by reduction, which means to put the colored glass in a gassy environment. This is done intentionally with colors that have a high silver or gold content and creates a metallic sheen effect. The other way of changing the way a color looks is by striking it, which usually has to be done with reds. This is done by bringing the colored glass up to a high temperature to make sure the color reaches its full potential of brightness and vividness. Borosilicate color has so many ways to work with specific colors. The way a color turns out depends on your flame chemistry, where you hold it in your flame, and even how long you work it. There is one borosilicate color in particular that comes to mind, Slyme, which I have been told you need to preheat in a hot bushy annealing flame before working it in order to have the color reach its full potential. There are too many variables for me to understand, which is why I have had a hard time gaining control over how a color looks when I use it.

PART II – GRANT MAYBERRY

Appreciating glass seems to be in human nature: from its color and brilliance to its form and function, everyone can relate to it and enjoy it. It is beneficial for an individual making glass to be aware of benchmarks and identifiers in glassware, such as but not limited to material or type of glass, size and thickness, color and cold working applications and piece construction. Some interesting commissions and experiences over the past nine years have exposed me to unusual problems and solutions in making glass. Here are just a few helpful ideas to keep in mind when making glassware. It should be noted that success in creating an artistic piece depends on your client's wishes and your ability to make the object and a profit.

Recently a metal fabricator and I were asked to make twelve beer taps for the Detroit Athletic Club (DAC). Being a well-respected club, we came up with two timeless designs. One style consists of gold-leafed glass medallions with stainless steel handles and a brass accent totem. The other was made with cast bronze handles and a glass baseball diamond shaped medallion with a bronze faceplate attached on the front. After looking over the approved design, I realized that grinding and polishing each shape was going to take me a minimum of three hours. This meant a little more than four eight-hour days would be needed to complete the shapes. Needing a fast way to cut 1⁄2" thick float glass and 1⁄2" fused 96 C.O.E. glass, I found that professionally contracted water jet cutting was a great solution for the problem. After spending $200 on cutting and $100 on glass, I was able to have all twelve pieces cut in less than three hours without wasting days grinding and shaping. Thankfully, the cutting was 100% successful making it easy to move forward with the project.

After nine years of blowing soft glass, I have made and assisted making many pieces that required a high level of skill and understanding of the material. From serving bits and utilizing color to blowing and sculpting repeatable shapes, I have always tried to understand the most efficient process for making my work. Furnace blown glass is demanding due to the fact that the glass is only at working temperature (1200º-1900º F) for about 30 seconds in between heats. Also, during this time you have to realize what shape you have and how to get to what you want, how you are going to get the piece off the pipe, what you need from an assistant, and what major moves need to be made with the heat you have. This is a lot of information for you to process while focusing on the end piece. Core heat can be used to make extreme changes in a piece in a very short amount of time. Using and understanding this heat can easily cut your working time on a piece in half. This is especially important when working on large pieces due to the weight of the piece and exposure to heat in the hot shop.

Having completed my water jet cutting as well as some polishing on the pieces for the DAC, a gold leaf logo needed to be applied to the front of the medallions. The easiest way to do this in my circumstance was to use a photographic emulsion product called "Rayzist" that transfers images to film that is then placed on glass and sandblasted. After that, sizing glue, a 24-hour curing glue, was painted on the sandblasted surface where the gold was to be applied. Next, while holding my breath so as not to disturb the ultra light gold leaf, I carefully placed gold leaf over the now-tacky surface of the sandblasted logo and used a small brush to adhere it into the surface. The non-adhered gold was simply brushed away. Of the six that were gold leafed, half needed a second coat for the edges to look clean.

PART III – ERIN MAYBERRY

My journey with glass began six years ago. I began working with solid borosilicate, then moved on to hollow sculpting before being formally trained in scientific glassblowing. My first glass experience working with anything other than 33 C.O.E., and not by myself, occurred during my first semester at Salem Community College. With three years of (non-scientific) borosilicate work under my belt, I enrolled in my first hot shop class. In some aspects, it made things easier; however, I was surprised about quite a few things. It was quite the learning experience.

Firstly, while it may seem advantageous to be working with a partner, I did not find this to be so. With flame working you are typically working alone, and any assistance needed is usually just a quick helping hand. Not so in the hot shop. While in a hot shop, both the gaffer and the assistant need to be completely aware of their every move and be able to anticipate any and all future movements. A slight delay in opening a door, providing a heat shield or even just getting out of the way could result in serious bodily injury or destruction of the piece. This was something I found extremely uncomfortable as I had only ever worked alone - if I burned or cut myself, or ruined a piece, it was my fault. The solution to this I found was to focus on being the best assistant possible. Too often, people only focus on the gaffing part, forgetting that assisting can sometimes be of even more value to the piece. While the gaffer creates and is responsible for design, the assistant has to make sure the item receives proper heats, the necessary tools and materials are available, not to mention being able to prepare punties and bits correctly. The assistant is usually the one running around the hot shop. To quote my teacher, Jenna Efrein, "If you cannot assist properly, you will never be able to work efficiently or safely in a hot shop."

One of the reasons I attended Salem Community College was the opportunity to work with a variety of different glasses and techniques. Besides scientific, I was able to take classes in kiln casting, hot shop and artistic flame working, amongst others. It was during an artistic flame working class that we worked on the torch with soft glass that had a C.O.E. of about 96. It flowed at a much lower temperature than borosilicate. While I understood that the melting temperature was lower, I foolishly thought the heat signatures would be similar. My first attempt at pulling 96 C.O.E. cane was laughable. Because the glass has a higher expansion, just sticking a rod in the flame would not work – it would explode! Cane has to be pulled using chunks of rod preheated in a kiln. I gingerly heated the glass until it became too floppy to handle, and then promptly lost control of it. A pile of stringers resulted, not to mention color loss and devitrification. Instead of the bright orange color that is present in properly heated and flowing borosilicate, soft glass has more of a warm, reddish-orange glow, and stays pliable even after all of the visible heat signature is gone.

Once the proper heat signature for 96 C.O.E. has been learned, the amount of work time available is impressive compared to borosilicate. When working with borosilicate glass, if there is no color visible then it is (generally) not considered workable. This is not the case for soft glass. Once a piece is heated to the warm, reddish-orange glow, it can be worked even after the visible heat has left. One of my favorite demonstrations of this in the hot shop is "pulling a pony." The gaffer takes one gather from the furnace and sculpts an entire pony without any additional heat. In the beginning, the glass is hot but before the pony is finished there is no visible heat left. As a borosilicate lamp worker, this seems impossible! If you are able to determine the approximate temperature of the glass using the heat signature, it can be an incredible advantage.

CONCLUSION

While everyone seems to have their own approach to glass, the techniques and tricks discussed above seem to work universally. You may find these tips can help you depending on your background in glass. We have come to the conclusion that the way someone deals with glass has a lot to do with the first kind of glass with which they worked. We hope that having three different personal experiences with glass and how we have learned to work with it will be helpful.

Writing on Glass: Flame, Temperature, and Solvent Resistance of Commercial Writing Implements

by
Joshua Greenfield*

ABSTRACT

Numerous commercially-available writing implements are specifically designed to write on glass, but not all of them can withstand the extreme environments that are frequently encountered by scientific glassblowers and chemists. This paper provides a brief overview of the flame, temperature, and solvent resistance of twelve different writing implements capable of marking on glass.

While presenting an excellent technical paper at the 2015 ASGS Symposium in Milwaukee, WI, Brian Markowicz mentioned that while heating samples in tubes to 575º-600º C in preparation for isotopic analysis, the labels written with a Sharpie® marker would burn off; this necessitated specific placement in an annealing rack and careful handling to avoid mixing up the tubes afterwards.[1] As I myself work in a chemistry lab that specializes in high-temperature reactions (up to 1100º C), I mentioned that metallic Sharpie® markers withstand much higher temperatures without burning off; this fact appeared to be relatively unknown to those present, and it was recommended that I submit it as a Lamp Shop Hint. I discovered in the February 2016 issue of *Fusion* that James Hodgson had apparently beat me to it, and not only that, he also compared how all three colors of metallic Sharpie® responded to annealing.[2] Nevertheless, I thought it worthwhile to test a larger variety of writing tools to determine how well each withstood common solvents, high temperatures, and direct exposure to flame.

Since there exist hundreds of different tools for writing on glass, the subjects of this test were selected with specific consideration for what might withstand the testing conditions, yet were readily available and relatively inexpensive. The fourteen writing implements chosen for this test include six pencils (solid pigment), five felt-tip markers (alcohol-based ink), and three paint markers (oil-based ink), as shown in Figure 1.

The pencil category included a soapstone pencil, a Ti-Pen™, a Stabilo® All wax pencil, Markal® Silver-Streak® and Red-Riter® welder's pencils, and a high-heat Dixon® Phano® China Marker (grease pencil). The felt-tip contenders included a Sharpie® Pro Industrial marker, a Markal® Dura-Ink® 15 marker, four colors of Staedtler® Lumocolor® permanent markers, and both silver and gold Sharpie® metallic markers. The final three candidates were a gold Sharpie® paint marker, a gold Sakura® Pen-Touch™ paint marker, and a Markal® Pro-Line® HT high temperature paint marker.

After collecting all of the pencils and markers, I began the first and perhaps most critical test – determining whether they write on glass. I began by writing the name of each marker on a piece of soft glass plate, as shown in Figure 2A. This initial test disqualified

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[1] Brian Markowicz, "Glassware for Isotope Analysis Processing Samples for Mass Spectrometry," *Proceedings of the 60th Symposium on the Art of Scientific Glassblowing*, Ed. Marylin C. Brown, Ph.D., (Milwaukee, WI: July 2015): 39-47.

[2] James R. Hodgson, "Lamp Shop Hint – Marking on Glass," *Fusion* LXIV.1 (February 2016): 47.

Figure 1: *A selection of writing tools designed to mark on non-porous surfaces like glass*

both the Silver-Streak® and the Red-Riter® welder's pencils; even though they boast exceptional resistance to torch flame on metal, they simply do not mark on glass and they will not be considered further. The remaining four pencils all produced legible marks, albeit with some difficulty, and all of the markers performed admirably. All of the marks were dry to the touch within seconds or minutes of application, but were allowed to dry overnight just in case. The following day I attempted to remove the marks with a Kimwipe® yielding some unexpected results. As shown in Figure 2B, (very) firm pressure with lint-free tissue will completely remove both the wax pencil and the grease pencil, leave only traces of soapstone, and smudge most of the felt-tip markers. The silver metal-

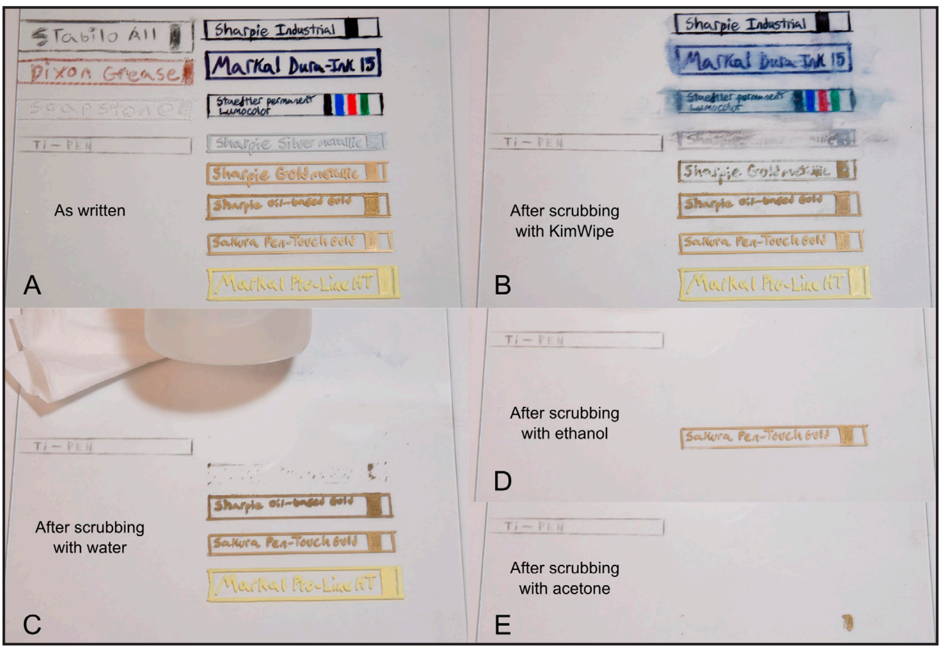

Figure 2: *Each marker was used to write its name on a soft glass plate (A). The marks were then scrubbed with a dry Kimwipe® (B), and then with water (C), ethanol (D), and acetone (E).*

lic Sharpie® was rendered illegible, while only the Sharpie® Pro Industrial and the paint pens remained unscathed. The next test was simply to wet the Kimwipe® with water and repeat the scrubbing, and this produced even more surprising results, as shown in Figure 2C. The only survivors were the Ti-Pen™, the three paint pens, and the very last illegible traces of the gold metallic Sharpie® One further scrubbing with ethanol (Figure 2D) removed both the gold Sharpie® Paint and Markal® Pro-Line® HT, and only after extensive scrubbing with acetone (Figure 2E) did the gold Sakura® Pen-Touch™ fail, leaving only a small patch where the paint had been applied most heavily. The Ti-Pen™ was the only writing implement that was unaffected by any amount of scrubbing with any solvent, though writing with it was also the most difficult.

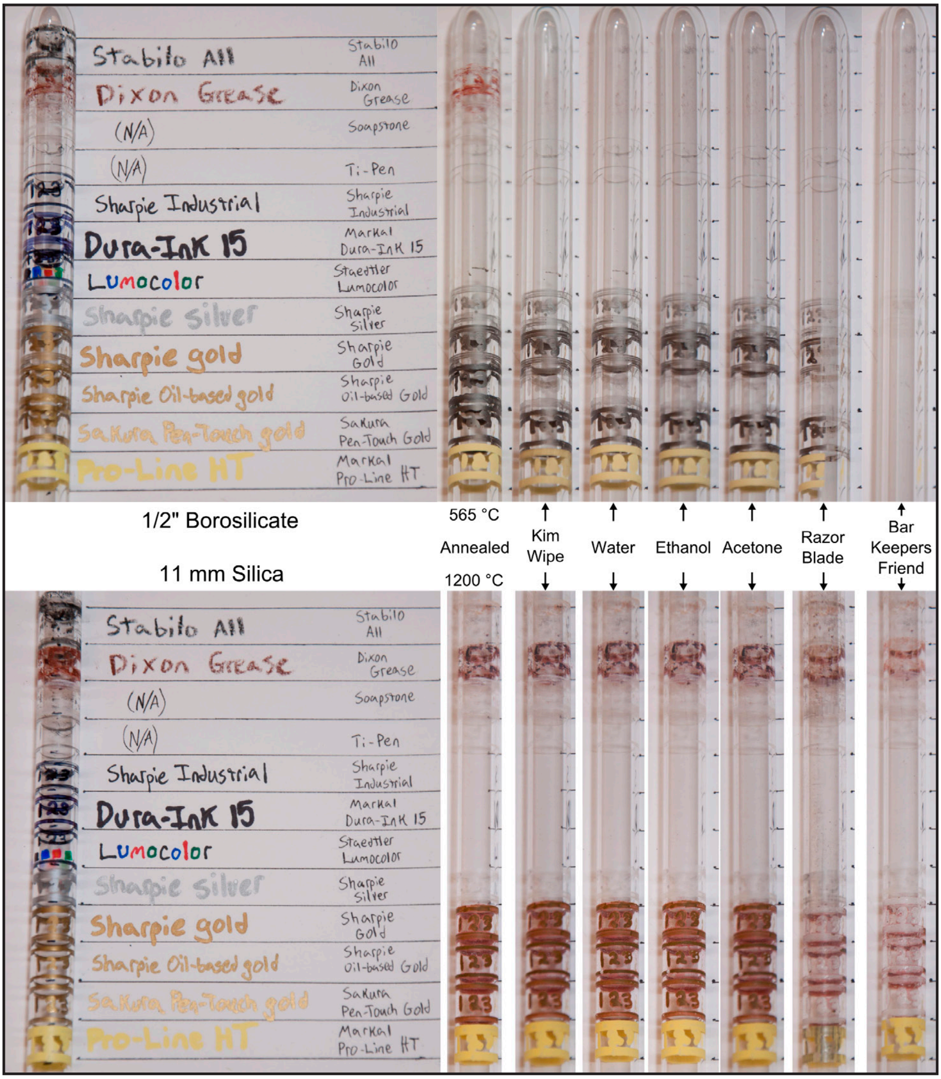

Figure 3: *Far left: borosilicate (top) and silica (bottom) tubes prepared with each writing tool, as well as a comparison with how each writes on paper. Progressing to the right shows the tubes after annealing, followed by attempts to remove the marks with a dry Kimwipe®, water, ethanol, acetone, a razor blade, and finally Bar Keepers Friend®.*

To test resistance to annealing in an oven, I prepared both borosilicate and silica tubes by using each writing tool to mark the numbers '123' bordered by two circumferential lines at 1 cm intervals; the borosilicate tube was then annealed at 565º C and the silica tube at 1200º C in a closed muffle furnace for twenty minutes, after which they were allowed to cool naturally. The results of this annealing, as well as subsequent attempts to clean the marks off the tubes, can be seen in Figure 3.

While all twelve writing tools can mark on both borosilicate and silica tubes, not all of them are ideally suited to labeling tubes smaller than ½"; the marks produced by the wax pencil, the grease pencil, and the soapstone were visible, but they were far from legible. The Ti-Pen™ and the markers were much easier to use in this instance, though the broad tips on the Dura-Ink® 15 and the Pro-Line® HT markers made it somewhat difficult to write on such small tubes. Following a standard annealing cycle, it immediately becomes apparent which writing tools have survived. For the borosilicate tube, the wax pencil lost its color, the grease pencil lightened considerably, and the soapstone and Ti-Pen™ were unchanged; the felt-tip markers all burned off completely except for the metallic Sharpies® of which the silver lost some of its color and the gold darkened to gray, though each remained legible. The gold paint markers both darkened to a similar gray, while the Pro-Line® HT became a slightly more subdued yellow, but all three could be read easily. As far as cleaning these marks off the tube, scrubbing with a dry Kimwipe® removed all of the pencils except the Ti-Pen™, slightly faded the color of the Pro-Line® HT, and nearly completely removed the gold Sharpie® Paint, while the remaining marks were unaffected. Scrubbing with water, ethanol, and acetone had no further effects, but scraping with a razor blade was able to completely remove the Pro-Line® HT and partially remove the other markers. Finally, scrubbing with Bar Keepers Friend® (oxalic acid) was able to completely remove all of the remaining marks except for a slight shadow from the silver metallic Sharpie®, and of course the Ti-Pen™ was largely undamaged. The effectiveness of oxalic acid in removing marks from metallic-colored inks is due to its ability to chelate the metal particles adhered to the surface of the glass; in general, acids will be much more effective than basic cleaners as most metals are resistant to attack by alkalis. Though it is resistant at room temperature, even the pure titanium left by the Ti-Pen™ can be removed by boiling the glass in a solution of oxalic acid.

The annealing test of the silica tube also revealed a few surprises as none of the tested markers claimed to be able to withstand 1200º C (the Pro-Line® HT is only rated to 1148º C), yet four of them survived. As before, the wax pencil lost its color, but this time the grease pencil got even darker as it burned into the surface of the tube. Soapstone will convert to enstatite ($MgSiO_3$) and cristobalite (SiO_2) at this temperature, and as such, the marks become faint, illegible, and nearly impossible to remove. Similarly, titanium will oxidize to TiO_2 at 1200º C, leaving faint white lines where the marks were. All of the non-metallic felt-tip markers burned away completely, while the silver Sharpie® lost all of its color but etched the surface of the glass. The gold metallic Sharpie® and the two gold paint markers all turned a similar dark brown color but remained completely legible, while the Pro-Line® HT even retained its bright yellow color. As far as cleaning the marks off the silica, nothing had any effect until scraping with a razor blade which removed a great deal of the colored deposits and revealed the extent of the etching underneath. Scrubbing with oxalic acid removed the rest of the color from the grease pencil, and it actually restored the yellow color of the Pro-Line® HT marker. However, any mark that remained after annealing at 1200º C caused significant etching on the surface of the

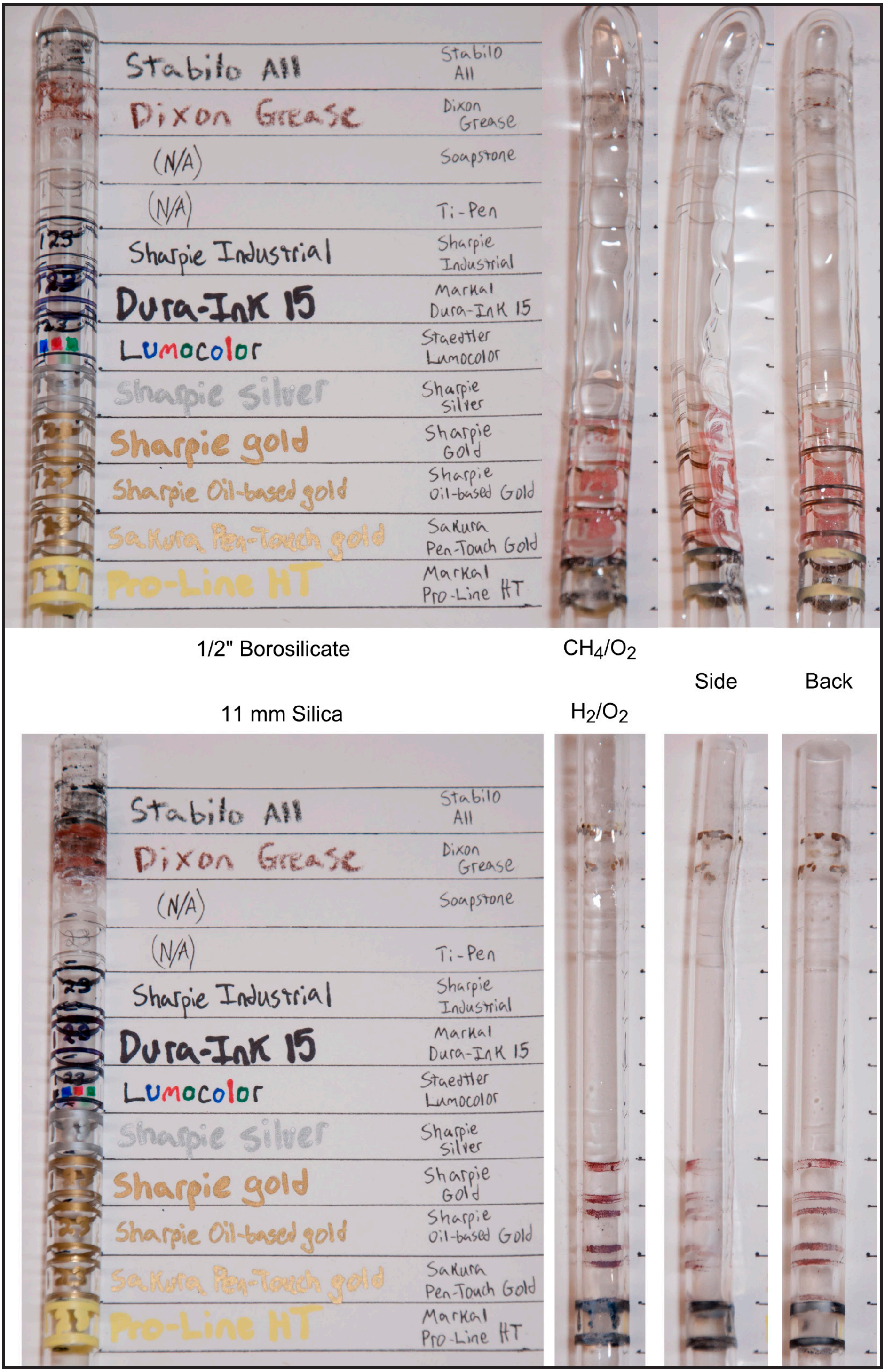

Figure 4: *Left: borosilicate (top) and silica (bottom) prepared as above. Right: front, side, and back views of the tubes after heating to the softening point on one side.*

silica, and this should be taken into consideration if it is an undesirable outcome for a given application.

As a final test, a similar set of borosilicate and silica tubes were exposed to direct torch flame. A neutral methane-oxygen flame was used for the borosilicate tube, while a neutral hydrogen-oxygen flame was used for the silica tube; each was heated on one side until the glass softened and started to dimple inwards. The effects are shown in Figure 4.

The results for the borosilicate tube were similar to those from furnace annealing, although none of the marks survived completely. The wax pencil burned off relatively cleanly as did a large portion of the grease pencil, while the soapstone was only removed where the torch hit it directly. The mark from the Ti-Pen™ was also removed by direct contact with the flame, though this is understandable given that titanium can oxidize at much lower temperatures in oxygen-rich environments. The non-metallic felt-tip markers burned away cleanly, while the metallic Sharpies® simply started to fade away. The oil-based paint markers glowed brilliantly under the flame and left colored etchings full of small bubbles wherever the flame contacted them, though the marks only darkened on indirect heating. These results were largely the same for the silica tube, though in the case of the oil-based paints they burned off before they etched the silica significantly, likely due to the much higher softening temperature. The usual attempts at cleaning were performed, but no meaningful reduction of the marks was observed for either the borosilicate or the silica.

Having completed the aforementioned tests, it is now possible to make a few recommendations. Based on the solvent-resistance tests, it would appear that vigorous scrubbing can remove much more than originally anticipated, especially with the aid of water; it also became apparent that even extremely similar markers may have starkly different properties, as exemplified by the gold paint markers. Only the Sakura® Pen-Touch™ was resistant to ethanol, and it was also fairly resistant to acetone, so it may be a good choice for those interested in solvent resistance. From the annealing tests, it became obvious that pencils were not the best choice, mainly due to the difficulty of writing on tubes with them, and that metallic Sharpies® (especially gold) do hold up under extremely high temperatures. For temporary marks that burn off cleanly, any non-metallic felt-tip marker will work, but the Sharpie® Pro Industrial seemed the most resistant to smudging. Only the Pro-Line® HT could produce a mark that did not change in appearance up to 1200º C, but one that also could not be removed afterwards. For marks that have not been etched or fired into the surface of the glass, acid cleaners such as Bar Keepers Friend® will be effective for a broad variety of metallic inks. As for exposing marks directly to a torch flame, it would appear that everything except the soapstone and the felt-tip markers etched the glass and became extremely difficult to remove. For a cheap, readily-available, easy-to-use, durable marker that will survive a borosilicate annealing cycle and still be completely removable afterwards, I would personally recommend a gold metallic Sharpie® – I always keep one in the front pocket of my lab coat.

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