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THE FIFTIETH ANNUAL

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ON THE
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2004 & 2005



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Symposium

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Papers

COLORS IN GLASSES

by

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Abstract

There are two methods to provide colored glass for the lamp working industry: direct melting, and clear glass ion exchange. A recent development in the ion exchange process has made this method a viable product for the industry. The rapid growth of the number of glass blowers has spurred an interest in colors and what colors can contribute to their sales.

Introduction

The coloring of glass has intrigued artisans for thousands of years. Many of the color discoveries were kept as deep secrets to protect the uniqueness of their product. With the expansion of the glass blowing industry world-wide, there is a continuing quest to supply colors to this growing market.

There is a vast store of information on producing colors in glass. Most of this body of knowledge deals with soft glass compositions having a coefficient of expansion (COE) in the range of 95×10^{-7} . The glasses are usually melted in pots or small continuous furnaces because of technical difficulties in developing the colors and smaller volume requirements for the product. The colors are produced by a metal oxide or several oxides, usually in combination with special batch materials that are needed to facilitate the desired color shade. This subject was discussed extensively by S. R. Scholes in his book "Modern Glass Practice" published in 1946. The high COE make these colored glasses impractical for the scientific lamp worker.

Scientific apparatus requires good chemical resistance and lower COE to meet the rigors of the development laboratories. The "hard" glass also allows the glassblower to form the intricate designs of the lab technician without frequent use of an annealing furnace. Until recently, there was very little in the way of colored product available to the scientific glassblower who made artistic glass on the side. With the large increase in interest in the glassblowing trade and the rapid expansion of people learning the trade, there has been a growing demand for colors compatible with the low expansion property of the borosilicate glasses.

Several glass chemists recognized the demand and set about developing special glass colors that could be used with regular hard glass tubing. The borosilicate composition does not lend itself to the same coloring techniques that are used in the soft glasses so a whole new body of knowledge had to be developed. There are several companies that now have an extensive line of colored rod available to the glassblower. Some of the metal oxides are severely restricted by OSHA and care must be used when working with the colored rods in the flame due to possible outgassing of the metals. It is also necessary to use careful flame adjustment to develop the proper conditions for the desired color.

There is another method of permanently coloring glass that introduces the metal oxides into the molecular structure after the glass has been melted and formed. This process uses clear glass articles and converts them to colored items. This same process can be used to color the finished article that the glassblower wants in a color. This high temperature chemistry process also uses metal oxides but is limited by the character of the metal

ion used in the process. A limited number of colors can be produced by this process but the color intensity is variable from light pastels to nearly opaque. The stain penetrates into the surface of the glass from 20 to 50 microns deep. The resulting color and intensity depend on a number of process parameters:

1. How the metal compound is applied to the glass surface.
2. At what temperature the article is processed.
3. How long it is held at firing temperature.
4. The sequence and type of chemicals used.
5. The atmospheric conditions in the firing chamber.
6. Any secondary process that is needed.
7. The surface chemistry of the glass being stained.

Since the ion exchange coloring process is VERY sensitive to surface chemistry, variations not normally detected in a clear glass piece can show up as color differences. Even handling defects such as scratches and fingerprints can be affected by the coloring process and burned into the glass surface. The forming process used in producing the glass article can impart a unique character i.e., the vello tube drawing process can leave a continuous line the length of the tube that shows up as a lighter streak. The glass is formed before the ion exchange is applied and some glass defects can become more objectionable. In fact the ion exchange process has been used to detect surface cords in baking dishes that might cause failure when used to bake a cake.

When gas flames are played directly on the glass, they can change or distort the colored glass at the surface. Here again, flame characteristics are important in developing the desired color affect. A sharp oxidizing fire will usually have less adverse affect on the coloring oxides. When the colored surface can be shielded from direct flame impingement, the color of the glass is relatively unaffected. Thus a layer of clear glass or cladding over the color surface can protect the metal from undesirable flame action.

This concept has been carried a step further by applying the stain colors directly to the inside of the borosilicate tubing. The colored surface is protected from the flame effect by the wall of clear glass between the inside color and the outside flame. Heat by itself does not distort the color. A few glassblowers have used this product with very good results and the product is now being introduced to the market. In fact, several suppliers are showing the items here at the conference. Red and yellow colors in several sizes and walls are available and other items are in the development stage.

A high temperature mass spectrometric analysis was made on several of the tubes colored on the inside to check for outgassing. The glass was heated slowly from room temperature to 900° F and the vapors were analyzed every 10 degrees. The normal vapors which are emitted from clear borosilicate glass were found but no detectable metal ions from the coloring process were found at any temperature.

Conclusion

The small glassblower industry has grown rapidly in recent years and their suppliers have developed new products in response to the needs of the industry. The new colors available to the industry in borosilicate compatible glass have added a new dimension to their palate of products.

CO₂ Water-jacketed Laser Tube

by

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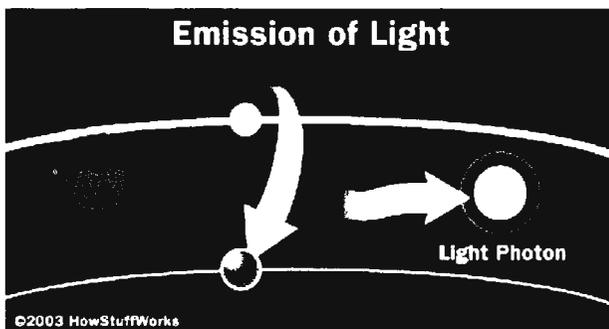
Abstract

The step-by-step construction of the laser tube will serve to illustrate some possible solutions to many glassblowing difficulties. For example, connecting a long narrow precision inner tube to a very thick wall outside end piece without a maria or olive, the use of tools and fixtures to maintain concentricity after adding all the side connections through the outside wall. I will explain and illustrate how some of the topics covered could be used to solve many other little everyday problems in the construction of better or more ergonomic glassware.

This paper attempts to present some little tricks and tools that could help facilitate the construction of CO₂ water-jacketed laser tubes. I hope that many of these ideas can be applied to the construction of other glass apparatus.

The Laser

“A **laser** is a device that controls the way that energized atoms release photons. “Laser” is an acronym for **light amplification by stimulated emission of radiation**, which describes very succinctly how a laser works. Although there are many types of lasers, all have certain essential features. In a laser, the lasing medium is “pumped” to get the atoms into an excited state. Typically, very intense flashes of light or electrical discharges pump the lasing medium and create a large collection of excited-state atoms (atoms with higher-energy electrons). It is necessary to have a large collection of atoms in the excited state for the laser to work efficiently. In general, the atoms are excited to a level that is two or three levels above the ground state. This increases the degree of **population inversion**. The population inversion is the number of atoms in the excited state versus the number in ground state. Once the lasing medium is pumped, it contains a collection of atoms with some electrons sitting in excited levels. The excited electrons have energies greater than the more relaxed electrons. Just as the electron absorbed some amount of energy to reach this excited level, it can also release this energy. As the figure above illustrates, the electron can simply relax, and in turn, rid itself of some energy. This **emitted energy** comes in the form of **photons** (light energy). The photon emitted has a very specific wavelength (color) that depends on the state of the electron’s energy when the photon is released. Two identical atoms with electrons in identical states will release photons with identical wavelengths.”¹



¹ <http://science.howstuffworks.com/laser3.htm>

Laser Light

“Laser light is very different from normal light. Laser light has the following properties: The light released is **mono-chromatic**. It contains one specific wavelength of light (one specific color). The wavelength of light is determined by the amount of energy released when the electron drops to a lower orbit.



Picture 1. A 30 cm CO_2 laser tube completed and ready to be fitted into cavity.

The light released is **coherent**.

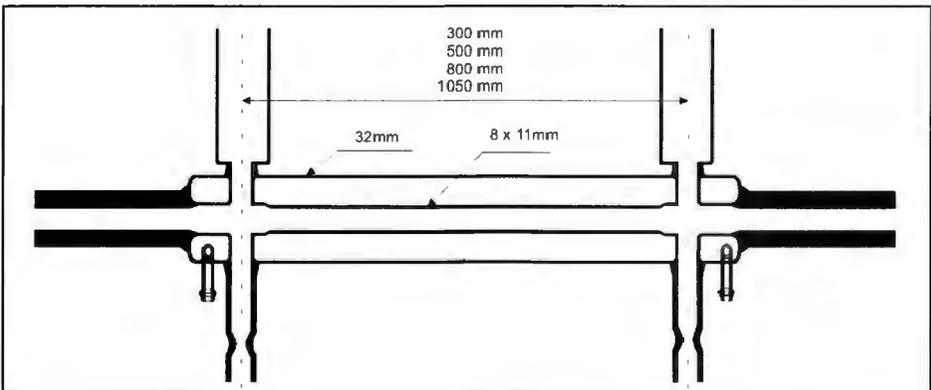
It is “organized” — each photon moves in step with the others. This means that all of the photons have wave fronts that launch in unison.

The light is very **directional**. A laser light has a very tight beam and is very strong and concentrated. A flashlight, on the other hand, releases light in many directions, and the light is very weak and diffuse. To make these three properties occur takes something called **stimulated emission**. This does not occur in your ordinary flashlight — in a flashlight, all of the atoms release their photons randomly. In stimulated emission, photon emission is organized.



Picture 2. One CO_2 laser in its cavity.

The photon that any atom releases has a certain wavelength that is dependent on the energy difference between the excited state and the ground state. If this photon (possessing a certain energy and phase) should encounter another atom that has an electron in the same excited state, stimulated emission can occur.

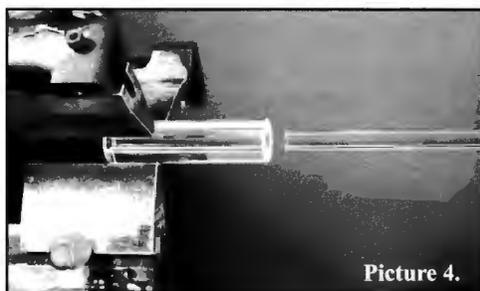


Picture 3. Schematic of CO_2 glass laser tube.

The first photon can stimulate or induce atomic emission such that the subsequent emitted photon (from the second atom) vibrates with the same frequency and direction as the incoming photon. The other key to a laser is a pair of **mirrors**, one at each end of the lasing medium. Photons, with a very specific wavelength and phase, reflect off the mirrors to travel back and forth through the lasing medium. In the process, they stimulate other electrons to make the downward energy jump and can cause the emission of more photons of the same wavelength and phase. A cascade effect occurs, and soon we have propagated many, many photons of the same wavelength and phase. The mirror at one end of the laser is “half-silvered,” meaning it reflects some light and lets some light through.”²

In this picture, one can see the thick end piece that will be attached to the precision bore center tube. Those two pieces could not be welded together before having been tooled to a more gradual taper and a lip formed to facilitate the double walled connection to the outer water chamber.

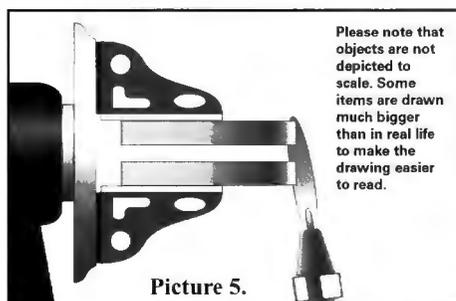
Before being welded, the pieces will need to be fire polished. (Picture 4)



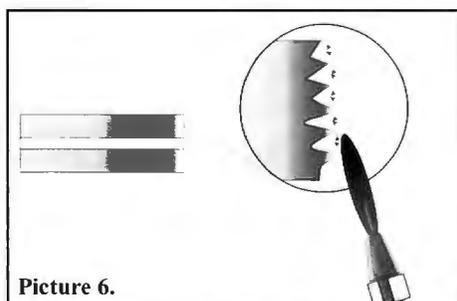
Picture 4.

But it is important to do that step the right way. (Pictures 5, 6, 7, 8, 9, 10, 11 & 12)

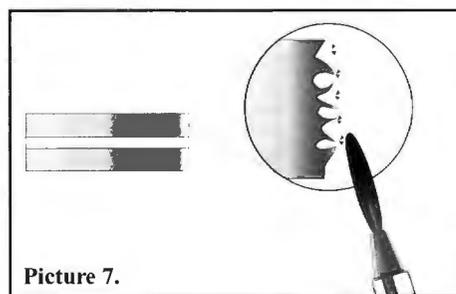
Wrong technique: the flame is applied towards the cut.



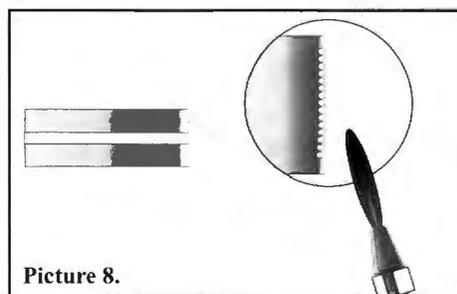
Picture 5.



Picture 6.



Picture 7.

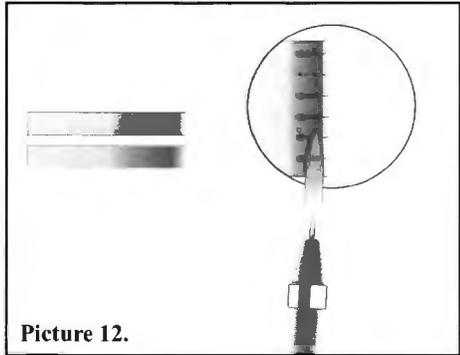
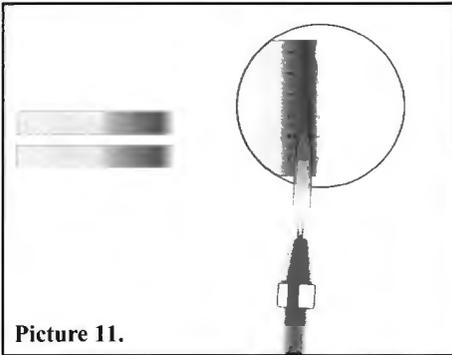
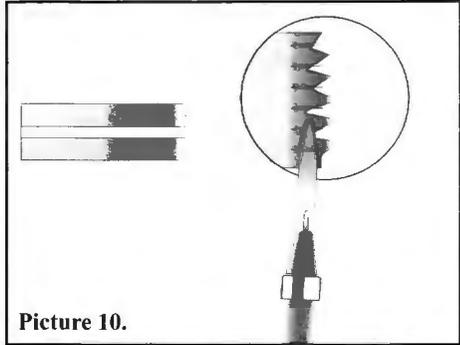
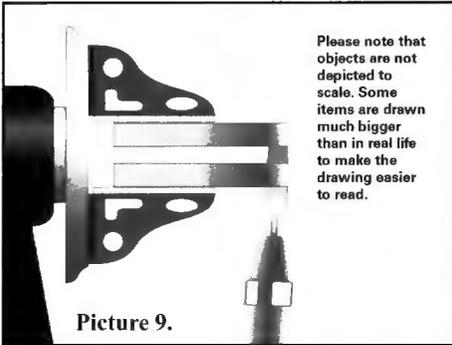


Picture 8.

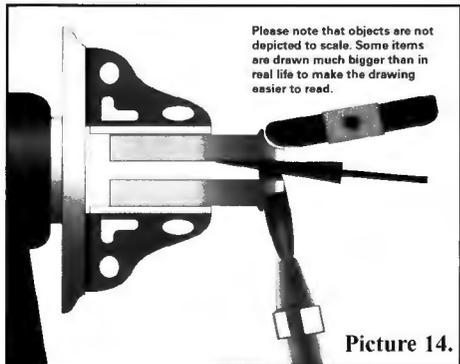
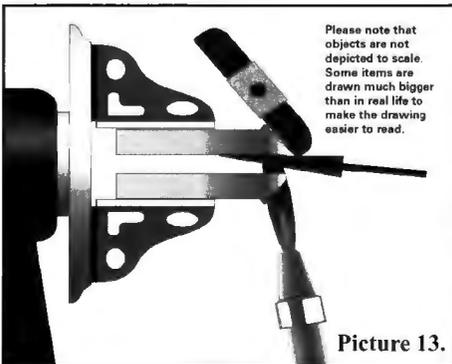
Glass, when cut on a wet saw stays rough; actually, if observed under powerful magnification, one can see that the surface consists of countless microscopic cavities. Those cavities, if melted too quickly with a flame applied towards the front, will close upon themselves and will trap air bubbles leaving a bad surface. (Pictures 5, 6, 7 & 8)

² <http://science.howstuffworks.com/laser4.htm>

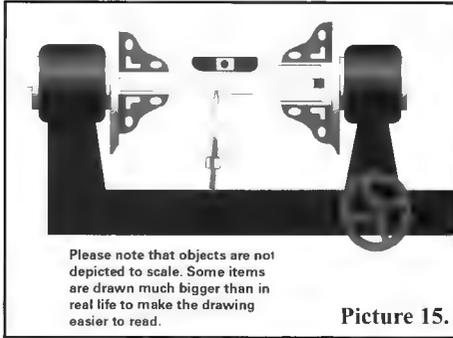
Right way: the flame is applied behind the cut.



It has been observed that if a glass piece is fire polished in such a way that the flame is coming from behind the section cut, the heat will come from the inside of the glass and probably the surface tension will “pull” the glass towards itself giving a high polish that will be free of air bubbles. (Pictures 9, 10, 11, & 12)

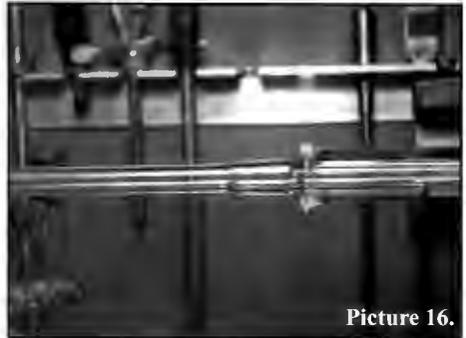


To prepare the end piece, it is necessary to, first make a cone and then, with the rounded part of the carbon paddle, to form a more gradual tapering towards the precision bore tubing that will be welded to it. (Pictures 13 & 14)

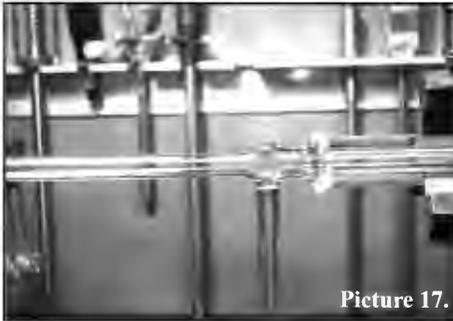


Please note that objects are not depicted to scale. Some items are drawn much bigger than in real life to make the drawing easier to read.

Picture 15.



Picture 16.



Picture 17.

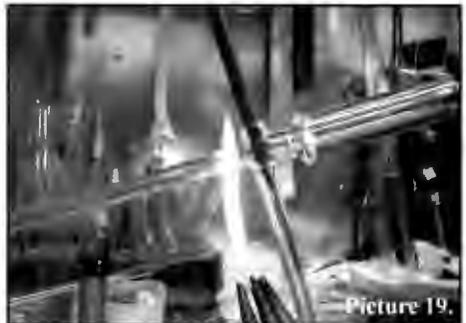


Picture 18.

First the end piece is welded to the precision bore and the tube is slightly enlarged over about 1.5" where the side arms will be attached.

Once the side arms are welded in place, they are cut, slightly longer than necessary since they will be thickened and flared. (Pictures 15, 16, 17 & 18)

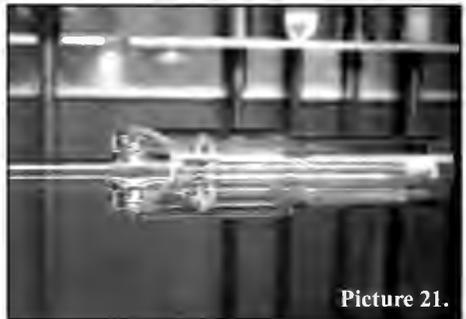
The side arms are then flared to offer a very thick ring and checked for perfect fit using a special fixture designed for that purpose; note on picture 20 that the fixture has been cut at an angle to permit checking the first connection without touching the second side arm. In picture 21, the reference tube has been rotated to check both side arms for perfect fit. (Pictures 18, 19, 20 & 21)



Picture 19.



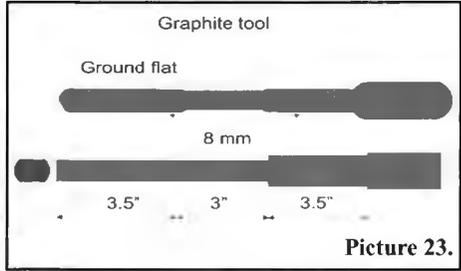
Picture 20.



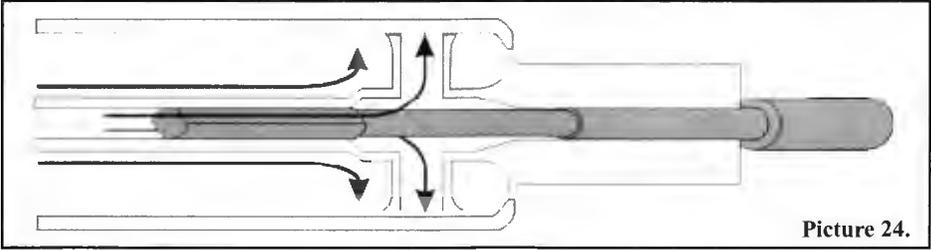
Picture 21.



Picture 22.



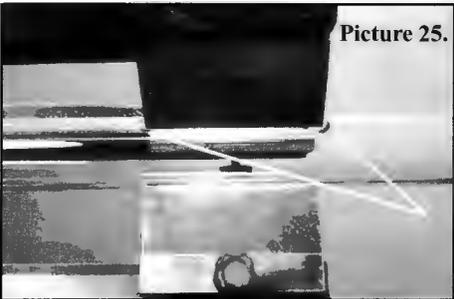
Picture 23.



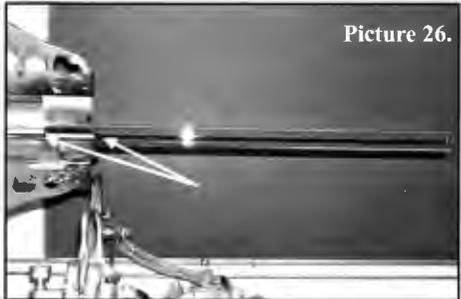
Picture 24.

After the side arms have been welded in place, it is necessary to straighten the piece since the stress will have distorted it. That operation is done over a graphite mandrel (Picture 22, tooled as per Picture 23).

The rod has been flattened to enable air to pass for blowing the connections. (Picture 24)



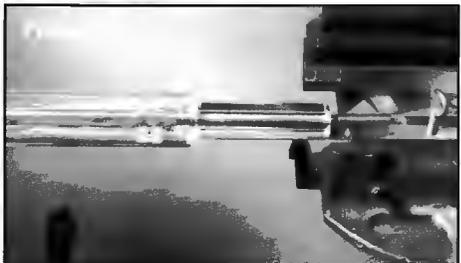
Picture 25.



Picture 26.



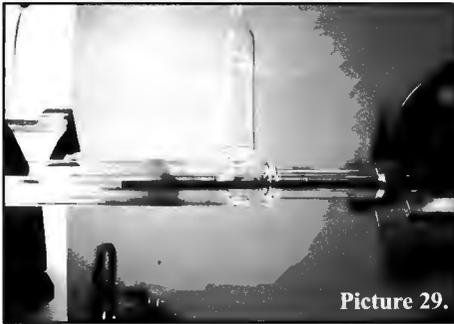
Picture 27.



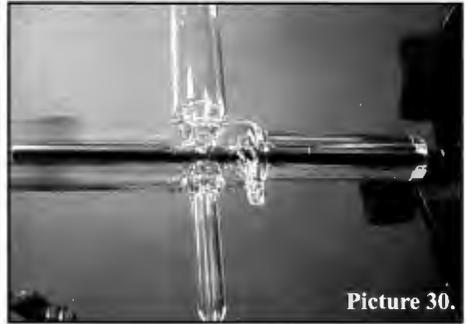
To straighten the outer housing, the center of the glass tube is marked for reference and the tube straightened on both sides using a soft bushy flame. That reference point will be used to support the tube while welding the inner part. (Pictures 25 & 26)

Then the inner tube is inserted and secured in place on one side with masking tape. (Picture 27)

The tube is ready to be welded. (Picture 28)



Picture 29.



Picture 30.

To attach the inner tube to the outer water jacket, first the jacket is welded to the end piece then one inner connection is welded to the wall and allowed to cool (slightly) for support. The second connection is then welded properly and the electrode housing installed in place. After that, the pumping tube and the water inlet are added. Then the complete piece is re-warmed on the graphite mandrel until it is running true. I have found that disengaging the tail stock to keep the graphite mandrel stationary makes a straighter tube. (Pictures 29 & 30)

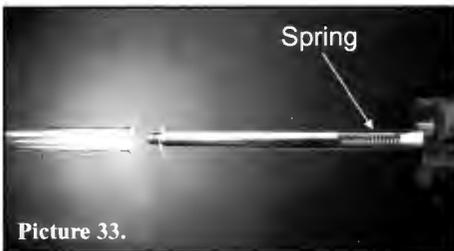
A laser tube would not work without electrodes. Since those platinum electrodes can become extremely hot, a quartz guard ring will be placed between the two pieces to avoid stress to the Pyrex electrode housing. (Pictures 31 & 32)



Picture 31.



Picture 32.



Picture 33.



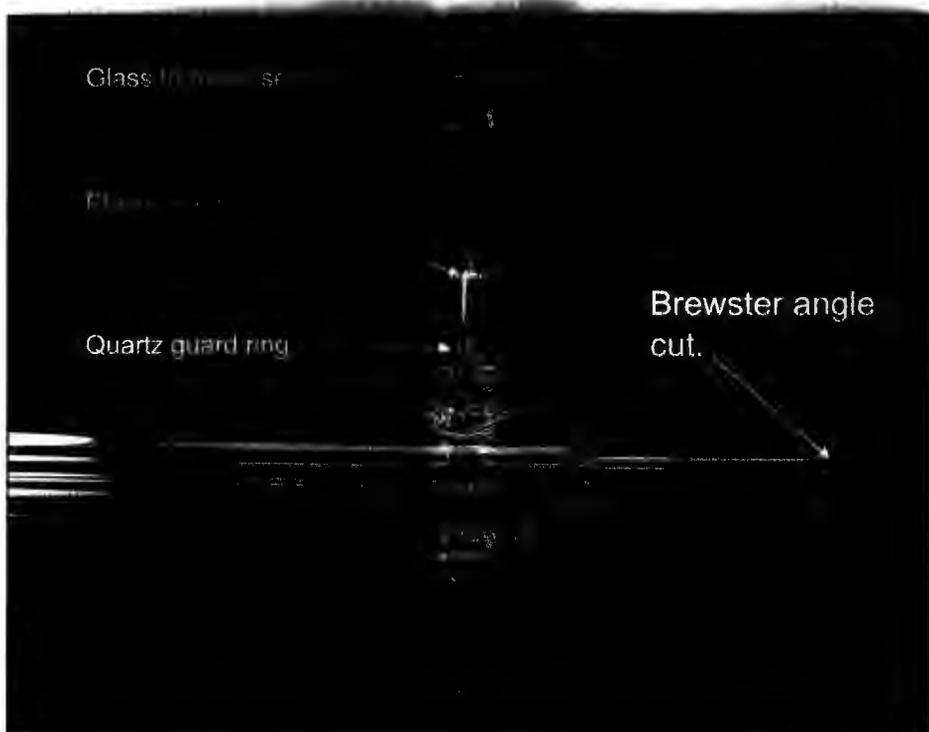
Picture 34.

I devised a simple device to support the inner cup while welding it in place. It consists of a stainless steel rod held in a glass tube. A small spring will maintain a slight pressure on the inner cup while welding it in place to the outer tube. The three legs are added later and the guard ring is cut to size and fire polished. (Pictures 33 & 34)

Completed guard ring. (Picture 35)



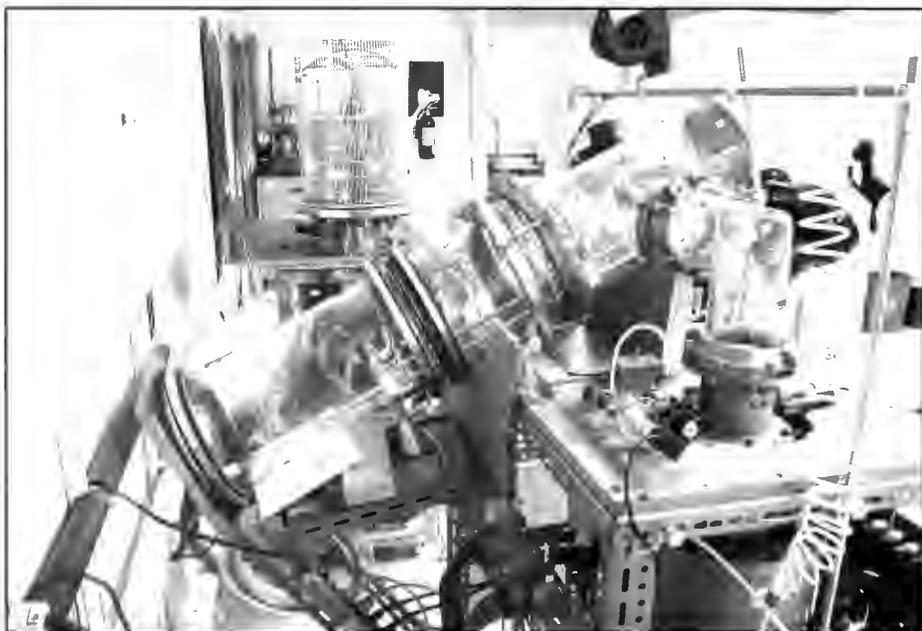
Picture 35.



Picture 36. *Installing the quartz guard ring and tungsten electrode.*



Picture 37. *Baking the laser tube in an oven under vacuum.*



Picture 38. *Vacuum chamber to seal windows under ultra high vacuum.*



Picture 39. *The completed CO₂ laser is inserted into its cavity and is ready to be shipped to a customer.*

Acknowledgements

Thank you to Dr. Lennox, Chairman of the McGill Chemistry Department and to Mr. Normand Trempe, administrator, whose support enabled me to participate in this Symposium and to present this paper.

My sincere gratitude to M.P.B. Communications engineers who opened their lab to me to let me take some of those pictures.

Development Of A Triple Surface Condenser For Chemical Laboratories

by

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Abstract

In the chemical industries, the important and widely used physical separation is distillation which is defined as a process involving partial vaporization. The condenser is the heart component of the distillation assembly. The principal governing factor in the design of these condensers, as is well-known, is its inner cooling surface area. Because of the lower efficiency, the time of operation and loss of chemicals were more during the reactions. In view of this, it was thought to evolve a design to fabricate with greater efficiency of condensation. The development of a Triple Surface Condenser is the result of these efforts.

Introduction

Various methods such as evaporation, distillation, extraction, absorption & filtration have been employed by the chemical industry for separating components from their mixtures. However, the most important and widely used physical separation operation is **distillation**, which is defined as a process involving partial vaporization. The chemical industry has been demanding purer products of greater efficiency and this has necessitated continued research into the techniques of distillation. The distillation assembly has many glass components of which the heart component is the **condenser**. Without this, distillation will not take place. Several types of condensers have been in use in chemical laboratories and chemical industries. **The principal governing factor in design and fabrication of these condensers, as is well known, is its inner cooling surface area.** Several designs are available in catalogues of well-known laboratories and glassware manufacturing companies, but the **triple surface condenser** is our own development. Because of lower efficiency, the time of operation and the loss of chemicals were greater during the reactions. In view of this, there evolved a design that would fabricate with a greater efficiency of condensation. The development of a **triple surface condenser** is the result of these efforts.

Description

This new condenser design has five wall extensions, thus making provisions for triple jackets, i.e., having three cooling areas for the *vapour condensation* and double jackets for the *area of vapour*. This design has been done in borosilicate hard glass at usual glass blowing facilities. No special technique is involved thus enabling an adequately skilled scientific Glass Blowing Technician to fabricate it as per the design.

We can design **3 types of triple surface condensers** as follows.

1. Tube type
2. Coil type
3. Coil & Tube type

To judge its performance, comparative distillation experiments on different solvents were done and the results are given in the tables 1, 2 & 3. Identical conditions of the heating

source, the cooling water and the solvent were maintained. The distillation study was carried out with four types of condensers, such as single surface, double surface, coiled type and triple surface, keeping the dimensions of the condenser and time as constant parameters; the output was then measured.

Results revealed that the output from the triple surface condenser is 25% greater than compared to other types of condensers. Thus, it can be concluded that, for the given length of the condenser, the triple surface condenser is 25% more efficient than other types of condensers. More importantly, this efficiency was obtained without involving any intricate fabrication work.

Table – I Acetone Distillation (Done over 15 Minutes)

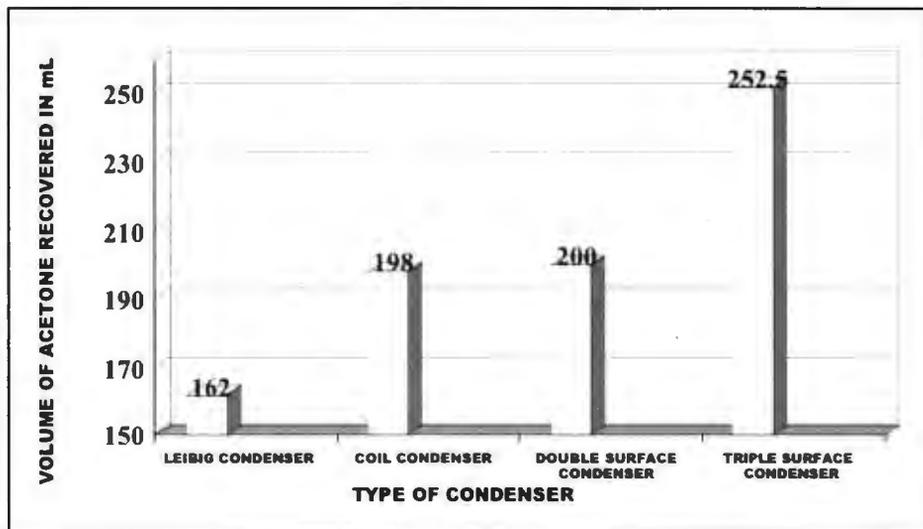


Table – II Ether Distillation (Done over 8 Minutes)

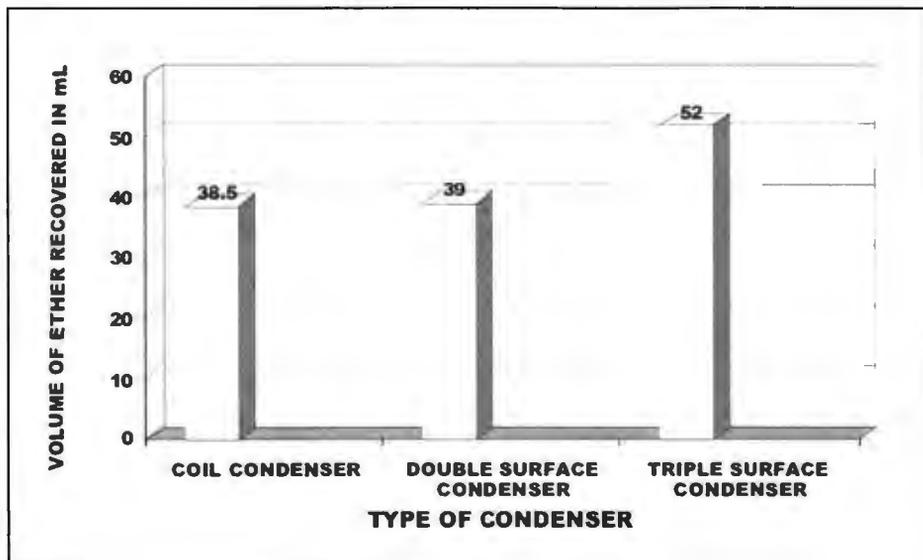
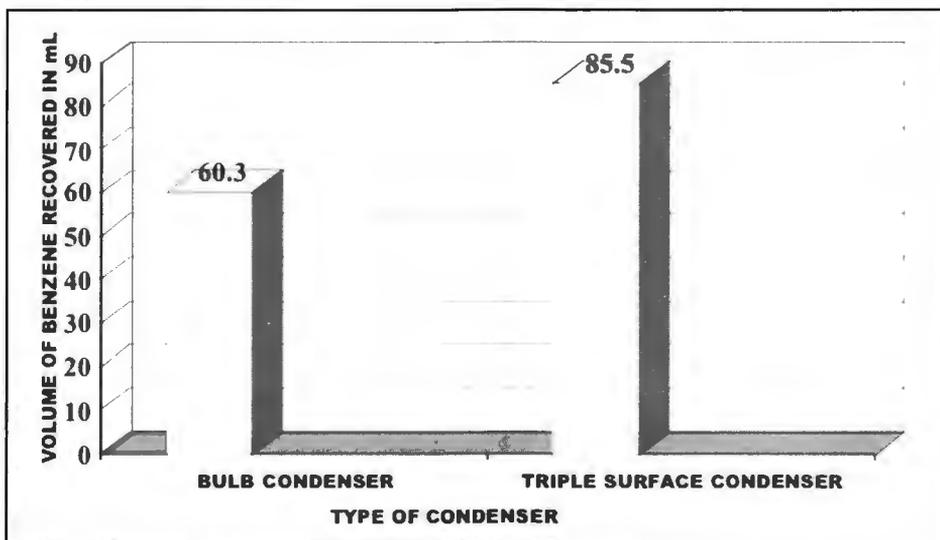


Table – III Benzene Distillation (Done over 5 Minutes)



The time required for its complete fabrication in comparison with the other designs was also studied. It takes hardly an hour more than the double surface variety. Despite the marginal extra time and the greater quantity of material required for its fabrication, the triple surface condenser is worthy because of increased efficiency and minimum loss of costlier chemicals, which are considered to be very important parameters in chemical laboratories and industries.

Method of Fabrication

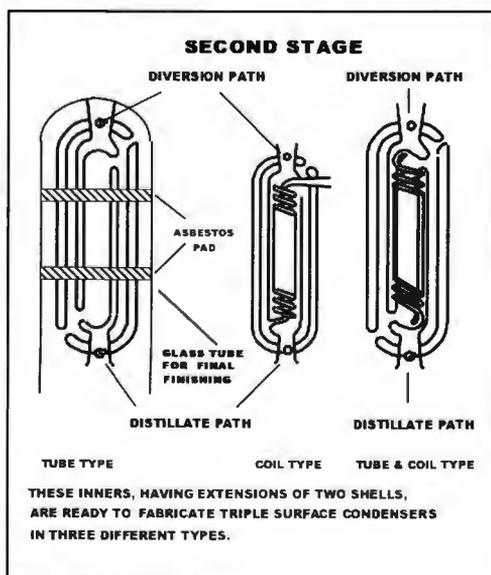
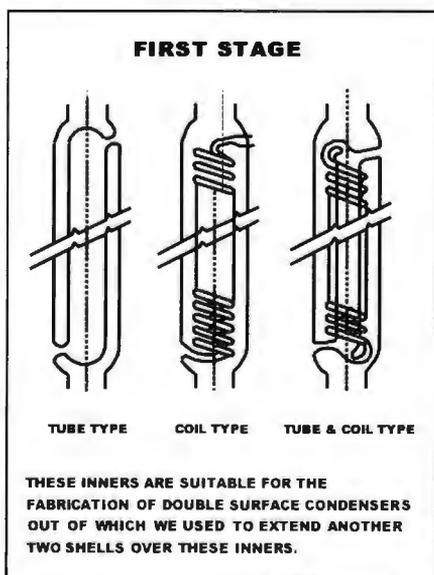
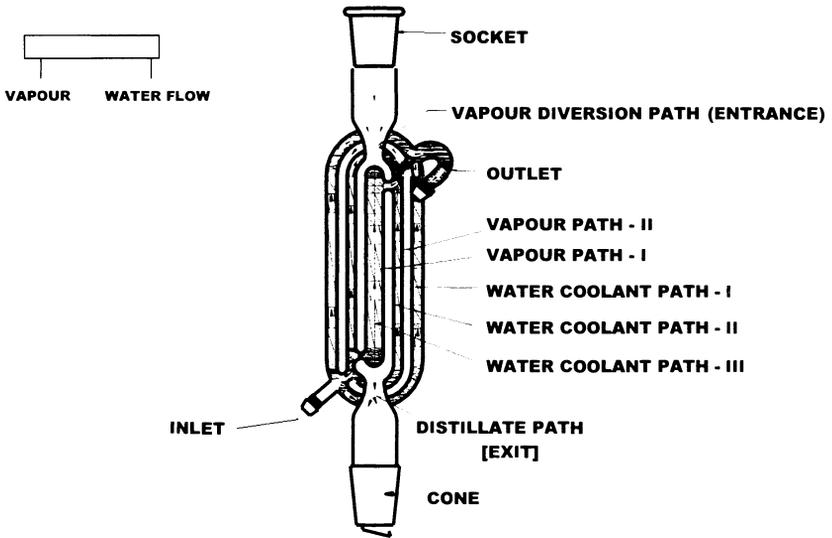


Figure 1.

Figure 2.

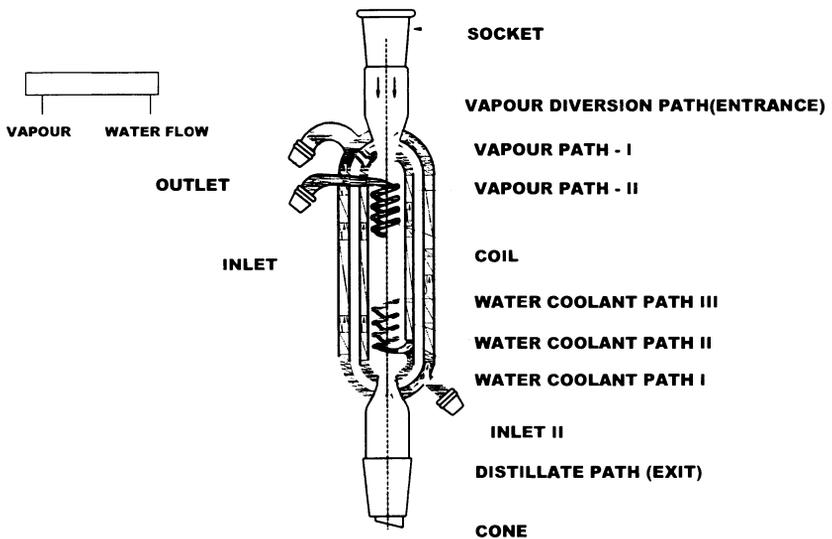
DEVELOPMENT OF "TRIPLE SURFACE GLASS CONDENSER"



COMPLETED DESIGN OF TUBE TYPE TRIPLE SURFACE CONDENSER

Figure 3.

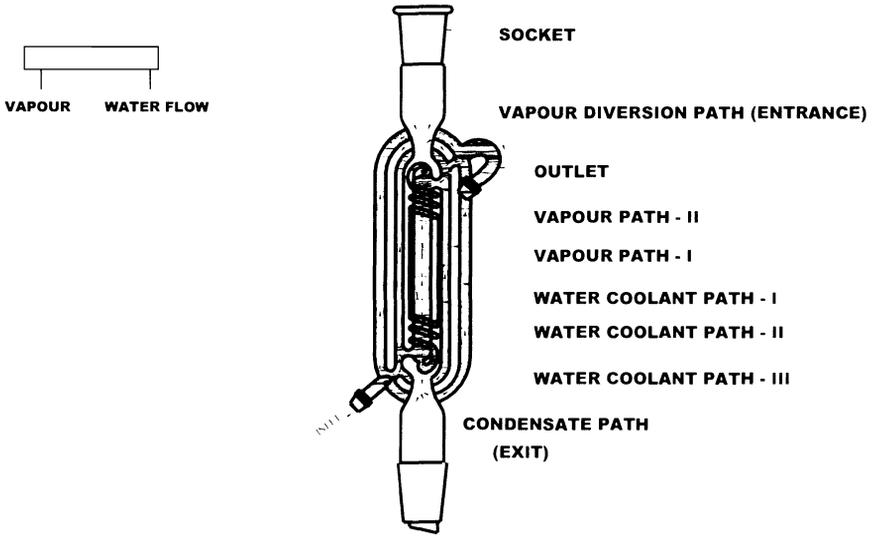
DEVELOPMENT OF "TRIPLE SURFACE GLASS CONDENSER"



COMPLETED DESIGN OF COIL TYPE TRIPLE SURFACE CONDENSER

Figure 4.

DEVELOPMENT OF "TRIPLE SURFACE GLASS CONDENSER"



COMPLETED DESIGN OF COIL & TUBE COMBINED TYPE TRIPLE SURFACE CONDENSER

Figure 5.

TRIPLE SURFACE CONDENSER VS DOUBLE SURFACE CONDENSER

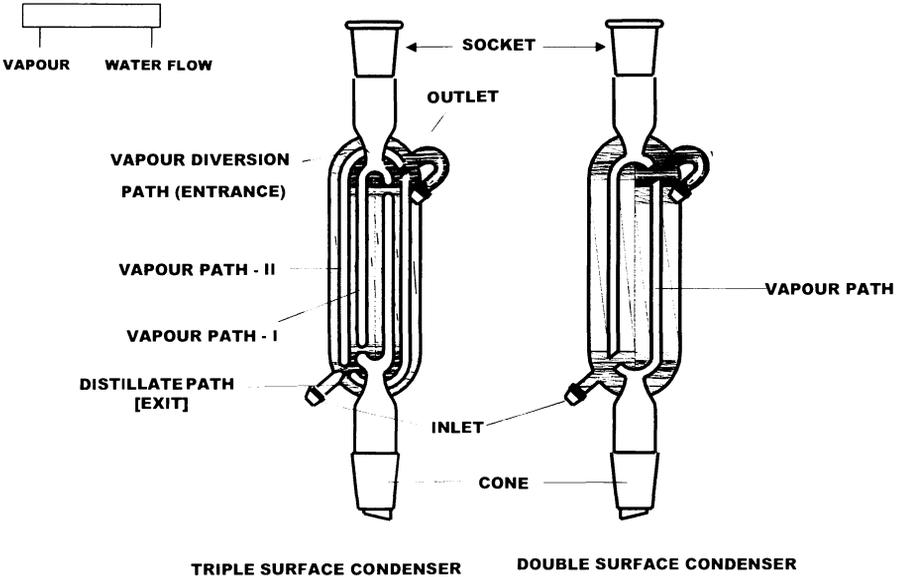


Figure 6.

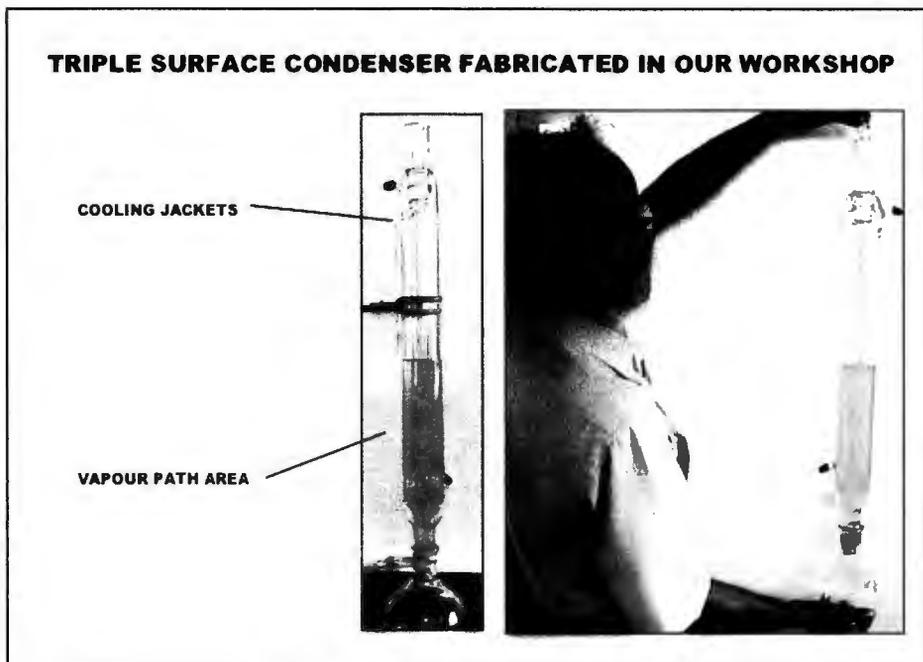


Figure 7.

Acknowledgements

The author wishes to thank the Management of Orchid Chemicals & Pharmaceuticals Limited for providing the necessary resources, facilities and the opportunity for innovative research. Thanks are due to Dr. Om Reddy (President and Chief Scientific Officer, R&D Centre), his team and other associates for all the encouragement provided. I wish to thank Dr. S. Mahendar Rao (GM, Synthesis) for the valuable input provided in the preparation of this presentation.

My sincere thanks are due to Dr. U. P. Senthilkumar and his team for their valuable scientific and kinetic study of the '*Triple Surface Condenser*' to evaluate its efficiency.

I am very much grateful to Dr. G. Krishna Prasad (Asst. Manager, HS&E) and his colleagues for their editorial work and their assistance in preparing the presentation.

I will be failing in my duty if I do not thank the Human Resources and Administration Departments and my Glass Blowing Technicians for all their efforts and timely help.

My sincere thanks to the Company for having agreed to sponsor my participation in this 2004 ASGS Symposium.

Glassblowing Technology Innovation in Photonic Components used in Optical Telecommunications

by

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Canada

Abstract

Advances in glassblowing technology have occurred in the field of optical telecommunications over the last decade. Glassblowers outside this niche may not be aware of how significant these advances are and how challenging they have been. This paper gives a brief overview of basic optical telecommunications and the contributions made and challenges faced by glassblowers producing optical fiber and glass alignment parts.

Introduction

Contributions to optical telecommunications and photonic devices made by glassblowers may not be well known within the glassblowing community at large. Specifically, making optical fiber and manufacturing glass parts to align this fiber were significantly advanced by glassblowing techniques. While a comprehensive review of optical communications, photonics or photonic components is beyond the scope of this paper, there are a few essentials that must first be understood in order to appreciate the contributions glassblowing has made to optical communications. Index of Refraction, Total Internal Reflection, and the basics of optical communication are first explained to help in understanding the challenges faced and achievements made.

Index of Refraction

Index of refraction is a way of measuring the speed of light in a material. Light travels fastest in a vacuum (300,000 kilometers per second, or 186,000 miles per second). Dividing the speed of light in a vacuum by the speed of light in some other medium gives the index of refraction of that medium.

Index of Refraction = Speed of Light in a Vacuum / Speed of Light in a Medium

The Index of Refraction of a vacuum by definition has a value of 1; the larger the index of refraction, the more slowly light travels in that medium. Table 1 gives values of index of refraction for various media.

In Table 1, the core refers to a material at the center of an optical fiber made mostly of Quartz with a small amount of impurity added in a controlled manner. Surrounding the core is cladding also made mostly of Quartz with a different impurity added. Surrounding the cladding is a buffer, an acrylate coating added for mechanical strength protection.

Medium	Index of Refraction	Speed
Vacuum	1.0000	Faster
Air	1.0003	
Water	1.33	
Cladding	1.46 (typical)	
Core	1.48 (typical)	Slower

Table 1.

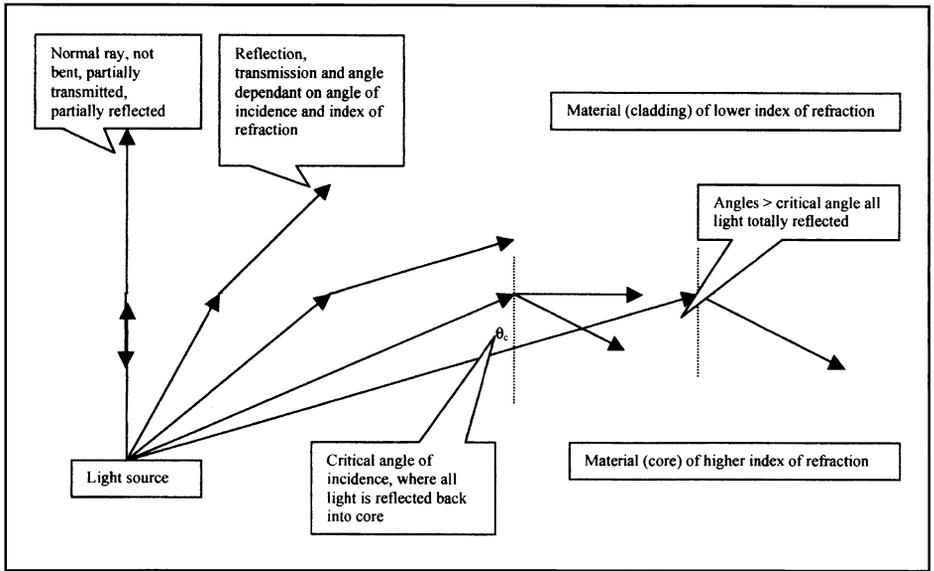


Figure 1. Index of refraction.

Total Internal Reflection

When light travels from one medium to another at right angles to the surface, some light is reflected back and some light travels straight through at a different speed. When light strikes a different medium at an angle other than 90 degrees however, not only is its speed changed, its direction is changed as well. The speed and direction of light in the newly entered medium is determined by the index of refraction.

Fiber optic cabling and components are designed so that light traveling down the core of the fiber does not experience any loss of light, a condition known as total internal reflection (TIR).

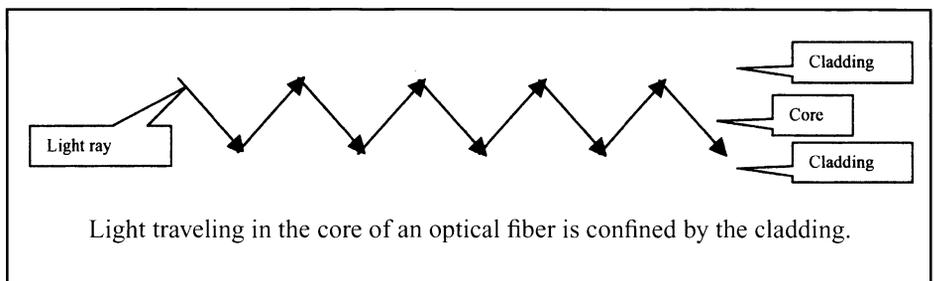


Figure 2. Total Internal Reflection.

Glassblowers are likely to be more familiar with the phenomenon of total internal reflection when heating glass, especially Quartz glass, in the flame as in Figure 3. Light generated by heating the Quartz travels in the walls of the glass; all light generated at angles greater than the critical angle for Quartz/air is totally reflected within the walls and travels down its length. Under certain conditions, light energy can be sufficient to char rubber or cork in the end of the tube while other parts of the tube are cool enough to manipulate by hand or lathe.

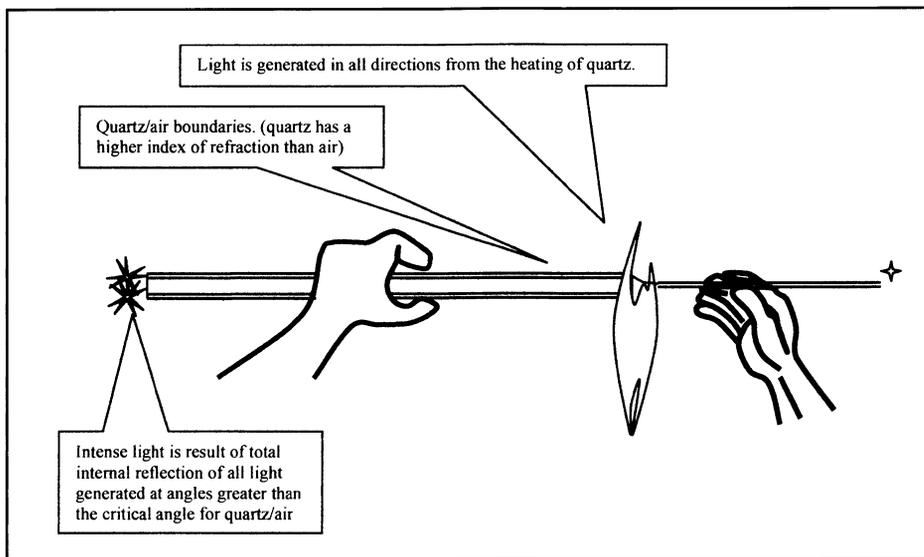


Figure 3. TIR in a quartz tube.

Optical Communication

The current telecommunications infrastructure is a mix of fiber optic cables and copper wire. Telephone, fax transmission and internet signals rely on pulses made of photons in the former case or electrons in the latter. Photons are much better than electrons for many reasons, especially their speed and lack of heat generation, making transmission less hazardous and more reliable and secure. Furthermore, light can travel further in a fiber than electrons in a wire before needing a boost. Fiber does not corrode, it is not affected by lightning, there is no possibility of a spark if broken, and it does not produce electrical radiation making it more secure against tapping.

There is another, less obvious attribute that makes sending a signal by light superior to electricity: light comes in many different colors. Dense Wavelength Division Multiplexing (DWDM) splits lightwaves into different frequencies of infrared light. A single wave of light can have information encoded on hundreds of “channels”.

Every year nearly 200,000 kilometers of underwater cable are installed worldwide. Technology is constantly upgrading the processing of light signals so that a single strand of fiber can contain more information and travel farther without having to be re-amplified.

The Precision Challenge

In order to fully appreciate the challenges the telecom industry demanded of the glass industry, one must consider that the light signal is traveling down a core as small as 8-9 microns. Additionally, from source to receiver, virtually every component along the way must be reliable in a variety of conditions. Optical fiber is produced with +/- 1 micron precision in its core, cladding and coating cross-sectional diameter. Optoelectronic devices that push the signal into this fiber, boost it, split it into different channels, route it and convert it to a signal that the receiver can understand also must have this kind of precision. With such tight tolerances even Coefficients of Thermal Expansion (CTE's in the telecom device maker industry, or how much the glass is going to move with every degree of temperature change) of materials are of critical concern to the alignment of

fiber to these devices. Moreover, the precision must also be repeatable in volume production of hundreds of thousands of parts per week. To appreciate just how tight these tolerances are consider the size of a micron.

A micron, also called a micrometer, can be put into perspective by comparison to a

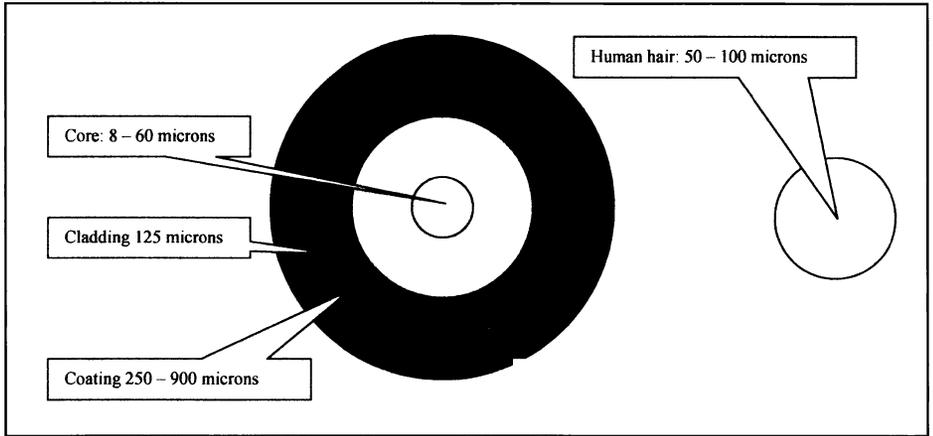


Figure 4. *Cross section of fiber and human hair.*

human hair, or it can be described as a millionth of a meter or a millimeter divided a thousand times. However, a stunning example of how small a micron is can be found by comparison to fingernail growth. An average fingernail grows about 1 mm per week. This means that in 10 minutes a fingernail grows about a micron!

Preforms, Billets and Draw Towers

The precision challenge, i.e., producing glass fiber and alignment parts to tolerances less than the amount one's fingernails have grown in the time it takes to read this paper, has been achieved through the draw process. The draw process is a glassblowing technique; simply stated it is the vertical equivalent of pulling a point. It starts with a tube or rod five to one hundred times the diameter of the desired end product. As with pulling a point, the amount of glass heated, the temperature of the heat source and the rate in which glass is pulled away are controlled in order to execute the technique. Glassblowers have been significantly advancing this technique for at least the last five decades, making precision drawn tubing and rod available for countless applications. In the 1970's, applications in optical communications started to become very important. Visionaries in telecommunications started seeking the edge of the precision envelope in drawing Quartz rod for fiber. The scientific method was applied to the art of pulling a point.

Glassblowers, glass engineers, ceramic engineers, scientists and glassblowing equipment makers pooled their talents to make optical fiber manufacture what it is today. The starting rod, called a preform, can cost hundreds of thousands of dollars each, made by Modified Chemical Vapor Deposition (MCVD, the inside process), Outside Vapor Deposition (OVD), Vapor-phase Axial Deposition (VAD). Plasma-activated Chemical Vapor Deposition (PCVD) or another process.¹ In all cases the underlying machinery is much the same

¹ Details of some of these processes have been presented as ASGS Symposium technical papers in the past and will not be repeated here. Essentially these processes 'lay down' soot or in some other way produce a silica blank with a core and surrounding cladding of differing indices of refraction.

as a traditional glassblowing lathe with motion control and other computer driven process controls and clean-room conditions laid on top to meet the precision requirements.

In keeping with its similarity to pulling a point, the preform is fed into a heat source and pulled to a fraction of its diameter and a multiple of its length. This occurs in a draw tower, several stories high with controls to feed the preform, as well control the temperature and rate of pull. A large preform can yield a kilometer of optical fiber with core, cladding and buffer² diameters guaranteed within a micron. During the draw, the diameter is measured by the shadow the fiber casts as it passes through a laser. If the diameter is not in specification, both in size and roundness, the rate of feed, the positioning of the preform, the rate of pull and/or the temperature of the furnace are adjusted.

Both preform manufacture and optical fiber draw evolved from glassblowing techniques, yet there are few glassblowers in modern day fiber manufacturing plants. A single operator can control one or more draw towers to produce commodity-level volume production and preform manufacture is in the domain of high tech engineers. As advanced as fiber manufacture is, it is still only a part of the optical communications picture. Fiber must be made to interface with devices on the information superhighway. Pushing coded light signals into an 8 micron core and extracting it requires highly advanced alignment parts. Trailing the explosion in demand for precision fiber was the explosion in demand for device interface and intra-device alignment parts. Soft glass, borosilicates, Quartz and other glasses emerged as desirable materials for many high-end precision applications and lent themselves to scalability of production rates. Once again engineers and scientists teamed up with glassblowers to produce alignment parts.

In general, the process of manufacturing alignment parts starts with the draw tower. Instead of a fiber preform, a billet is fed into the draw furnace. Billets, and the resulting drawn glass are not solid as is the usual case for fiber. Single- and multi-bore, rectangular-bore and other high precision tubing (typically about 2 mm outside diameter and 0.126 mm inside diameter) is produced then further processed to make sleeves, ferrules, spacers, V-grooves and other high precision glass parts that help to align and hold the optical fiber. In the 1990's, glassblowers who could innovate with traditional techniques to produce these parts became essential to optical communication device makers. In fact, one of the most successful device makers, JDS Uniphase, who set records at stock exchanges in the 1990's made their first (of many) acquisition in 1996 when they bought a glassblowing company!

Understandably, the details of the techniques used to make the alignment parts are proprietary and cannot be disclosed. However, having had a first-hand account of these techniques, the author will attest that the techniques are modern innovations of traditional glassblowing techniques.

Conclusion

Glassblowing and glassblowers have made significant contributions to the information superhighway. First in the manufacture of fiber preforms and fiber draw and then in the manufacture of alignment parts, glassblowers have been essential to optical communica-

² Buffer is the protective polyimide coating applied during the draw process before water in the atmosphere has a chance to attack glass surfaces, making the fiber incredibly strong and flexible enough to twist into a knot without breaking it.

tions as we know it today. The high tolerances demanded by optical telecommunications gear makers presented challenges and glassblowers incredibly met them.

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Large Scale Quantitative Head Space Analysis Apparatus

by

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Abstract

Discussed will be the large scale Headspace analysis apparatus developed and used by the Snacks and Beverages division of The Procter and Gamble Company. This equipment was originally designed in Germany by Dr. Gerhard Zehentbauer and published under the title of "Apparatus for Quantitative Headspace Analysis of the Characteristic Odorants of Baguettes" while he was doing his doctoral thesis work at the Technical University of Munich. The design was adapted after much trial and error here at Procter & Gamble (P&G) beginning in May 2003 through a collaborative effort with Dr. Zehentbauer, James Conatser and Kevin Tewell of the P&G Machine Shop, and myself.

As usual, my customer first approached me about this piece of equipment with nothing more than a rough sketch and a description from his publication (Figure 1). After describing to me what he intended to accomplish with the unit, I refined his drawing into a workable diagram (Figures 2 & 3). The

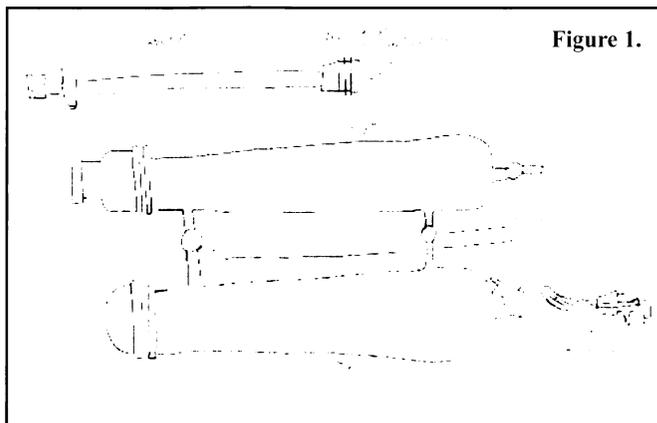


Figure 1.

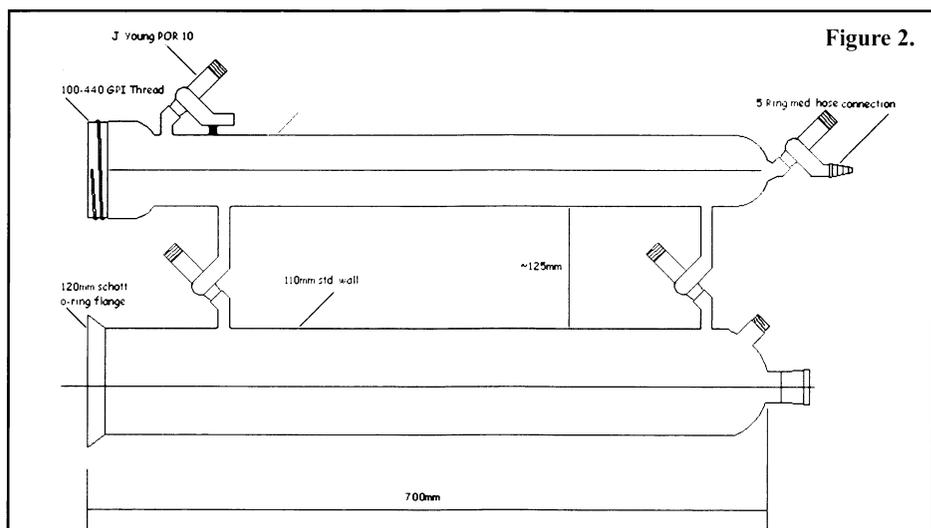
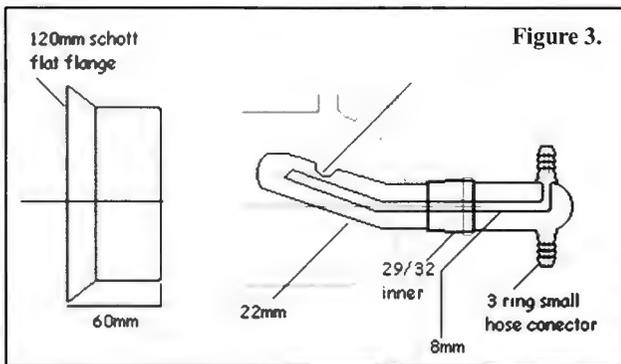


Figure 2.

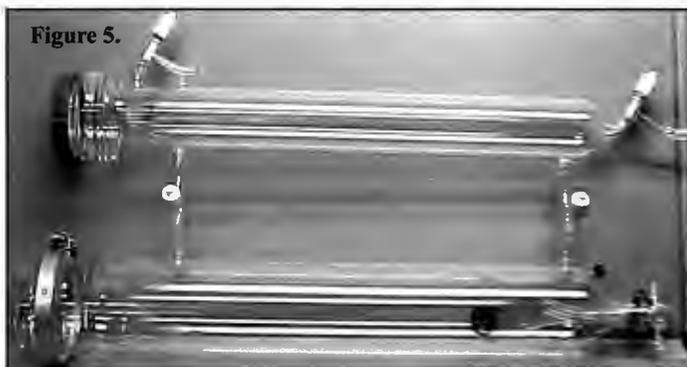
basic idea was that a material with an unknown head space would be placed in the bottom chamber and, through an air tight hand pump, the “scented” air (head space) could be transferred into the top chamber and isolated from the original material to be analyzed by a Gas Chromatograph (GC). The “hot finger” on the bottom chamber (Figure 3) was a way to introduce a solvent based standard into the head space. This way the GC had a “tracer” chemical in the final gas on which the GC operator would focus his instrument.



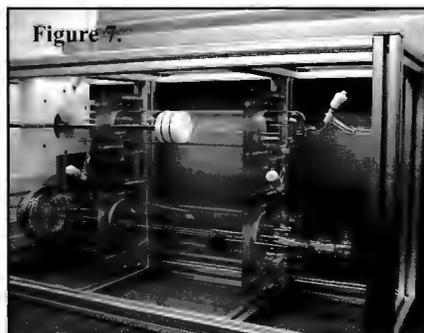
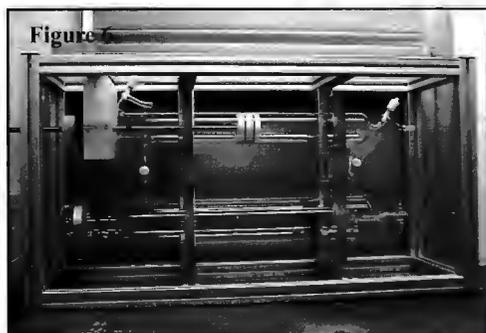
Through a collaborative effort with James Conatser and Kevin Tewell of the P&G machine shop, a hand pump was designed and fabricated using stainless steel, Teflon, and TFE encapsulated Viton O-rings. The pump was fitted with a 100-440 G.P.I. plastic cap with Teflon liner (Figure 4). Figure 5 shows the first of the head space pumps to be fabricated.



For the sake of minimizing breakage, an aluminum cage was assembled (again by Kevin Tewell) to house the equipment (Figures 6 & 7).



After the first use of the equipment, tragedy struck, and the whole end of the top chamber was



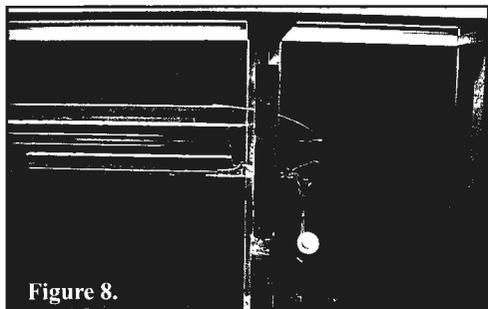


Figure 8.

shattered (Figure 8). It was determined that the top tube had too thin of a wall weight, and that the TFE encapsulated O-rings were too stiff to allow for the small changes in diameter and roundness of standard glass tubing. Redesign was necessary. It was decided that heavier wall weight tubing would be necessary to limit future breakage. The two O-rings were also replaced with three leather fins

which allowed for more conformity to the unpredictable inner walls of glass tubing. Since the top tube needed to be rebuilt, all stopcocks and seals were pushed as close as possible to the far edges of the equipment, thus allowing a larger path length for the pump to work (Figures 9 & 10). Figures 11, 12, & 13 show the rebuilt and redesigned pump. Since the

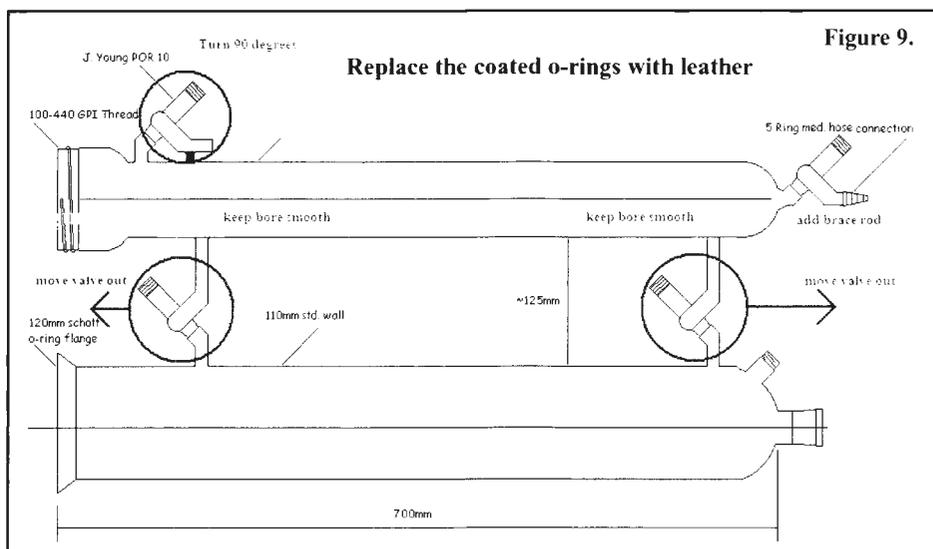


Figure 9.

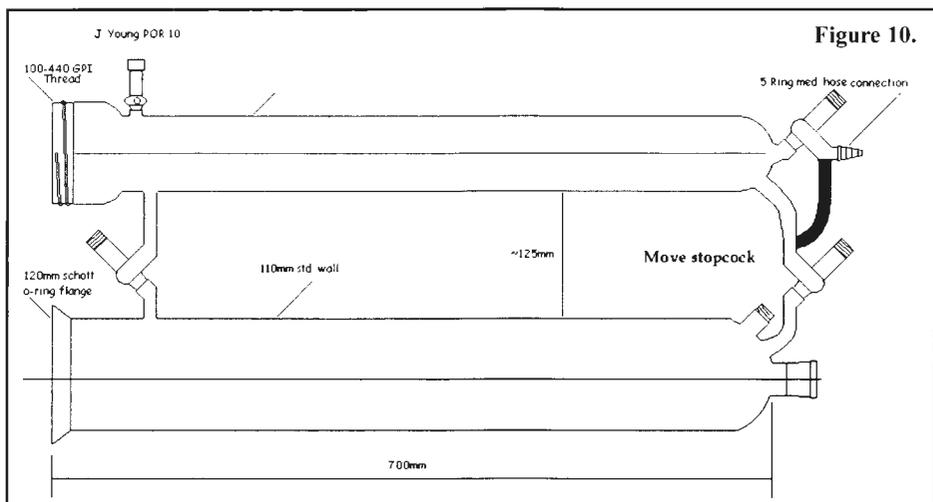
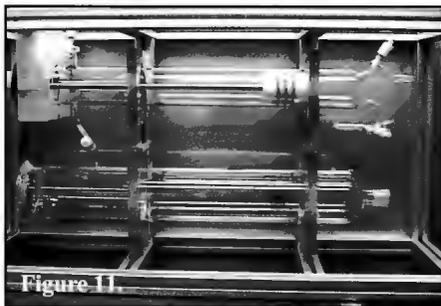
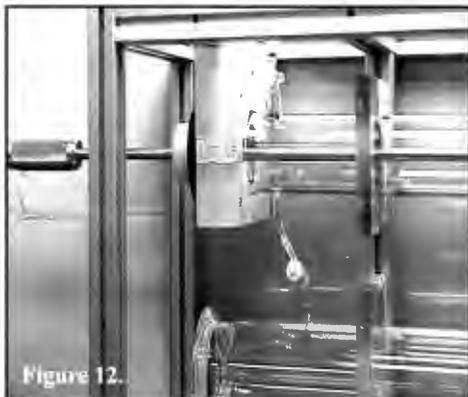
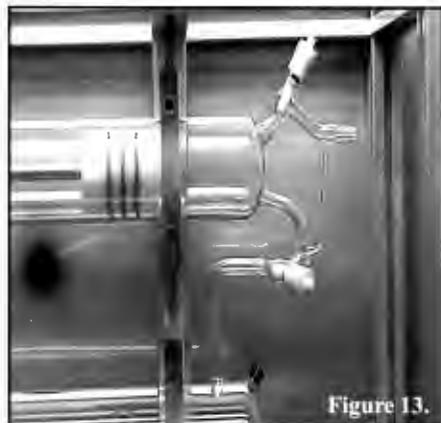


Figure 10.

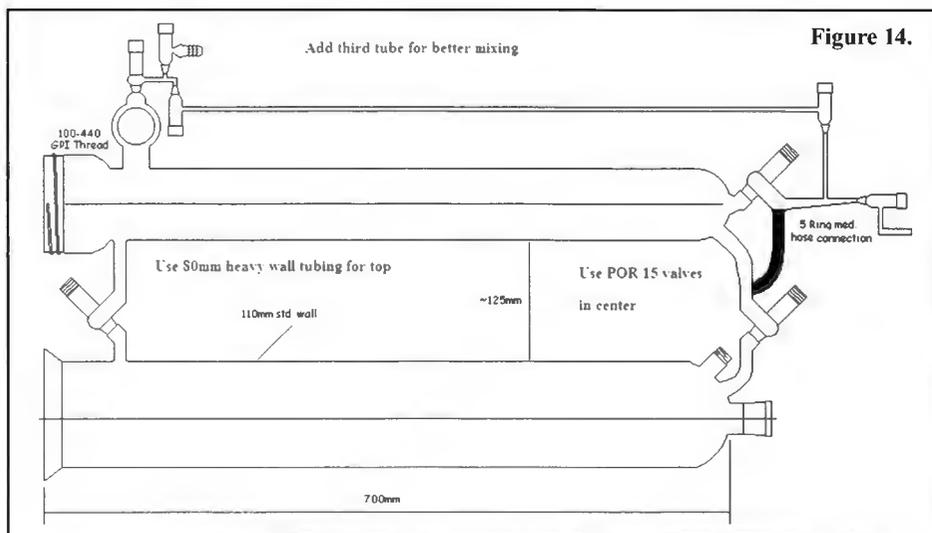
bottom tube was re-used, the two connecting stopcocks look a little out of place, as compared to the revised drawing (Figure 9).



At this point, the pump basically worked, but the unit was not operating as efficiently as was hoped. Further improvements were desired. Among the problems was a slow transfer of gas from bottom tube to top tube, as well as uneven distribution of gas on one side of the TFE pump plug and the other. Only the gas on the one side of the pump plug was passing



over the standard finger. There was also a big problem with the standard being absorbed into the coffee itself. After much discussion about how to deal with the standard finger problems, I suggested adding yet a third tube and placing a hot finger on it. Then the bottom tube could be isolated, the top tube could be mixed with itself, and all head space gasses would have the opportunity to pass over a hot finger. I suggested using larger stopcocks between the bottom and (now) middle tube (Figure 14). I also made the executive



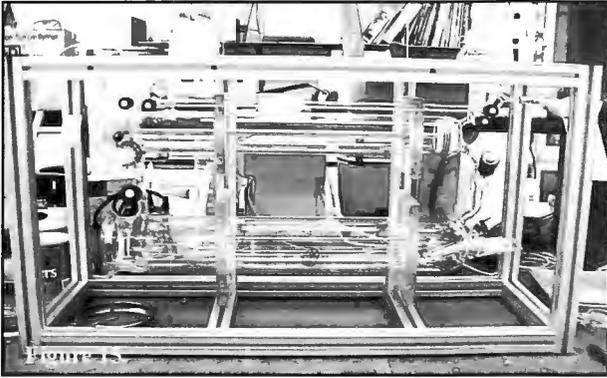


Figure 17.

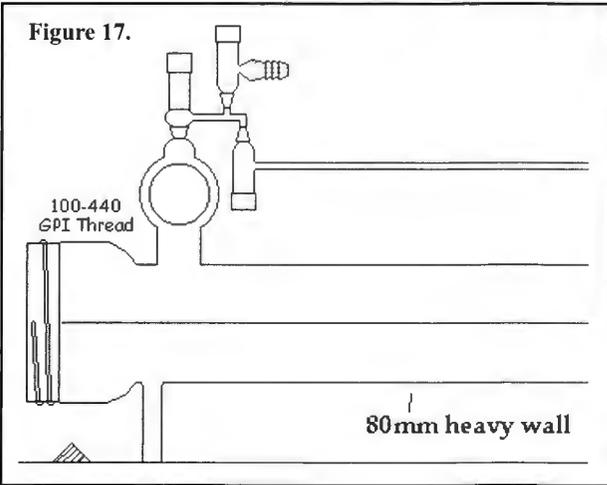


Figure 18.

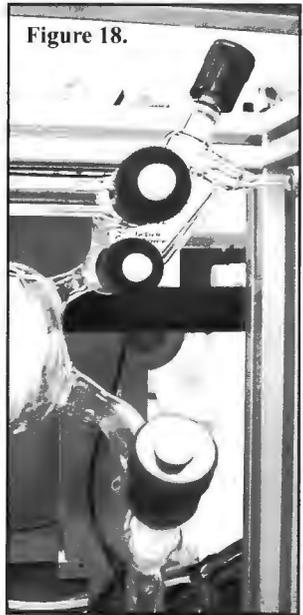
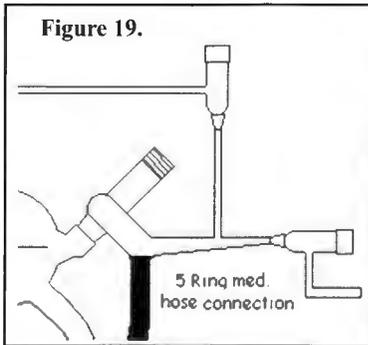


Figure 19.



decision that I had modified the original unit enough, and out of my own vanity, fabricated a new unit, scrapping the old (Figure 15). You will also notice the machine shop fabricated a new pump plug: the original was too large and heavy, and the excess weight was causing small leaks in the system around the 100-440 thread cap. Figures 16 & 17 show the rebuilt “front” of the unit, in both concept and the final product. Figures 18 & 19 show the “end” of the unit.

In order to ease cleaning of the bottom tube, Dr. Zehentbauer requested a large sample boat to hold the sample (Figure 20). This was fabricated from a piece of 80 mm standard wall tubing and was 26" long. A handle made of $\frac{1}{2}$ " medium wall was added, and the piece

was cut in half lengthwise. The capacity of the boat allowed Dr. Zehentbauer to place 1 lb of coffee into the boat. All improvements completed, the unit was ready for use.

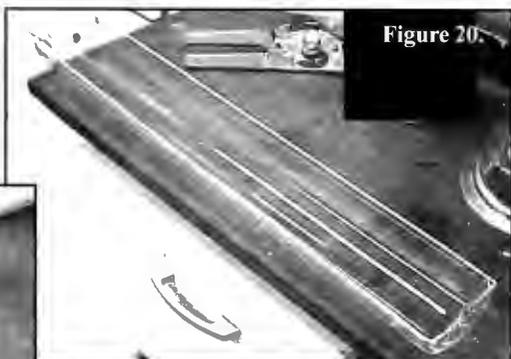


Figure 20.



Figure 21.

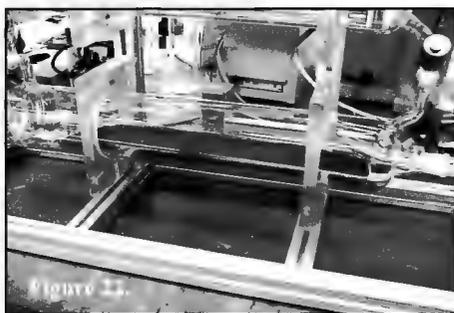


Figure 22.

To use the apparatus, you first load the boat (Figure 21), and then slide the boat into the unit (Figure 22). Once the cap is in place and the sample is isolated, the J. Young POR 15 stopcocks in the center of the unit are opened and all other stopcocks are closed (Figures 23, 24, 25, 26 & 27). The hand pump is then actuated (Figure 28). This will circulate the air from the middle tube to the bottom tube and back up to the middle (Figure 29). After an equilibrium time of 30 minutes pumping three times a minute (which allows the head space gasses proper time to travel to the middle tube), the POR 15 stopcocks are now closed, the solvent

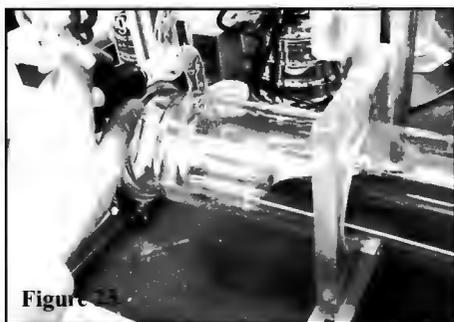


Figure 23.



Figure 24.

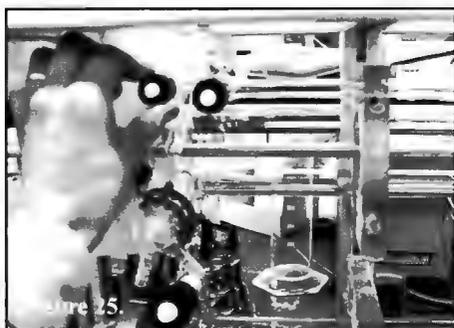


Figure 25.



Figure 26.

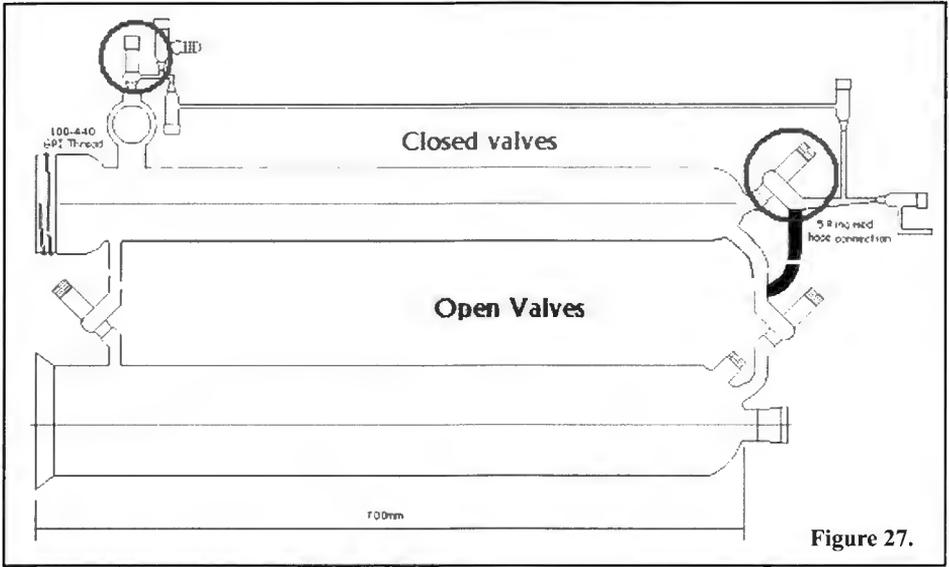
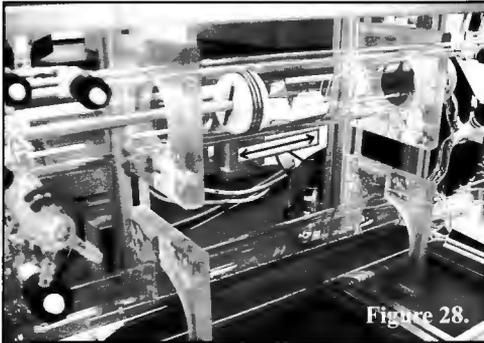


Figure 27.



based standard is inserted to the new hot finger on the top tube (Figure 30), and the J. Young POR 10 stopcocks between the middle and top tubes are opened. The inlet and outlet are still closed at this point (Figures 31, 32, 33, 34 & 35). The pump is again actuated (Figure 36), this time circulating the head space gases between the middle and top tube and allowing the gas to pass over the hot finger (Figure 37).

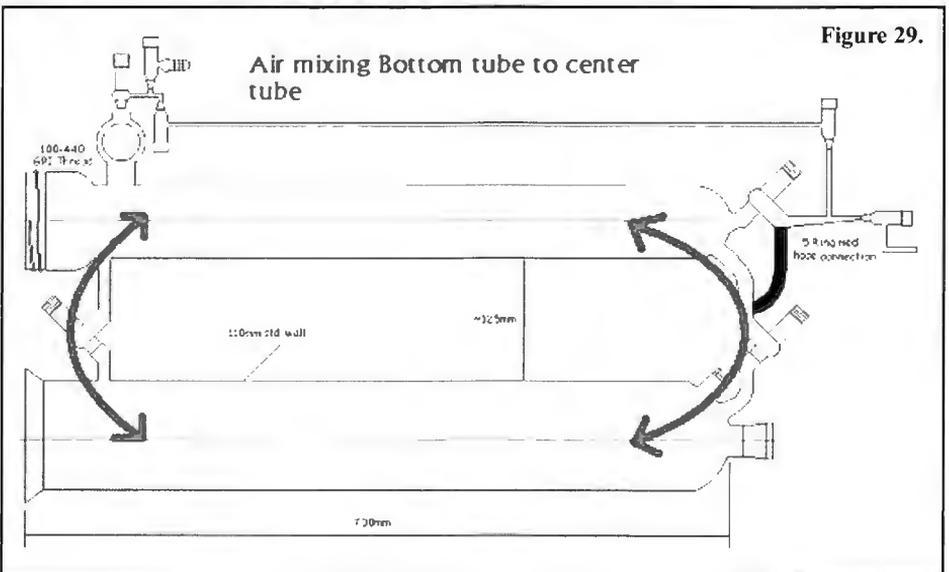


Figure 29.

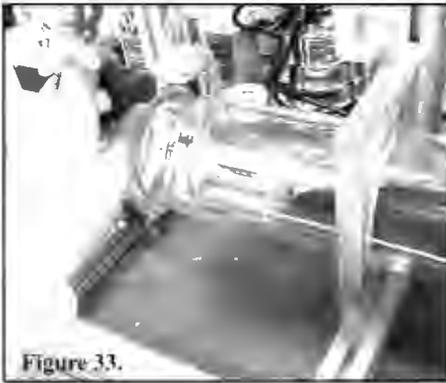
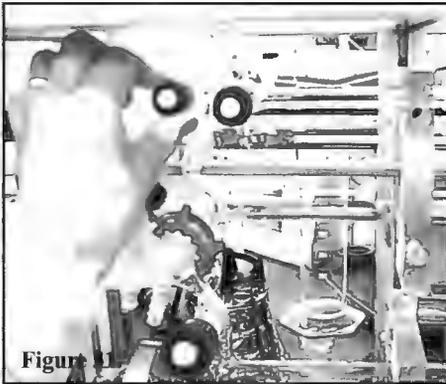


Figure 35.

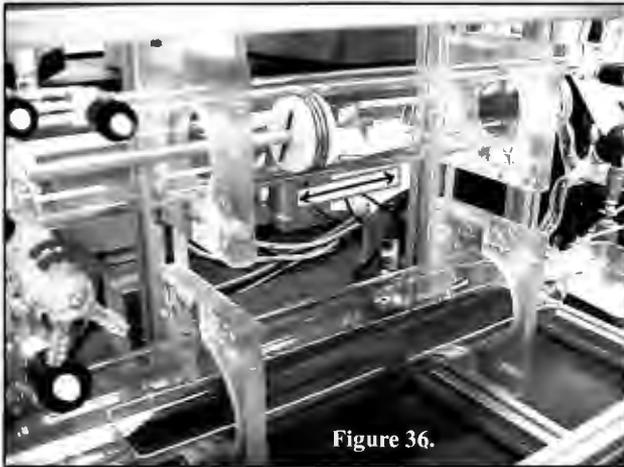
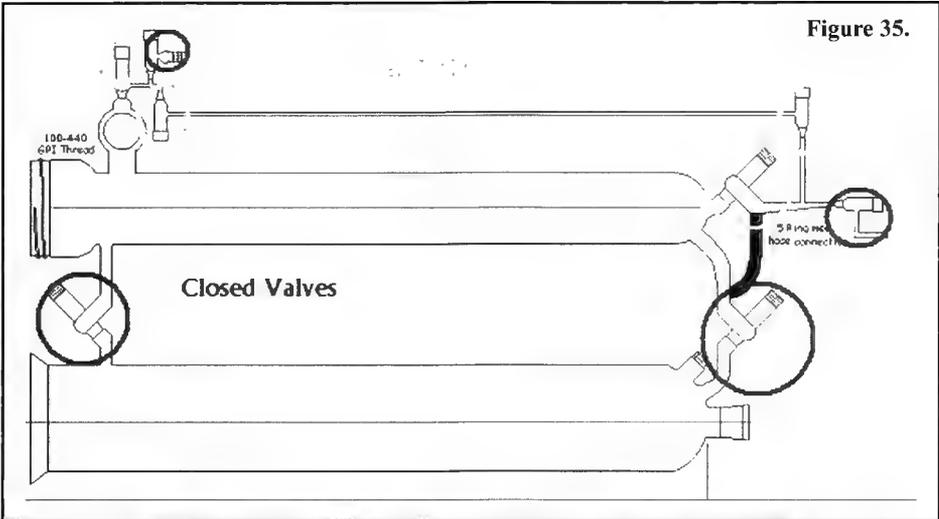
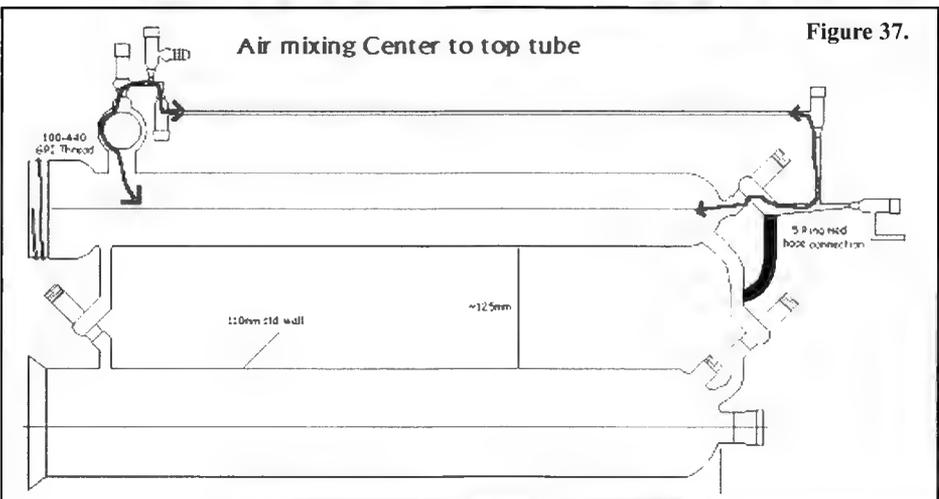


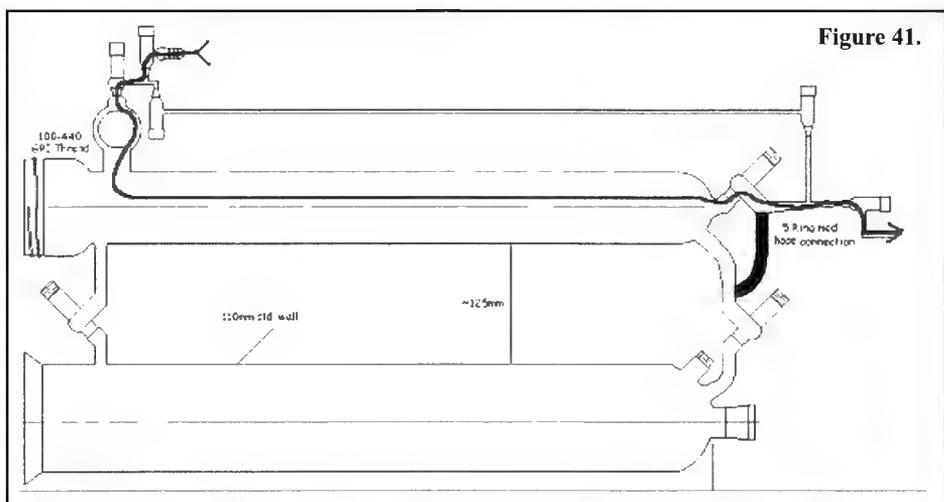
Figure 36.

Figure 37.



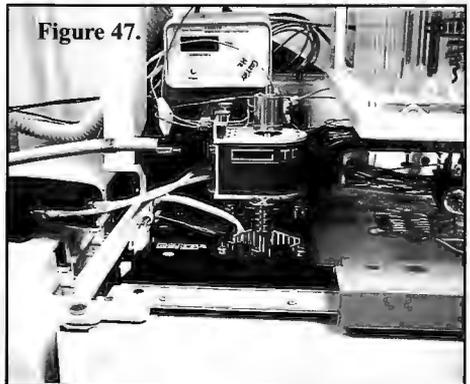
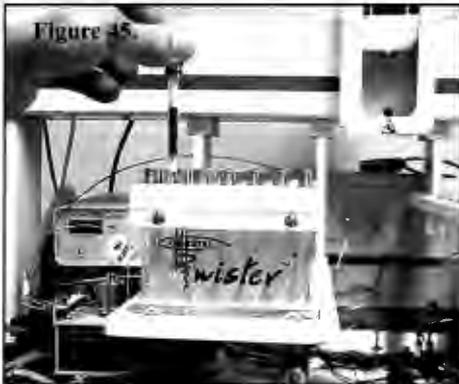
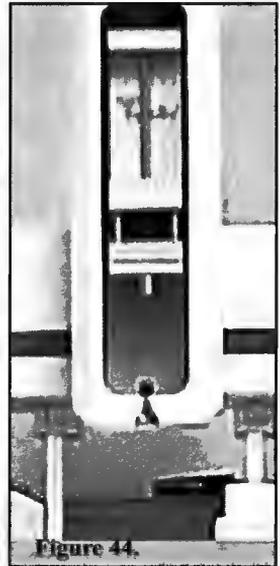


Once all gas has been successfully transferred and isolated from the sample material, a gas sampling trap is connected to the outlet of the unit (Figure 38). The outlet stopcock and the inlet stopcock are opened (Figures 39 & 40) and, using a nitrogen purge, all collected gasses are pushed out into the trap (Figure 41). The loaded purifying trap, once removed (Figure 42), is then taken to the GC for analysis (Figure 43). The trap is placed in the auto sampler (Figure 44), and the trapped gasses are “desorbed” into the GC inlet (Figure 45). The sample is then injected into the GC where analysis of the gasses takes place (Figure 46 & 47).



This unit was designed by the Snacks and Beverages division of P&G to analyze the unique smell that comes from a freshly opened can of coffee. However, its application is relatively universal, and other divisions of our company have expressed interest in using the equipment to analyze their products as well.

Special thanks to Dr. Gerhard Zehentbauer, James Conatser, Kevin Tewell, and Donald Patton and Dr. Jainjun Li for their assistance with the GC.



Reactor, Stirrer and Baffle Design For Optimum Mixing

by

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Abstract

The main purpose of this paper is to discuss the general process objectives that need to be considered when designing and building a Reactor, Stirrer and Baffle for Optimum Mixing. These designs and results are all based on years of experience between Wyse Glass Specialties, Inc. and the Mixing Expertise Center at The Dow Corning Corporation. I will discuss Process Objectives, Mixing Vessel, Wall Baffle and Stirrer designs along with other considerations.

Process Objectives

There are two main types of mixing to consider, Single Phase and Multi Phase. Single phase consists of the process of mixing of two or more miscible liquids. Keys to single phase mixing are as follows:

- Uniformly mixing and distributing the ingredients throughout the entire mixture.
- Mixer must be designed to promote very good flows throughout the mixer.
- Minimize dead zones.
- Swirling motion is an indicator of poor mixing.

Multi Phase consists of mixing oil and water (emulsifications), dispersing a gas into a liquid or suspending/dispersing a solid into a liquid. Key points to multiphase mixing include the key items in single phase mixing but also include a major emphasis on the following:

- Mixer must be designed to promote major shear (turbulence) to break up drops and bubbles.
- Mixer speed must be sufficiently high to achieve the targeted process performance.

Reactor Vessel

The mixing vessel design for both single and multi-phase mixing is universal and eliminates the need for two different reactor body designs. Testing has shown that round bottom flasks even if equipped with wall baffles provide far less superior mixing than a cylindrical shaped reactor. To achieve the goals required, a vessel designed with the liquid height equal to the vessel diameter (Square batch) has been tested as the most efficient. The bottom shape of the reactor

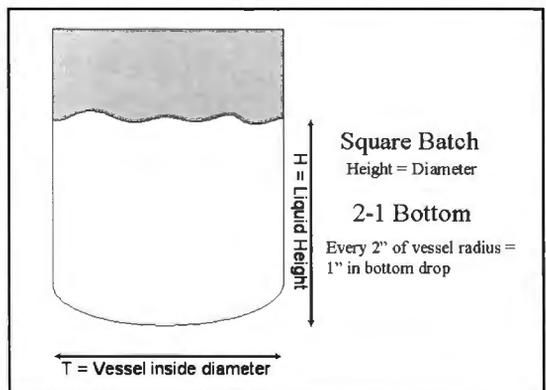


Figure 1. Mixing Vessel.

also has major effects on the flow patterns and the elimination of dead spaces in the vessel. An elliptical dish shaped bottom with a 2-1 ratio has proved to provide the most optimal performance.

Wall Baffles

The purpose of a baffle is to convert unproductive swirling action around the outer wall of the vessel into up and down flows for better mixing. The most typical baffle cage is made up of four evenly spaced baffles spaced around the vessel wall. Creating a baffle that is spaced away from the vessel wall eliminates a stagnant zone where unmixed solids and liquids can build up. Baffle cages can be made from glass, Teflon, stainless steel coated with Teflon, and uncoated stainless. There is one exception to using a baffle assembly: when mixing high viscosity fluids (greater than 10,000cP) a baffle can have detrimental effects, therefore making a removable baffle cage more desirable. All baffle dimensions are based on the i.d. of the vessel with the baffle height covering the entire liquid height.

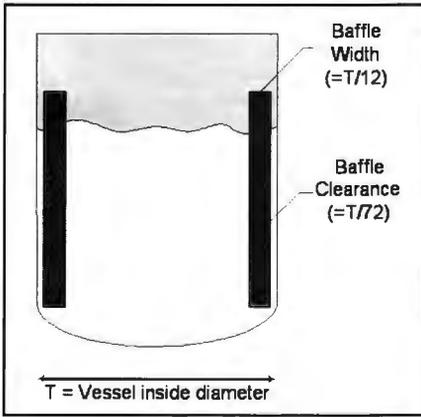


Figure 2. Wall Baffles.

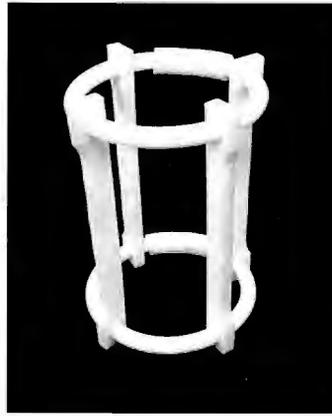


Figure 3. Teflon Baffle Cage.

Stirrers

Axial impellers (hydrofoil and marine prop) are low shear, require less power draw and create strong up and down flows. These are designed to push the liquid in a downward direction while the stirrer is rotating clockwise. These are best used for the simple mixing of low viscosity fluids and fluids requiring rapid heat transfer or solid suspension.

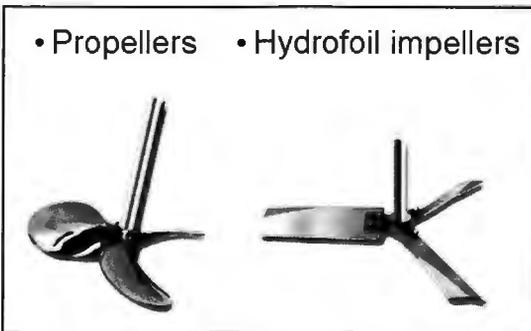


Figure 5. Axial Impellers.

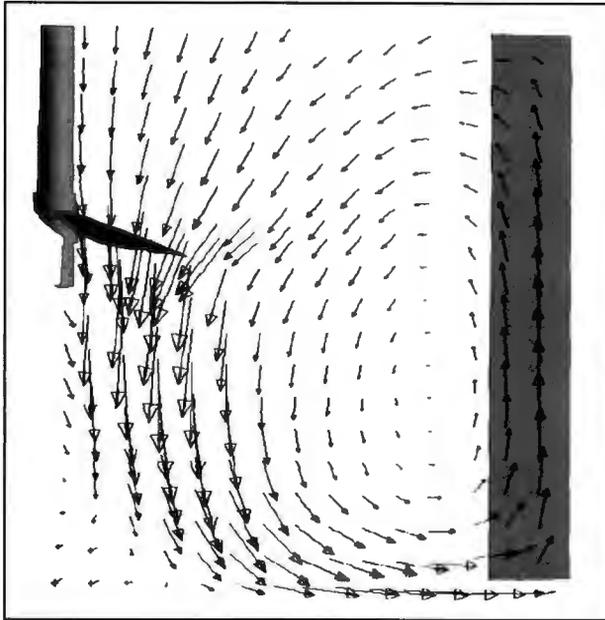


Figure 6. *Flow pattern for Axial Impellers.*

Radial impellers (flat vertical blades) are high shear, high power draw and create flows in the radial direction. These are best used for fast reactions, gas-liquid, liquid-liquid and solid suspension mixing.



Figure 7. *Radial Impellers.*

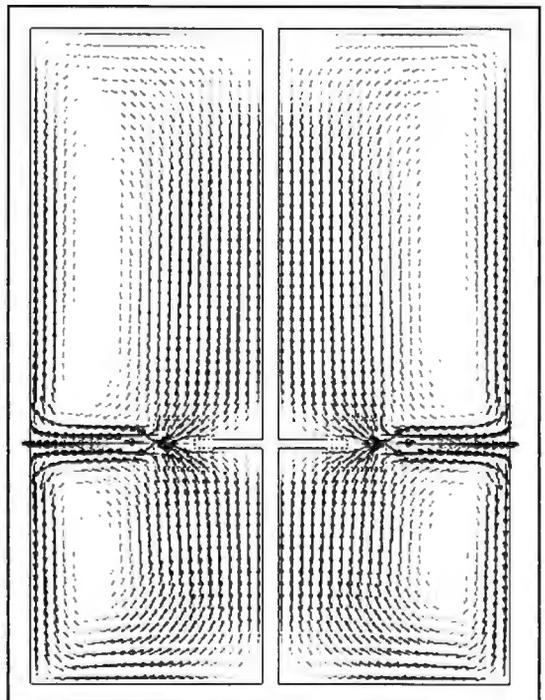


Figure 8. *Flow pattern for Radial Impellers.*

Mixed Impellers (Pitched blade turbine) generate good shear and turbulence, especially in the impeller zone. These are also designed to push the liquid in a downward direction while the stirrer is rotating clockwise. Flows generated are in both the radial and axial directions. This style is best used for liquid-liquid and solid suspension mixing.

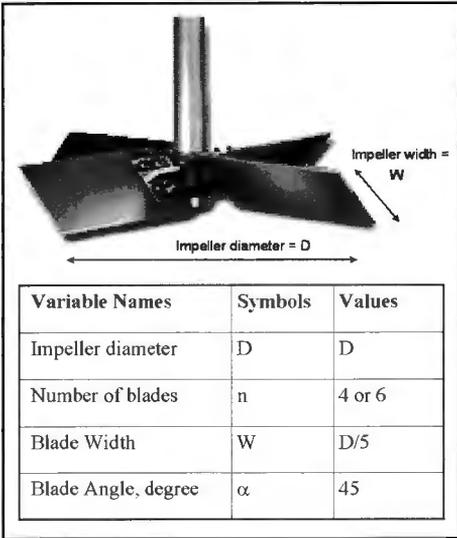


Figure 9. Pitched Blade Turbine (PBT).

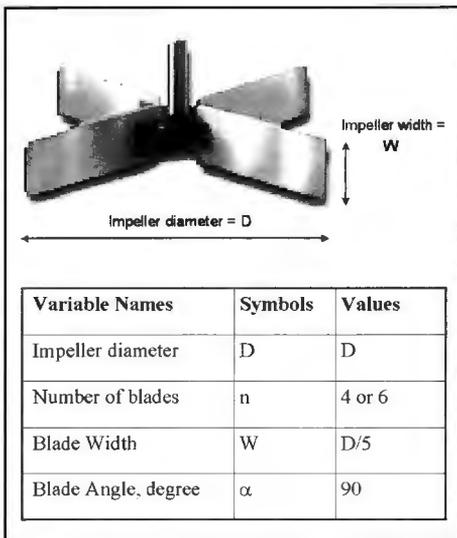


Figure 12. Flat Blade Turbine.

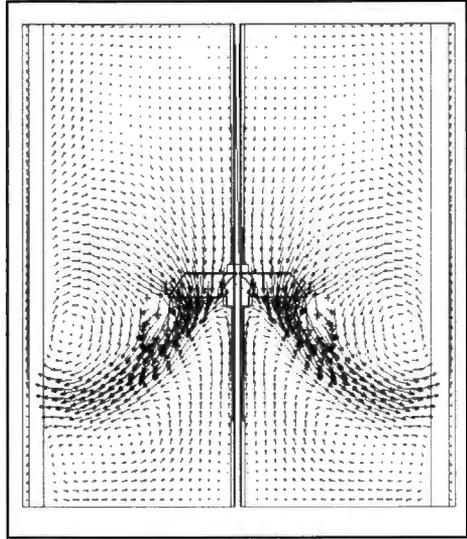


Figure 10. Flow pattern for Pitched Blade Turbine (PBT).

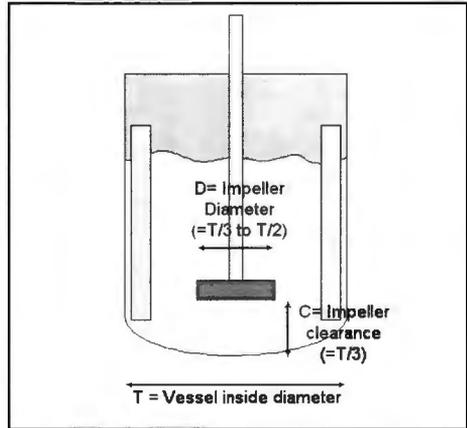


Figure 11. Guideline on Impeller Size.

The overall diameter “D” and clearance “C” of an impeller are based on the vessel’s diameter “T” and can be calculated using the guidelines in picture 11.

After the diameter “D” has been calculated, you can then calculate the individual impellers blade width, length and, in case of the Rushton Impeller, the disc diameter. The tables (Figures 12 and 13) will help guide you through the process.

Additional Considerations

Other items that help make your mixing vessel work more efficiently and which should also be considered in your design are listed below.

- Extended stir bearing to stabilize the stir shaft (large vessels).
- Stir shaft retainer to support stir shaft and prevent accidents.
- Schott style flanged lid connection with quick release clamp for easy assembly and cleaning.
- Jacket for heating and cooling.
- Flush bottom discharge valve to eliminate dead space.
- Flexible stir shaft connection.
- Variable speed motor with reverse and speed indicator.

Conclusion

These are the general guidelines we have established and use to help us create a more efficient mixing apparatus, whether it be a small 50 ml reactor or a 100 Liter pilot plant unit. These design elements can be used together in many ways to help create a vessel that will best fit a particular mixing application.

Special thanks to Mr. Hahn Vo, Ph.D., Dow Corning Corporation.

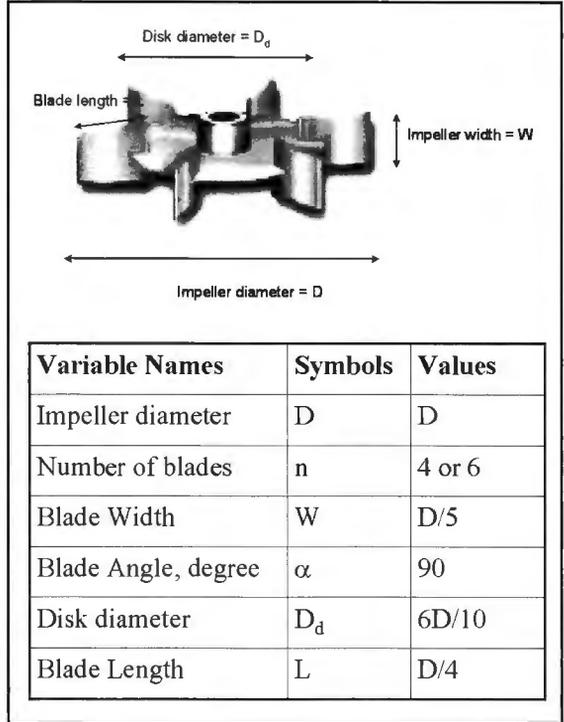


Figure 13. Rushton Impeller.

A Review of the Associate of Applied Science Degree in Scientific Glass Technology

by

Daryl C. Smith

Scientific Glass Technology

Salem Community College

Carney's Point, NJ 08069

Abstract

Salem Community College, first as a technology institute then a community college, has educated scientific glassblowers for 45 years. This Scientific Glass Technology program review is intended to provide an understanding of the curriculum, course content, references and laboratory recommendations. It was prepared to provide an overview of the status of the curriculum used to educate highly skilled scientific glassblowers. The program is designed as two-year Associate of Applied Science degree.

Introduction

Scientific glassblowers create glass apparatus for scientific research in laboratories, universities, and industry. Scientific Glass Technology combines classroom study and hands-on laboratory techniques, blueprint reading and design, so that the students are able to fabricate apparatus according to technical specifications. Upon successfully completing the program, a student should be able to demonstrate competence in the technical skills of scientific glassblowing, including cutting, heating, shaping and sealing, function as a scientific glassblower in an industrial, research or manufacturing setting, and demonstrate an understanding of technical drawing and advanced fabrication. The primary objective of the total degree program is the training of qualified scientific glassblowers. As technicians, they will work and communicate directly with scientists, supervisors, and other professional personnel. They will be expected to perform as successful employees and have the opportunity to grow into supervisory and administrative positions.

To accomplish these goals, the curriculum is carefully planned and implemented. In many ways, more is expected of the 2-year Associate of Applied Science graduate than of the 4-year liberal arts graduate. As graduate technicians, they will be expected to be well-informed, active, responsible members of society. The scientific glassblowing graduate will be responsible for the design, fabrication, and repair of laboratory glass apparatus and, therefore, they become an essential element in the scientific research team. Through close cooperation between the glassblower and the researchers, large and complicated apparatus designed for the particular problem at hand can be built, assembled, and installed so that the research project can achieve its intended goals.

Program Content and Structure

Curriculum requirements for Scientific Glass Technology-Associate of Applied Science

<u>First Semester</u>	<u>Credits</u>
SGT 113 Introduction to Scientific Glass	6
ENG 101 College English I	3
MAT 136 Intermediate Algebra	4
CS 115 Microcomputer Application	<u>3</u>
Total	16

<u>Second Semester</u>	
SGT 114 Basic Apparatus Fabrication	6
SGT 115 Tech. Drawing and CAD	3
Social Science elective (limited)	3
Math elective	3
SCO Elective	<u>1</u>
Total	16

<u>Third Semester</u>	
SGT 210 Advanced Fabrication I	6
CHM 101 College Chemistry I	4
Humanities Elective (limited)	3
PHY 101 Physics I	<u>4</u>
Total	17

<u>Fourth Semester</u>	
SGT 211 Advanced Fabrication II	6
CHM 102 College Chemistry II	4
SGT 120 Cold Construction	3
ENG 122 Business and Occupational Writing	<u>3</u>
Total	16

Total Credits earned 65

As a reference, the following description from the Dictionary of Occupational Titles, U.S. Department of Labor, presents some of the activities which the graduate will be expected to perform:

Fabricates, modifies, and repairs experimental and laboratory glass products, using a variety of machines and tools, and provides technical advice to scientific and engineering staff on function, properties, and proposed design of products, applying knowledge of glass technology. Confers with scientific or engineering personnel to exchange information and suggest design modifications regarding proposed glass apparatus, such as distillation and high-vacuum systems. Cuts glass tubing of specified type, using cutting tools, such as glass saw and hot-wire cutter. Heats glass tubing until pliable, using gas torch, and blows, bends, and shapes tubing to specified form, using blowhose, hand tools, and manual pressure. Performs finishing operations to fabricate glass product or section, using machines and equipment, such as lapping and polishing wheels, spot-welding and sandblasting ma-

chines, internal-plating equipment, and drill press. Measures products to verify dimensions, using optical scanner, micrometers, and calipers, and examines glass coloration for degree of internal stress, using polariscope, to determine annealing requirements. Anneals products, using annealing oven. Joins and seals subassemblies to assemble finished product, using gas torch, hand tools, and vacuum pump. May operate special equipment, such as radio-frequency-fusing machine, to bond glass to metal, quartz, and ceramic materials. May identify glass of unknown composition by heating with gas torch and evaluating curvature, bondability, and color characteristics. May direct and train GLASS BLOWERS, LABORATORY APPARATUS (glass products; inst. & app.). May design fixtures for use in production of prototype glass products and prepare sketches for machine-shop personnel. May prepare cost estimates for prototype glass products. May requisition or recommend purchase of materials, tools, and equipment. May specialize in specific types of glass scientific apparatus and have knowledge of effects of special environments on glass, such as radioactivity, vacuums, gasses, chemicals, and electricity.¹

Syllabi for all required courses are available by contacting, Faculty Secretary, Office of Academic Affairs, Salem Community College, 460 Hollywood Avenue, Carney's Point, NJ 08069, (856) 299-2100, info@salemcc.edu.

Curriculum Analysis

Candidates for the program must enter in the fall semester and, as best as possible, complete all required courses to graduate with an Associate of Applied Science Degree in two years. Curriculum and courses are planned for maximum effect. Each course is designed to develop its particular knowledge and skills and still be closely integrated into the whole curriculum. The curriculum's technical content is intended to give the student an understanding of the scientific glass apparatus and an expertise in its design, fabrication, and repair. The sequence of courses is such that each one is placed in the most strategic position for its correlation to other courses. A parallel development takes place in the student's understanding of the apparatus and their skill in its fabrication. Courses in mathematics, chemistry, and physics lay the groundwork for understanding the sciences that the glassblower supports. Ability must be developed in manipulative skills; much time is devoted to laboratory scientific glassblowing experience. While it is true that the glassblower requires technical knowledge, it is also true that they will not be successful in employment unless they have adequate physical skills. An interested student of average coordination and dexterity will gradually become proficient, but this is accomplished normally only after many hours of laboratory experience.

Frequent visits to representative industrial and university research laboratories as well as scientific glassblowing production industries keeps the instructor as completely aware as possible of the graduates' employment environment and needs. Course content and objectives are presented and recorded in the course syllabi. Such a record of course activities ensures continuation of program goals regardless of time or location of course delivery or instructor involved.

The syllabi are reviewed and approved by the Salem Community College Curriculum Review Committee prior to the Middle States Accreditation and the Scientific Glass Technology Advisory Committee.

¹ Dictionary of Occupational Titles, U.S. Department of Labor, 006.261-010 Scientific Glass blower (4th ed., rev. 1991) <http://www.oalj.dol.gov/public/dot/REFRNC/DOT01A.HTM>

The Scientific Glass Technology Advisory Committee was formed to analyze program content in relation to industry needs. The following individuals served on this Committee, and their input was highly effective and much appreciated:

Darrell Hill (Ace Glass Inc.), Alan Durham (Chemglass, Inc.), Tony Rocco (Chemglass, Inc.), Parker Stowman (Chemglass, Inc.), Bill Robbins (Kontes Glass Co., Inc.), Michael J. Souza (Princeton University), Wes Lutz (Andrews Glass), John Cannon, Jr. (Andrews Glass), Bill Wentzel (H.S. Martin Inc.), Ed Powell (Astra-Zeneca Pharmaceuticals), and Dennis Briening (Hercules Research).

The Committee met on the following dates: February 20, 2002, May 6, 2003, November 18, 2003, and April 20, 2004. At each meeting, a presentation of course content and any proposed program changes were made. Skills required in positions in which graduates could be employed were analyzed by way of a survey of the Scientific Glass Technology Advisory Committee. Open discussion generated valuable input on several pertinent topics.

Instructional material is kept up to date by involvement with the professional Society of scientific glassblowers. The American Scientific Glassblowers Society maintains a web site with a technical resource page, publishes a quarterly magazine, *Fusion*, and the *Proceedings* of the annual symposium, which includes the technical papers presented. The Society also offers a technical questions and answers e-mail list. Salem Community College also owns the publication rights to E. L. Wheeler, Scientific Glassblowing, (New York: Interscience Publishers, Inc., 1958) which still remains an excellent, all-encompassing book on scientific glassblowing.

Student Enrollment/Retention Data

The following data outlines the number of students who entered the program from the Fall of 2000 to the Fall of 2002.

a. Fall semester matriculation data for A.A.S. candidates

i.	Entered	Retained	Graduated	Percent
	<u>FA-2000</u>	<u>FA-2001</u>	<u>SP-2002</u>	<u>Graduated</u>
	20	10 (2)	6	33%

Note: (2 students received certificate degree)

	Entered	Retained	Graduated	Percent
	<u>FA-2001</u>	<u>FA-2002</u>	<u>SP-2003</u>	<u>Graduated</u>
	20	12	5	25%

	Entered	Retained	Graduated	Percent
	<u>FA-2002</u>	<u>FA-2003</u>	<u>SP-2004</u>	<u>Graduated</u>
	17	12	6	35%

This data shows those students who graduated within the two-year recommended time period. A small numbers of students do receive their degree at a later date, but the numbers show no statistical trend

The program is open to all persons regardless of their demographic classification. Enrollment in the program is limited to 20. This policy keeps the enrollment at a steady number, and also ensures manageable class sizes. Potential candidates are first put on a

waiting list then, are required to submit a non-refundable deposit to secure a seat in the program. Students progress through the degree as a group and courses are scheduled so that students are able to complete the degree in two years.

Program Outcomes

Graduates of this curriculum can expect to find employment in research laboratories, scientific glass manufacturing companies, and repair and custom glass companies. Scientific glassblowers must be capable of working closely with scientists, researchers, and supervisors and coordinate activities with other skilled craftsmen and workers. Graduates serve as the effective bridge between theoretical knowledge and practical execution. The graduate must be able to understand sufficiently the professional's scientific and mathematical expression of laboratory glassware in order to fabricate effective apparatus. Of the eleven students who graduated in the spring of 2002 and 2003, eight are employed in the glassblowing field, two are currently seeking employment, and the situation of one is unknown. There were two certificate students who entered in the fall of 2000 and finished in the spring of 2001, one is employed, the other changed majors. 6 students graduate in the spring of 2004 and at the time of this writing have not entered the job market.

Faculty

The requirements of the instructor of the scientific glass technology program are as follows: an Associate of Applied Science in Scientific Glass Technology, a Bachelor's degree in a science discipline and teaching/training experience. They must be capable of overseeing and teaching borosilicate and quartz glass applications for production, and research and development process of technology. The instructor is responsible for the development of growing the curriculum as well as overseeing the development of the professional advancement program. They must establish relationships with industry and practitioners, be able to demonstrate excellent interpersonal skills, and have the ability to manage resources.

The main instructor teaches the following courses: SGT 113, and 210 in the fall semester and SGT 114, and 211 in the spring semester. Each of these is a technology-based course for 6 credits each. SGT 120 is a 3-credit course taught by a full-time faculty member during the spring semester. SGT 115, a 3-credit drafting course, is the only course taught by a part-time adjunct instructor. The current scientific glassblowing instructor, Daryl Smith, a member of the American Scientific Glassblowers Society since 1986, serves on its Board of Directors, the Education Committee, and previously as a Section Chair.

Instructors, through membership, obtain a continual source of instructional ideas and materials. The ASGS helps the theorist to understand practical applications and encourages the technician to deepen his theoretical understandings. The Society can be expected to be the first to announce and describe significant research and innovations in the field. Instructor membership in scientific and technical societies sets the stage for a close liaison with employers and interested members of the community. All instructors in the glassblowing technology program should be encouraged to be active members of their respective societies. In this way, each member of the team will be sharing with the other instructors the new developments in their own field for possible application to the glassblowing technology education. The effectiveness of the scientific glassblowing technology program depends primarily upon the competence and the enthusiasm of the teaching staff. Glassblowing technology instructors must have special competencies, which can be gained only through training, practice, and industrial and research experience in the technical subject matter.

The scientific glassblowing instructor is, of course, the central figure upon whom the program's success depends. Student interest, motivation, technical understanding and skills will be proportionate to that of the instructor. The student will sense his appreciation of the theoretical knowledge needed for a genuine technical understanding of the purpose, design, and function of the laboratory equipment which they fabricate. The major instructor's concern for precision in fabrication performance is matched by the constant realization that the graduates must communicate effectively about laboratory equipment with highly qualified chemists, physicists, and engineers. Continuing education is essential so that the scientific glassblowing instructor can keep abreast of developments and laboratory research procedures.

Instructors of supportive, related subjects should not only be competent in their specific subject areas, but also experienced or effectively oriented to the educational philosophy, goals, and requirements of technical education in general and scientific glassblowing in particular. Cooperation between the major instructor and all other instructors in the program is essential. The principles taught in physics, mathematics and chemistry to be emphasized are those relating to the scientific glassblowing technologist's work.

Facilities and Equipment

The core courses are offered in the Glass Center with the exception of SGT 115 Technical Drawing and CAD, which is offered in the computer lab. Laboratories and equipment for teaching glassblowing technology must meet high standards of quality and variety, since the objectives and the strength of the program lie in providing valid laboratory experience, basic in nature, broad in variety, and intensive in practical experience. Salem Community College is equipped with 20 workstations, four lathes, tooling bench, high vacuum system, annealing oven and a variety of cutting and grinding equipment for students to perform laboratory work as required for this program. The program offers students an opportunity to work with a wide variety of glassblowing equipment. The quality of the equipment and facilities are adequate for the program. However, the quantity of lathes is a hindrance to the expansion of the program to meet the needs of industry trends. The glassblowing lathe is an increasing necessity in manufacturing as well as research glass shops. Laboratory equipment and lathes are expensive, but are essential if training objectives are to be met. Other than the lathes, the equipment is indicative of employment environments so that laboratory work offers the student opportunity for valid experience.

Support Services

The Learning Resource Center (SCC Library) coordinates an Information Literacy component exercise in the second, third and fourth semester core courses, SGT 114, 210, and 211. Through those exercises students learn that scientific and technical societies are important sources of information for both staff and students. The publications of the American Scientific Glassblowers Society are probably the best means for keeping up to date in glass technology. New students benefit from exposure, which broadens their technical vocabulary, their knowledge of equipment and supplies, and their awareness of techniques in development. The contact information and a description of the Society and its advantages are given early in the student's career. From an introduction to the American Scientific Glassblowers Society in the first semester and the information literacy exercise in the second, third and fourth semesters, new and returning students are made aware of the literature and services of the scientific and technical societies related to the field of scientific glassblowing technology. They should be encouraged particularly to

apply for student membership in the ASGS. Consequently, the students will at least be aware, upon graduation, of the most recent developments in the field.

Student Services support has shown to be effective for admissions, and obtaining financial aid. Due to the specialization of the scientific glassblowing field, the main instructor handles the traditional role of Student Services with regard to advisement and career counseling. Administrative support, overall, is adequate. The unique nature of the program enables it to work well with public relations. Since an outside company operates the bookstore, there is no relationship with the SGT program. Students' tools and materials are provided directly from a supply company. The text book for the course, E. L. Wheeler's Scientific Glassblowing, is printed and issued to the students as part of their lab fee. The Business and Community Outreach Office has a Salem County-based focus, and since scientific glassblowing has an industrial base in neighboring Cumberland County and a research base nationwide, that office has not established a relationship with the SGT program.

Summary and Conclusion

The Scientific Glass Technology program combines classroom study and hands-on laboratory techniques, technical drawing and advanced fabrication. Students develop a solid understanding of scientific glassblowing so that they are able to fabricate apparatus according to technical specifications. Upon completing the program, students should be able to demonstrate competence in the technical skills of scientific glassblowing and function as a scientific glassblower in an industrial, research or manufacturing setting. Scientific glassblowers create glass apparatus for scientific research in laboratories, universities and industry. Therefore, the Scientific Glass Technology program prepares students to be educated, skilled scientific glassblowers. It is designed as a two-year Associate of Applied Science degree. Careful planning and development with regards to the curriculum, course content, references and laboratory environment have gone into the program. The courses are carefully inter-related and designed especially for this program. Attention is given to supplies, tools, and equipment characteristic of scientific glassblowing technology. Library facilities, content, and use are stressed. Salem Community College, first as a technology institute then a community college, has educated scientific glassblowers for 45 years. This experience was the foundation upon which the present day program exists. The future of the program rests on being able to give individual attention to students. This is a vital part of effective teaching; class size is of prime importance. This is particularly true in technical education. Laboratory classes are limited to 20 students. The manipulative skills of the glassblowing technologist are developed through student's patience, repetitive practice and the instructor's careful individualized instruction and observation. An overly large laboratory group creates a situation encouraging student frustration and the development of poor techniques. Since the program's ultimate objective is to produce high-quality graduates, it is essential that accepted students have certain capabilities. The program will not produce a scientific glassblowing technologist if the classes are composed of students whose intellectual or manipulative abilities are inadequate for the program's goals.

The scientific glassblowing technology program is a post secondary, Associate of Applied Science Degree program. A high school diploma or equivalent is required as well as a college entrance exam, the Accuplacer. Ideally, the students entering the program should have completed two years of high school mathematics, including algebra and geometry, and one year of chemistry. If the Accuplacer Test determines that a student

requires one or more developmental math courses, the student must complete those developmental courses prior to starting the third semester of the program. Essential to the successful glassblowing technologist are visual and manipulative aptitudes. Scientific glassblowing requires the development of a high degree of proficiency in spatial perception, form perception, motor coordination, finger dexterity, and manual dexterity. Any applicant who is deficient in any one or combination of these aptitudes should be discouraged from entrance into the program. The student should also have the potential for developing ambidexterity. Certain types of color blindness may negate their effectiveness in working in the fabrication of laboratory glassblowing.

In a properly organized program with truly relevant and coordinated courses, the student with average scholastic potential and average dexterity can be successful. Therefore, many high school graduates who were not motivated to attempt or successfully complete college preparatory mathematics and science courses at the secondary level are quite capable of becoming effective glassblowing technologists. If they are genuinely interested and properly motivated, they will achieve well in the educational program provided that they have the opportunity to upgrade their academic background beforehand. After taking the college entrance exam and determining placement in the appropriate math and science level, developmental courses are necessary in these cases.

The program is employment oriented. Consequently, placement is a high priority responsibility. In addition to placement, the instructor keeps in touch with graduates to evaluate their training and their progress. Follow-up is one of the most important tools in the continual study of the program's relevancy and effectiveness. Graduates receive assistance from the instructor in finding suitable employment. Placement should be considered a twelve-month activity. Employer contacts are maintained continually through telephone, e-mail, correspondence and personal visits. Employer representatives and on-location supervisors, who constitute the Advisory Committee, are supplied with copies of the curriculum, course descriptions, and if desirable, course outlines. They are invited to visit the facility and observe the classes. The placement function is an extremely valuable service to the student, the employer, and the educational institution.

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Sealed Glass Ecosystems

by

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Abstract

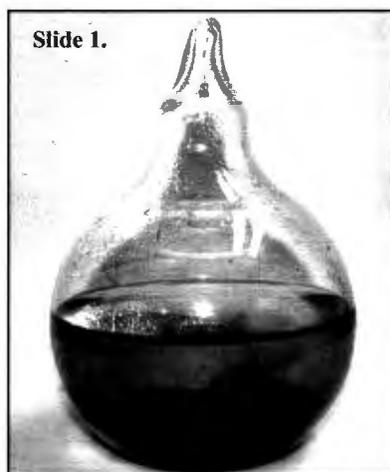
This paper chronicles the development of Sealed Glass Ecosystems that are monitored and evaluated by high school students. Sealing in simple necessities of life existence such as water, algae/compost, and air, allowed a completely isolated ecosystem to thrive according to the variable content proportions employed in each system.

Working on this project was truly an adventure for me. Perhaps this will sound like a documentary that allows me the opportunity to share the educational experience I encountered, while providing assistance to a highly motivated individual who invited my contributions. My purpose of stating this now, is because the role of the glassblowing process and the methods used are rather rudimentary, especially considering the level of talent of many of the people in this room. It also serves as a testimonial to the University of Illinois' continued involvement and support of the advancement of other Chicago area schools which have resulted in an investment in the local neighborhood community.

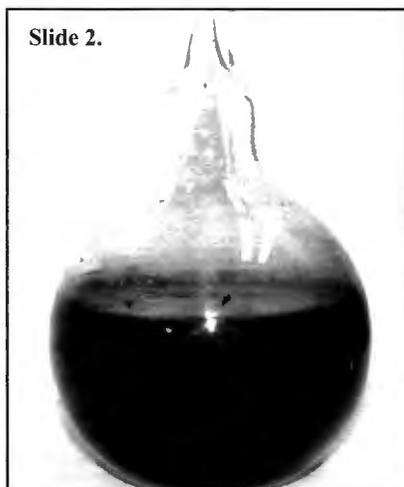
Of the many benefits of my position at the University, a favorite one of mine is the variety of requests that regularly walk through my door. I personally appreciate the education aspect. Still another advantage is the people I am privileged not only to meet but, after sometimes working with them for a period of time, to get to know. Often this human interaction is flavored with a global cultural exposure that would require many miles of travel for me to experience on my own. I find myself inspired by the interesting individuals I encounter who are committed to educating others; all possess a serious desire to improve themselves.

The story behind the sealed glass ecosystems project is an excellent example. You will hear a lot about Dan as it is he who drove this idea utilizing my help to him to develop and deliver it. As a Chemistry Ph.D. candidate, he was awarded an NSF grant through UIC, which not only provides resources but also coordinates professional staff and faculty participation for several schools including Crane High School where this project originated. Slide 1 is an early ecosphere from the program.

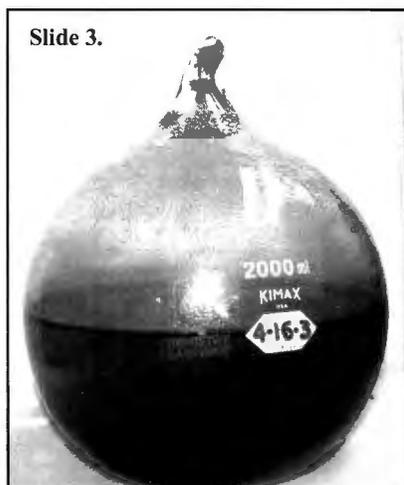
Dan Zavitz walked into my shop one day seeking answers and explained his project intentions. Overall he is committed to presenting science information to children with the best possible means of absorption. More specifically, Dan wanted to create a permanently sealed miniature ecosystem by sealing the basic necessities of life existence, such as air, water, a composting system and decomposers, all together within a glass bulb. This would



eliminate any possible tampering. Actually he not only wanted to create this system, he wanted his high school students and fellow teachers to do so as well (unfortunately deteriorating compost materials such as wood and plant portions in water eventually look very similar). (Slide 2) The characteristics of living, growing and sometimes dying ecosystems could then be studied. He also planned to do it for next to nothing, or at least for as little expense as possible. Creativity with minimum available resources too often replaces what could be adequate funding. Seen as a deterrent to others, it just seems to keep Dan searching. Actually I believe it has him conditioned so much, that he constantly concentrates on seeking less costly alternatives with every new idea.



This project required the students to design and create their own personal ecosystem. The lab experiment that Dan devised began with the initial requirements to search the internet and written articles for the best ideas on learning what makes up a successful ecosphere. Measured amounts of materials and sample organisms were first recorded and then introduced as well as the details of where they were collected from. This provided practical experience in research. The students were encouraged to seek out components from local waters such as Lake Michigan, the Garfield Park Lagoon, and even a Roosevelt Street sanitary canal (Slide 3) which essentially are all mini-environments in themselves. (The material located in the tip of this sphere was the result of a bored student inverting this system in hope of initiating some change. Systems allowed to settle are more easily viewed.) The students chose the amounts of each ingredient to be added to their ecosystem container and after closing, they were instructed to periodically monitor any changes over a period of time. At least one system produced an insect, the size of a fruit fly, which was recorded flying around one day and was dead the next. Its brief appearance sparked a great deal of interest in the class as well as among other science teachers inquiring about future plans for them to incorporate the project. Still later, another system produced both algae and small worm-like creatures such as larvae.



The semester curriculum also included other related environmental labs that discussed composition of soil and sunlight effect studies reviewing the ecosystem principles and requirements.

Among the substances offered early in the program was food coloring. (Slide 4) Unfortunately, it was learned later that color did not contribute anything but decoration,

such as pink gravel in the case of a rather uninterested female student. The food coloring proved to be a mistake as it produced a negative effect by doing little more than clouding the water making visual observations difficult. It was concluded that the color also limited light absorption which unfortunately resulted in a delay of related changes that prompted slight impatience and disappointment in those students who used it.

Earlier I mentioned “presenting information for the best possible method of absorption.” This is my interpretation of Dan’s style of instruction. He knows how extremely effective interactive laboratory sessions are. This is more than just holding students’ attention (which is a feat in itself, when they show up).

The environment of urban elementary schools today, especially in certain areas, is not complementary to the educating goals at hand and is also not easily altered. Peer pressure is ruthless and relentless in our independent youths’ world. Gone are the days when students sat quietly... (okay maybe I wasn’t always quiet either), but I would not have left my seat without asking permission or much less engaged in other rude and distracting antics that occur all too often. Today’s teachers have many challenges to overcome what seemingly has nothing to do with learning. It is an experience with unforgiving aspects as any of you truly involved parents know. Dan realizes the intriguing potential of curiosity that instantly surrounds our uncommon occupation and wanted to exploit it for his educating goals.

Since I personally often bridge language gaps by asking my international colleagues to sketch a simple drawing, pictures definitely are worth a thousand words. Considering this leads me to believe that live demonstrations must be worth several gigabytes of words! Dan capitalizes on this principle when he teaches. His style is to cater to the students in a “show me” kind of way, which usually evolves into: I’ll do it, now you do it. Computers in the classroom may bring far away places as well as any subject to a screen for convenient viewing; but practical demonstrations and interactive experiments remain the most successful, person-to-person educational techniques. (This particular ecosphere contained aquatic plant portions which survived much longer than other plant materials.) (Slide 5)

The initial projects involved 500 ml ecospheres. Flat bottom flask blanks were purchased. In an effort to be 100 % successful in the classroom, I reduced the size of the necks in advance. This proved to be a mistake as the constrictions limited the size of introducing certain solid substances. Fortunately we had the foresight to bring along lengthy glass



“packing” rods, such as those used to facilitate vertical movement in chromatography columns. This helped to coerce larger samples of compost and other materials through the overly-constricted area, although this is not recommended.



After preparation, students added the recorded components of their small ecosystem to the 500 ml flasks. Even the compost collections were photographed and filed. Citing how similar different compost looks, I spared you detailed photographs.

I agreed to seal the individuals’ systems closed during a visit to the high school. (Slide 6)

With a hand torch set up, this gave me an opportunity to demonstrate a few other glassblowing related facts and answer a few questions as well. One of the very first I distinctly remember and one for which I was not well-prepared, was that scientific glassblowers must make a lot of money! I said some certainly do...but I don’t.

My day trip to Crane High School was an eye-opener for me. Unloading the truck we discovered the elevator worked but not for us, so we decided to haul the Oxygen cylinder up three flights of stairs as well as the rest of the equipment we had brought. Even with an appropriate hand-cart, we will certainly be avoiding this in the future by using a smaller cylinder.

Unlike the neighborhood, the classroom was very clean and modern. I wanted to have a torch lit before class started. At the front of the classroom, I clamped a National Blowpipe to a long-necked faucet of a sink, because there was no lab stand to be found in what was classified as a “science laboratory room” and I had neglected to bring one along. (Slide 7) (You can see examples of the extended neck, overly-constricted flasks that I mentioned earlier.)



Little commands attention more in a classroom of arriving adolescents than an open flame. Immediately I heated the end of a glass rod in the flame and concentrated on doing little more than gathering up a ball. Over the years I have gained a true appreciation of watching other glassblowers demonstrating in front of a crowd. However, this is because I am able to scan the crowd's individual reactions. (When I have demonstrated in public, this can be difficult to do without risking getting burnt!). Naturally the students appeared in awe of my so-called artistic skill. Many were wide-eyed and some stared with gaping mouths. It is still fun after all these years and truly a uniquely rewarding experience being the instigator of such genuine curiosity.



The impressive mystique of our work can be overwhelming. Here several teachers stopped by to check out the excitement. (Slide 8) Eventually it surfaced that I also teach, glassblowing of course. This is when I revealed that none of my students ever sleep in my class...I simply explain that they have a tendency to catch on fire if they do.

Dan's quest for several angles to utilize his sealed glass ecosystem idea did not end with the small containers. We estimate that collectively about 100 total systems were created of capacities of 500 ml, 1 & 2 liters and a 22 liter sphere, as well as a few gallon bottles that were "recycled" after previous duties as wine containers. (Slides 9 & 10)



With the small $\frac{1}{2}$ liter ecospheres, I worked with Dan to rotate the hand torch flame around the circumference of the neck evenly, softening as large an area as possible. Flame annealing flasks of borosilicate glass offers a forgiving range of tolerance. This is not the case with the soft glass ex-wine jugs.

Dan was determined to seal a number of ecosystems in recycled glass to save on material costs. From home, he brought in several large soft glass jugs. After a theoretical instruction on the characteristics of working soft glass, I showed Dan how to use the EE



Lathe in my shop. I thought that using a Bunsen burner then progressing to an air/gas torch for gradual preheating would be enough to finally accept the intense heat of a gas-oxygen torch and to finally close the “recycled” glass containers. After many lost wine jugs, there was mutual concern of teachers’ capability to replicate this process.

This proved to be quite a challenge, with early initial successes undermining the difficulty of duplication. To avoid expensive equipment, Dan purchased a Mapp gas burner and a gas-oxygen torch at a local home improvement store. To limit the use of small expensive cylinders of Oxygen, Dan developed a successful method sequence at home. Progressing from a Mapp gas burner for less expensive preheating, he followed it by sealing with a limited amount of the more costly Oxygen and propane fuel mix from the cylinders. The intense heat softened the bottleneck to fuse it closed. The final gradual cooling and annealing stage was accomplished by returning to the Mapp gas and by increasing the actual distance of the torch away from the glass.

Several closing methods were experimented with and abandoned, including adding material from a softened rod to close the top instead of collapsing the neck and also fusing an extension of soft glass tubing to the bottle neck and collapsing it. If the preheat was successful, often the molten area was softened extensively and then simply twisted closed. For me, developing the process of working soft glass reinforced what has always increased my respect for prior generations of glassblowers who succeeded without the forgiving characteristics of modern borosilicate glass.

An additional challenge, overcome with practice, was to control the timing balance needed for the cooling of the softened area of glass involved. This was magnified by the long preheating required for soft glass work. By closely watching the color or heat base of the molten fused glass, it is possible to judge if the glass has become rigid enough to withstand the inside hot air’s expansion and to not blow out or contract in while the temperature was decreased. Annealing was predominately a lowering of the temperature gradually and continuing down the side and shoulder area of the containers.



The initial larger containers were sealed empty for practice, but in a lathe horizontally sealing a bottle with water and solid contents would certainly pose problems. (Slide 11) Dan thought of an excellent solution using an old record turntable to rotate the container with the contents in a vertical position.

Imagine my reaction when the (then current) next

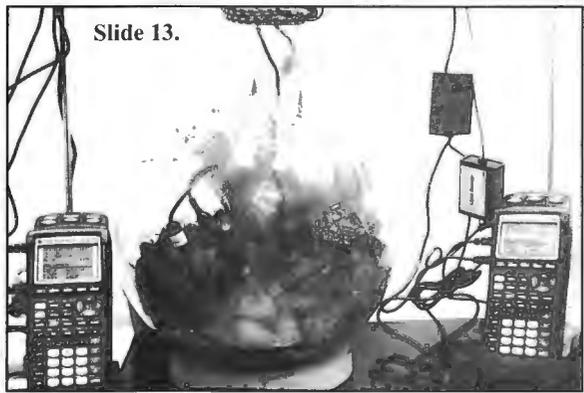
Fusion arrived in my mail. Mr. Bob Ponton had discovered much the same by using an old record player for fire-polishing and he had submitted it as a Lamp Shop Hint.

Eventually, Dan acquired a donated 22 liter flask and asked me if I could work with it.

He explained to me that he wanted to have a system into which he could introduce electrode sensors that would remain sealed throughout the experiment. With the large diameter neck of the flask, he envisioned several sensors passing through it into the flask body and its contents.

The seven different sensors measured factors that have a major influence on any ecosystem. Individual concentrations may also fluctuate over time causing a change with each increase or decrease affecting another factor. An extreme over-concentration could destroy the ecosystem. (Slide 12)

I removed the existing flange and fused a larger 75 mm O-ring joint onto the flask and then converted another matching O-ring joint into a multi-neck cap with five ground glass joints. This enabled testing as an open or closed system. Living systems could also be changed for different experiments. I fabricated matching adapters for the probes including two that were Y-shaped. The exiting sensors were connected to two monitors called TI 83 plus, LabPro Vernier Data Collection Systems. Although I did not bring an actual unit, you can see they are essentially hand-held computers. (Slide 13)



The introduction of this device expanded the value of the experiment by allowing the monitoring of specific quantitative data rather than just visual observations. Furthermore, it transformed the experiment into a classroom-sharing ecosystem, that would command more interaction of students who would be individually responsible for recording, comparing and drawing conclusions of some 21 different variable pairings such as light versus temperature. This confirmed that variables have multiple relationships through experiments of periods that lasted from two days to a week.



The effect of sunlight was

already realized to be very important. The large system revealed that respiration is going on and without photosynthesis it is an incomplete system. This is evident by the moisture forming on the inside of the flask. (Slide 14)

Each of the sensors would measure a different aspect of the environment such as temperature, pressure, levels of PH, Carbon Dioxide, Oxygen, humidity and light. Much of the data produced generalized conclusions. Temperature increased proportionately with an increase in light exposure. The students also learned that insects breathe in Oxygen and exhale out Carbon Dioxide; also that if the ratios are correct, the two organisms can support each other in a closed system, at least for a little while. Knowing that it is a delicate balance makes one think about water and air pollution in the ecosystem in which we live.

Besides the students developing the use of these information-storing devices, for further group experience, the study was structured for the students to be involved with training the



Slide 15.

next group of students. Although I considered his ingenious idea original, Dan revealed that it models an important aspect of modern science where teams of scientists often use the same equipment, such as the national lab system, Biosphere II, and NASA.

As with the majority of the real work involved with this project, my glassblowing involvement was a minor portion of the final production. In reality, the glassblowing skills required were of a minimum amount of experience and practice, yet a very appropriate initial element and a continuing catalyst. (Slide 15)



Slide 16.

Dan continues to discuss other ideas in expanding his basic idea of engineering environmental ecosystems for study programs. UIC has since donated the entire "Classroom Ecosystem" to Crane High School. This gift will continue to be a powerful learning resource for students many years after Dan Zavitz has graduated and moves on to what will be more of a dedicated career of enlightening young minds.

With the discovery of a flying insect and what appeared to be larvae, the students began questioning the possibility of introducing other forms of life into their ecospheres, rather than only plant life. This led to importing live fish to see what would result. It was concluded that



inevitably the fish would die and become another form of decomposing material. (Slide 16 – note fish) I must admit it was surprising to learn that some of the fish survived for up to two months in such a small volume container.

With our own ever-changing workplace environments, there is a message of accepting new responsibilities to strengthen our position and value as a university employee. Commercial and industrial glass workers who are not involved with their community's educational institutions may be missing out on a unique opportunity to reach out. Any children's group would welcome an offer from us whose occupation naturally mixes science with an irresistible intrigue and an artistic flare overshadowed with a hint of danger.

On a lighter note, I suggest you consider engineering an ecosphere for yourself, especially if you are fortunate enough to have windows in your shop. How about sharing this project by making one for your child? (Slide 17) Know someone who has everything and you never know what gift to give them? On an even lighter note, lately I have been thinking my cat would enjoy one!

I must thank Dan for sharing his work, Ms. Shakura Haqqe, the science teacher at Crane High School. I truly hope this was as interesting for all of you as it was for me.

Thank you for your time and attention.

Submicron Etchable Glass Materials

by

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Abstract

Using flint and etchable glass combinations, complex architectures can be made with portals or fine channels that would be difficult, if not impossible, to fabricate by other means. This paper describes a method to fabricate glass structures with submicron holes or channels. The fabrication process begins by placing an etchable glass rod inside an inert glass tube and stretching the composite to form a filament. The filaments are then stacked, fused and stretched again. This process is repeated several times until the desired dimensions are reached. The channels are exposed by wet chemical etching resulting in features with dimensions as small as 15 nm.

In the fabrication of complex glass structures, it is useful to have as many tools as possible in a given repertoire. This paper describes how the addition of an etchable glass to an inert glass structure can be used to create a composite with very fine features. When exposed to an acid to chemically remove the etchable glass, fine channels or portals can be created within the glass structure that would be difficult, if not impossible, to create by other means.

The composite glass structures described here can be made with glass materials from the flint family of glasses combined with etchable glasses found in Table 1. Glass combinations must be chosen to minimize residual stress and/or keep the composite structure under compression. Critical properties include the thermal coefficient of expansion (TCE) and softening points of both glasses. Glass features (feature glass) that are to be retained after thermal processing should have a slightly higher softening point (20° C – 90° C) than the

"INERT"							
Glass Code	TCE(10 ⁻⁷) 20-300C	T _g (C)	T _{SP} (C)	T _w (C)	Density gm/cm ³	Etch Rate μm/5min	n
0010	91	395	626	970	2.85		1.539
0080	92	470	696	1000	2.47		1.512
0120	89	395	630	975	3.05		1.560
8161	90	400	600		3.97	0.003	1.659
"ETCHABLE"							
S-8016	100	587	679	779	4.23	6.0	1.694
EG-1	91	503	617		2.4	11.1	
EG-2	96	560	663		4.2	6.7	1.66
EG-3	88	522	638		2.4	6.2	
EG-4	96	605	699		4.2	5.4	
EG-5	92	564	669		4.1	6.9	
EG-6	85	572	676		4.0	4.2	
EG-9	89	445	567		3.0	8.6	

Table 1. Properties of etchable and inert glasses.

Nano Channel Glass Fabrication

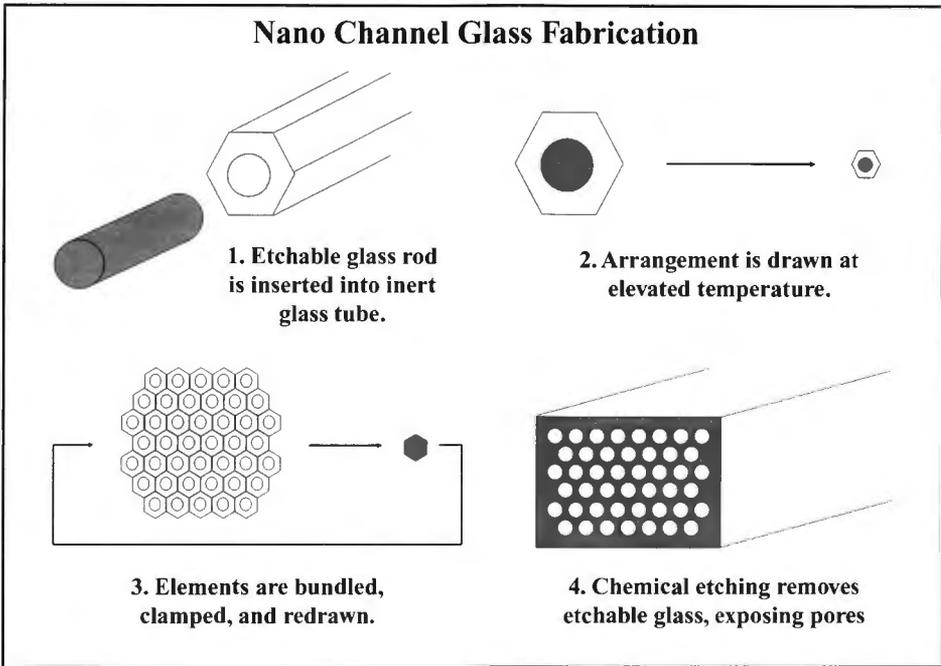


Figure 1. *Nanochannel glass fabrication process.*

matrix glass. This enables the matrix glass to evenly flow around the feature glass without deforming it. For creating high definition holes or channels in the glass composite, the differential etch rates between the two glass compositions should be as large as possible.

Glass with arrays of holes or channels as small as 15 nanometers can be made.¹ The process starts by inserting an etchable glass rod into an inert glass tube (see Figure 1). The composite is drawn down (stretched) in a furnace to a fine filament, similar to the way an optic fiber is made. The fibers are then bundled into a hexagonal shape and drawn again. The process is repeated until the desired feature size is attained. The glass is then wafered, polished and etched to expose the channels (see Figure 2). For this example we chose the glass combination of a EG-2 rod, 1 inch diameter, and Corning 8161 tubing, o.d. 1.4 inches and i.d. 1.1 inches. The feature glass (EG-2) has a higher softening point and higher TCE than the 8161 cladding glass allowing it to retain its shape while the 8161 glass flows around it at elevated temperature. The higher TCE of the EG-2 ensures the glass composite will be under compression at room temperature, for strength, after thermal processing. The core and clad were drawn at a temperature between 670 to 680 degrees C resulting in a fiber approximately 800 microns in diameter. The fibers were then bundled in a hexagonal pattern, fused and redrawn twice. The final bundle was placed in a 0120 glass tube and fused under vacuum for four hours. The glass was then wafered and chemically etched to expose the channels. The differential etch rate of the two glass compositions is approximately 2000 to 1. As can be seen in upper left and middle scanning electron micrographs

¹ R. J. Tonucci, B. L. Justus, A. J. Campillo and C. E. Ford, "Nanochannel Array Glass," *Science* 258 (1992): 783.

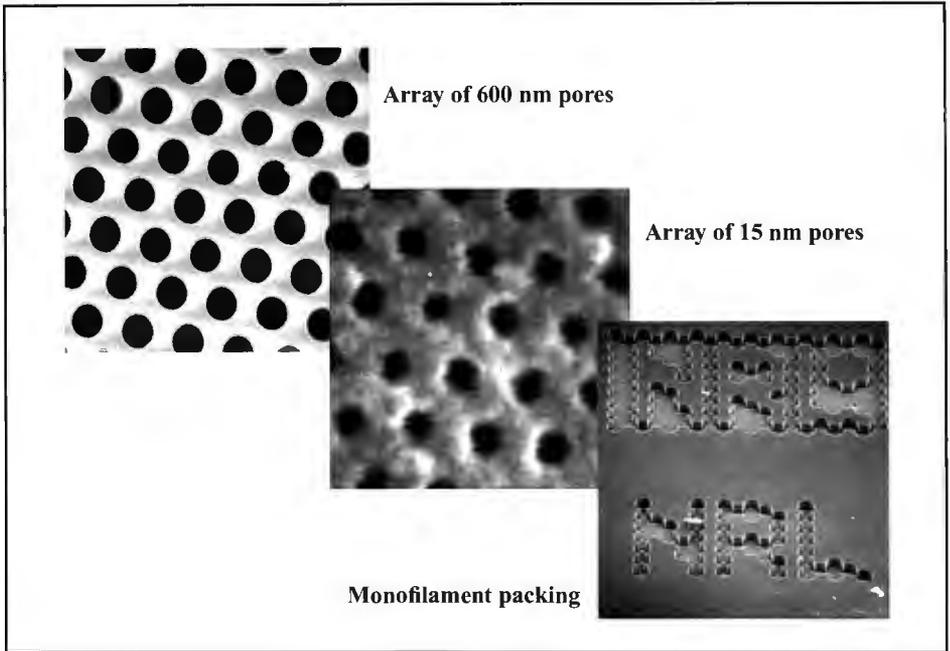


Figure 2. *Examples of channel glass after chemical etching.*

of Figure 2, the submicron feature size of the channels are very circular. The ability of the feature glass to retain its geometric shape and high definition after repeated thermal processing steps is a real advantage to this type of fabrication process.

Other types of glass with varying index of refraction, color or internal texture can be used in this process creating interesting artistic features. When the size of the features of the glass composite approach the wavelength of visible light (0.45 to 0.85 microns), diffraction effects can disperse the components of white light into its constituent colors.²⁻⁴ These effects can be dramatic, exhibiting vivid bright colors that change simply by rotating the glass in different directions.

Another way to incorporate etchable and inert glasses to make complex structures is to take advantage of a monofilament packing technique. As shown in Figure 3, fibers of etchable and inert glass are placed next to each other or in groups to form a bundle. The bundle can be fused and etched or stretched and rebundled as described above to form smaller features. The profile of the bundle is exposed after removal of the EG-2 glass by chemical etching (see Figure 2, lower right SEM micrograph). Very complex structures

² H. -B. Lin, R. J. Tonucci and A. J. Campillo, "Observation of Two Dimensional Photonic Band Behavior in the Visible," *Appl. Phys. Lett.* 68 (1996): 2927.

³ A. Rosenberg, R. J. Tonucci, H. -B. Lin and E. L. Shirley, "Photonic Band-Structure Effects for Low Index Contrast Two Dimensional Lattices in the Near-Infrared," *Phys. Rev. B* 54 (1996): 5195.

⁴ A. Rosenberg, R. J. Tonucci and E. A. Bolden, "Photonic Band Structure Effects in the Visible and Near Ultraviolet Observed in Solid State Dielectric Arrays," *Applied Physics Lett.* 69 (1996): 2638 .

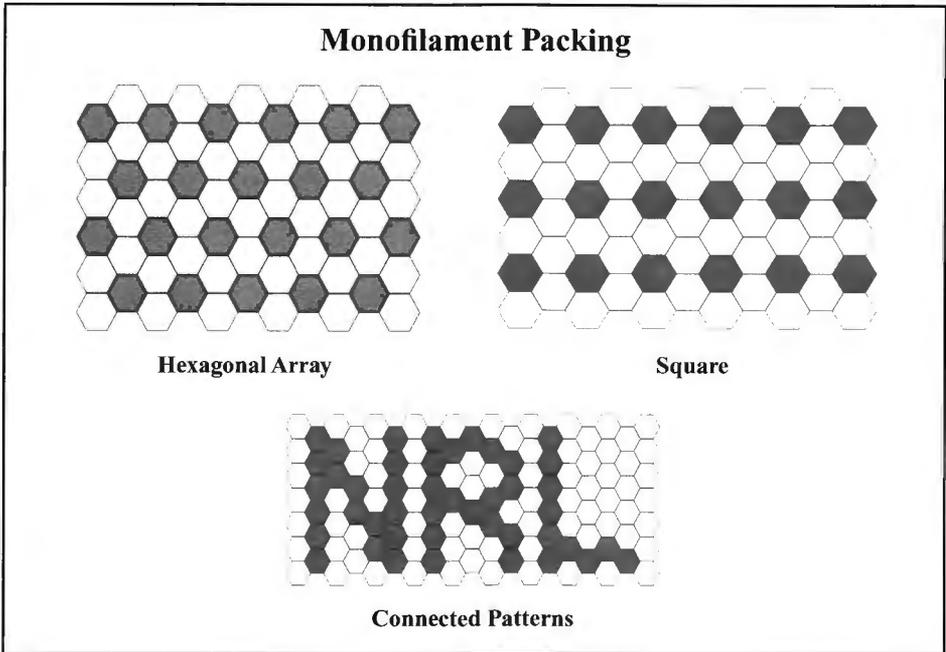


Figure 3. *Examples of how patterns and more complex structures can be made by packing monofilament fibers of etchable and inert glass. Dark areas imply position of etchable glass fibers.*

can be made with openings and closures anywhere within the structure as long as a path remains to etch out the desired material. The complex glass architecture can then be sealed at critical points leaving behind enclosed voids or conduits.

While this paper describes a process to create holes or channels in glass with submicron features, it is not necessary to create structures with such small dimensions. As shown in the lower right SEM micrograph of Figure 2, complex structures of almost any dimension and shape can be made. An ability to work with etchable glasses can add a new dimension or capability to the bag of tools utilized by professionals in the ASGS.

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Mark Andrews	Shaun Conroy	Karina Guevin
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Ron Banes	Mary Courtney	Anya Gushchin
Scott Bankroff	David Daenzer	Manna Gushchin
Paul Benn	Katrina Daenzer	Nancy Hagmaier
Karen Bessette	Girish Dahake	William Happer
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Bryan Bivins	William DeFlorio	Ricky Harrison
Kim Bivins	William James DeFlorio	Doni Hatz
Günther Boepple	Ralph Del Buono	Howard Hayman
Walter Boger	Michael Dennin	Mary Hedges
Michael Bracken	Margaret Dennin	Frank Hedges IV
Teresa Bracken	Tara DiCinque	Frank Hedges, III
Eric Brambani	Darcey Doering	Volker O. Herbert
George Bray	Elaine Doering	Hiroko Herbert
Jayne Bray	Art Dolenga	Newton Hill
Mike Bray	Carol Dolenga	James Hodgson
Dennis Briening	Mary Dolenga	C. Dave Hopkins
Allan Brown	André Dollé	Gwen Hopkins
Marylin Brown	Frank Dougherty, IV	Jim Horvath
Lu Brown	Tracy Drier	Jerry Howard
Tyrone Brown	Daniel Edwards	Thomas Howe
Daniel Brucker	Peter Elias	Tollie Howe
Deborah Camp	Robert Evans	Kieran Howes
Bob Campbell	Bob Evans	Kendal Hunt
Carl Carelli	Bambi Everett	Beth Hylen
Mike Carlson	Gary Farlow	Nancy-Ruth Jackson
Karen Carraro	Dave Fenili	Oscar Jackson
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Vera Carter	Victor Gallicchio, Jr.	Diane Jones
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Ken Christiansen	François Gaullier	Craig Kloss
Charles Christman	Rick Gerhart	Edward Koehnemann
Larry Circosta	Cédric Ginart	Angie Koehnemann
Bonnie Clark	Mr. Glaser	Georges Kopp
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James Coash	Ruth Gowell	Jan Kraft
Martha Coash	Bob Greer	Keith Krumnow

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Sonja Kummer
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Andy LaGrotte
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