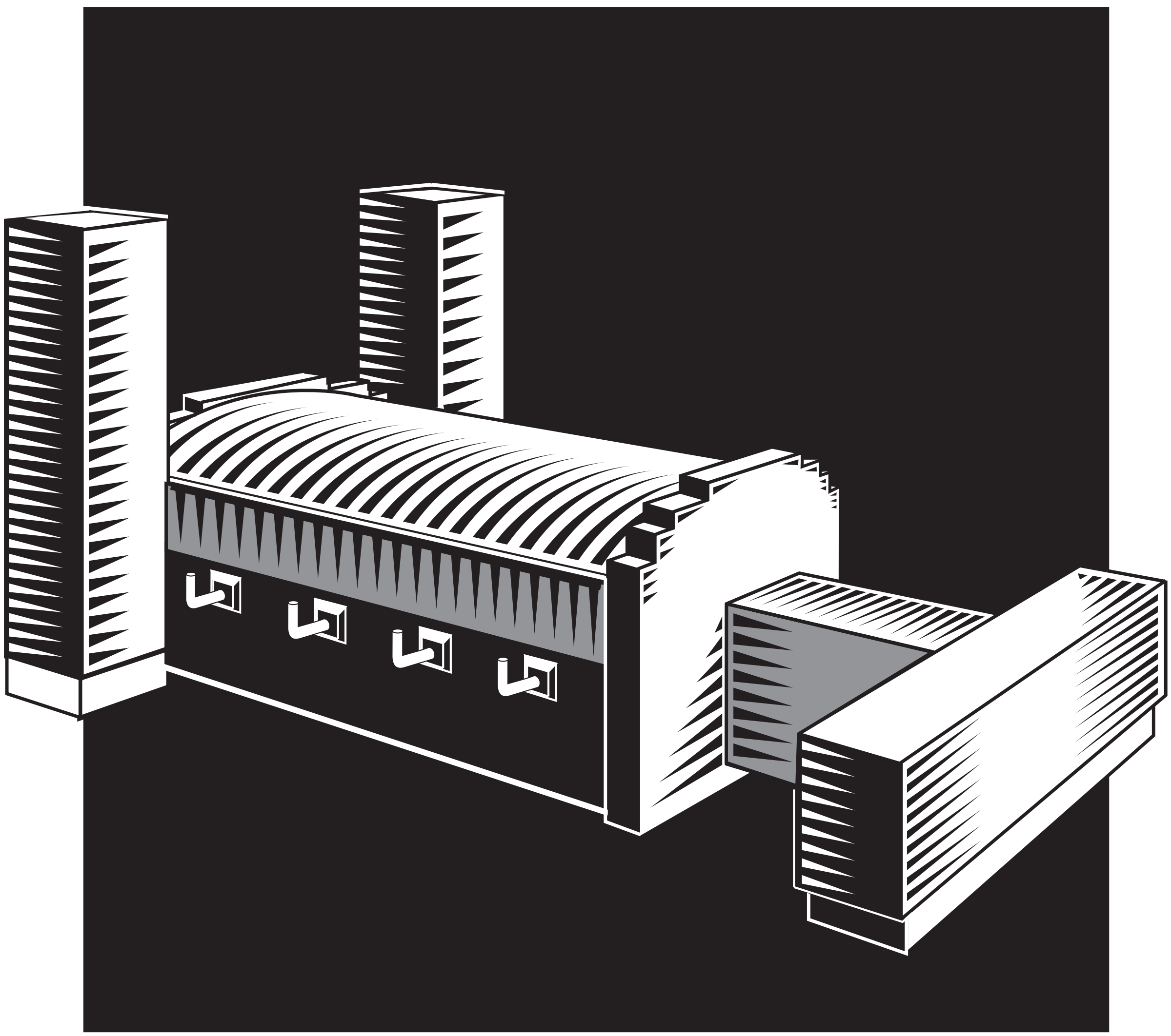
Glass
Industry of the Future

Quarterly Status Reports

As of March 31, 2010



U.S. DEPARTMENT OF ENERGY

02-GA50113-03

Glass

Industry of the Future

Quarterly Status Reports

As of March 31, 2010

Contacts

HQ Program Managers

Glenn Strahs	202-586-2305	glenn.strahs@ee.doe.gov

Field Office Project Managers

Brad Ring	303-275-4930	brad.ring@go.doe.gov

Other

Chad Sapp	303-275-4877	chad.sapp@go.doe.gov
Elmer Fleischman	208-526-9023	Elmer.Fleischman@inl.gov

Glass Projects

Rapid Conditioning for the Next Generation Melting System

Gas Technology Institute

GO16010

QUARTERLY PROGRESS REPORT

Project Title	Rapid Conditioning for the Next Generation Melting System
Covering Period	January 1, 2010 through March 31, 2010
Date of Report	April 13, 2010
Recipient	Gas Technology Institute 1700 S. Mt. Prospect Rd. Des Plaines, IL 60018
Award Number	DE-FC36-06GO16010
Other Partners	NYSERDA – project sponsor GTI Sustaining Membership Program (SMP) – project sponsor Johns Manville Owens Corning

Contacts

David M. Rue
R&D Manager, Process Heating
Gas Technology Institute
847-768-0508
david.rue@gastechnology.org

Project Team

Glenn Strahs
Glass Team Leader
U.S. Dept. of Energy
OIT, EE-20
1000 Independence Ave., SW
Washington, DC 20585-0121
202-586-2305
glenn.strahs@ee.doe.gov

Margo Gorin
Project Monitor
U.S. Dept. of Energy
Golden Field Office
1617 Cole Blvd.
Golden, CO 80401
303-275-4737
margo.gorin@go.doe.gov

Tim Ramsey
Reports Monitor
Golden Field Office
1617 Cole Blvd.
Golden, CO 80401
303-275-4933
tim.ramsey@go.doe.gov

Project Objective

The objectives of this project are to 1) test and evaluate the most promising approaches to rapidly condition the homogeneous glass produced from the submerged combustion melter, and 2) to design a pilot-scale NGMS system for fiberglass recycle. Techniques to produce higher quality glass from the melter will be investigated, and external fast conditioning approaches will be analyzed. The add-on rapid conditioning techniques evaluated through modeling and limited testing will rely on sonic energy, steam, and time discharge to speed conditioning

Statement of Objectives

The objectives of Budget Period One are to:

- Evaluate furnace operating parameters on glass quality. These parameters include burner firing patterns, melt temperature, glass residence time, etc.
- Conduct initial tests to evaluate the improvements achieved in glass quality using sonic refining
- Analyze product glass quality using advanced techniques for both on-line and off-line measurement of seed count and size
- Model other promising rapid conditioning techniques adaptable to the SCM
- Develop the engineering requirements for a Next Generation Melting System designed to recycle scrap fiberglass.

All work will be carried out using a single E glass composition. This approach will provide the largest impact of changing melter parameters and rapid conditioning conditions to be compared and analyzed.

Project Schedule

The project timeline is shown below. The first task will include the design and construction of the short heated discharge section and preparation of the sonic refining test setup and sampling methods. Task 1 will be nine months in duration. Task 2 will include all testing and analysis of samples and will also include modeling of other rapid refining approaches. It is anticipated that there will be up to 6 total melter tests performed over the 12 months of Budget Period One. Each melt will be 12 to 72 hours long and will include multiple experimental tests. These tests will incorporate evaluation of the impacts of changes in melter operation (pull rate, burner firing rate, burner patterns, etc.) along with evaluation of the sonic rapid conditioning method. The third task will be used to prepare for an engineering design and CFD model for a demonstration-scale NGMS process to melt scrap fiberglass. Task 3 will last 3 months. Quarterly reports and a Final Technical report will be prepared for all sponsors.

Task	Title	Budget Period One, months											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Preparation for SCM Glass Quality Tests												
2	Rapid Conditioning Tests and Analyses												
3	Engineering Design of NGMS for Scrap Fiberglass Recycle												

Performance Measures

Performance measures and go/no-go decision metrics are placed at the end of Year 1 of the project. Performance measures include the following:

Performance Measures
• Design, fabrication, and shake-down pilot SCM modifications including short refractory discharge zone and sonic refining equipment • Completion of SCM tests with variations in operating conditions and with sonic refining following by glass quality analyses • Initial modeling of other rapid refining techniques for the Next Generation Melting System • Preparation of engineering design parameters for a Next Generation Melting System for

The performance measures for Budget Period One will lead directly into the go/no-go decision points for continued project work in Budget Period Two. The go/no-go decision points will refer to all activities as well as to which quality improvement approaches will be evaluated further or discontinued from evaluation. Go/no-go decisions are:

Go/No-Go Decision Points - at the end of Year 1
• Completed modifications to SCM pilot unit for testing with multiple approaches to glass refining and to glass quality measurement • Conducted tests with sonic refining and shown significant glass quality

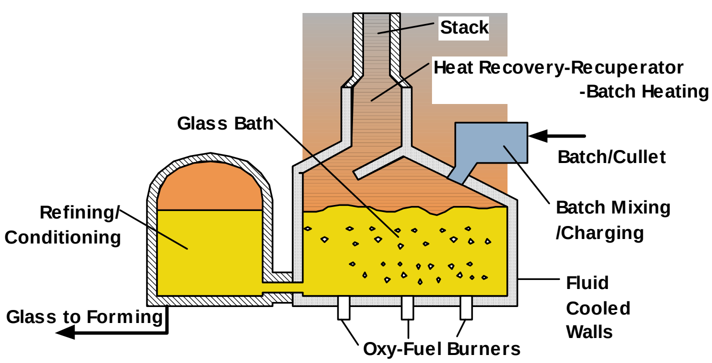
Background

Glass formation places heavy demands on the glass melting process. Quality requirements vary radically between industry segments, but all forming processes need a steady flow of molten, homogeneous glass of the chosen color (if not clear), with few to no unmelted sand grains (stones). This molten glass must be at a specific viscosity, with means temperature must usually be controlled to within several degrees. Along with all these requirements, each industry segment specifies molten glass must have the number and size of bubbles (seeds) for their product. In general terms, seeds must be below 0.1 mm in diameter, although optical glass demands are even stricter.

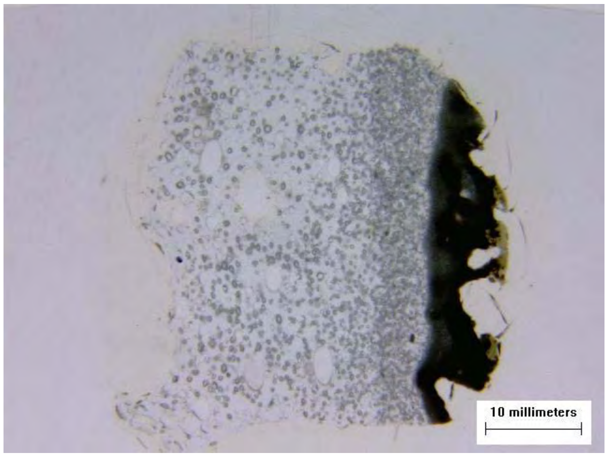
The U.S. Department of Energy is supporting collaborative efforts to develop a Next Generation Melting System (NGMS) that will produce glass of needed quality to the forming step of each glass industry segment. The submerged combustion melting technology, licensed and controlled by the Gas Technology Institute (GTI), is currently being developed by a GTI-glass industry consortium to serve as the melting and homogenization step of the NGMS process. NGMS envisions a segmented melting approach to achieve high energy efficiency, low emissions, and low capital cost. These goals are met by optimizing components of the melting process. SCM is particularly attractive because homogeneous, stone-free glass is produced while feed handling is less costly and simpler than for conventional furnaces, energy use is decreased, and emissions are lower, all with a far less expensive melter.

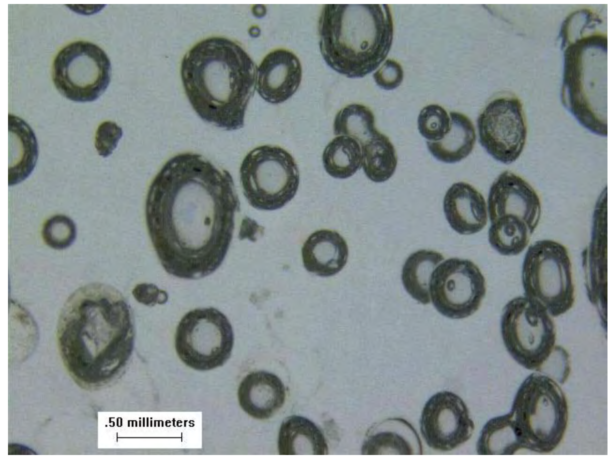
In SCM (shown below), fuel and oxidant are fired directly into the molten bath from burners attached to the bottom of the melt chamber. High-temperature bubbling combustion inside the melt creates complex gas-liquid interaction and a large heat transfer surface. This significantly intensifies heat exchange between combustion products and processed material while lowering the average combustion temperature. Intense mixing increases the speed of melting, promotes reactant contact and chemical reaction rates, and improves the homogeneity of the glass melt product. The melter can handle a relatively non-homogeneous batch material. The size, physical structure, and especially homogeneity of the batch do not require strict control. Batch components can be charged premixed or separately, continuously or in portions.

The many features and requirements for SCM have been discussed elsewhere and will not be covered in detail here. The technology requires careful and appropriate design of combustion systems, and GTI has filed for a patent in this area. Oxy-gas firing is imperative so that heat input can be maximized while nitrogen bubbles are eliminated and total gas volume is minimized. Refractory walls will be worn away by moving glass, so walls must be built from externally cooled walls on which a frozen glass layer forms to protect the wall. GTI and a glass company consortium (Corning, Johns Manville, Owens Corning, PPG, and Schott) have been developing SCM for use as the NGMS melting and homogenization step. Soda-lime and E glass compositions have been melted to date in a lab-scale SCM unit (shown below), and work is underway to design a pilot-scale 1 ton/h melter.



Operation of SCM with a range of industrial glass compositions from soda-lime glass to LCD glass is verifying the melter's capacity to generate homogeneous, stone-free glass. Photomicrographs of soda-lime glass produced in the pilot SCM unit are shown below.





Results to date with SCM are highly encouraging. The product glass, however, must be of higher quality to meet many industrial needs. There are multiple means to improve the glass quality, and the proposed project will focus entirely on improving the quality of SCM product glass. Many of the techniques evaluated, particularly the external conditioning methods, are also applicable to conventional glass melters, as indicated above.

SCM Operations Improvements to Improve Glass Quality

SCM glass quality can be improved through a number of melter improvements, some in components and some in operating techniques. Component improvements include

- feeding systems systems that control batch introduction and minimize particle and volatile discharge
- modified burners and combustion systems to give desired combustion and heat transfer patterns to generate large easily refined bubbles
- Optimum discharge taps located to discharge high quality glass and to control melt flow rate

Improved operating procedures include burner locations and firing patterns, temperature control, residence time contro, and control of melter mixing patterns. All of these techniques have potential to increase the size of bubbles, decrease bubble concentration, and eliminate small bubbles (below 0.5 mm). All of the techniques mentioned will be tested and evaluate in this project.

External Conditioning Approaches

Along with improved SCM operation, external, rapid conditioning methods can improve glass quality. These techniques will be modeled in this project, and the most promising will be tested in a bench-top lab apparatus, and potentially on the pilot SCM unit. Glass refining is made difficult by the small size of bubbles (0.1-2.5 mm) that must be removed, the high viscosity of molten glass (often 100-150 poise), and limitations on materials chemically and physically compatible with molten glass.[2] The upward velocity of small bubbles in a liquid is characterized by Stokes Law.

$$V \;\alpha\; d^2 g \rho / \mu$$

which states a bubble's upward velocity (V) is proportional to the square of the bubble diameter (d), the gravitational constant (g), and to glass density (ρ) and is inversely proportional to the viscosity of the glass (μ). All refining approaches modify one or more variable to increase V. Refining time is controlled by the time it takes the smallest bubbles to reach the glass surface. Gas diffusion rates through glass vary, with nitrogen and carbon dioxide being the most difficult to remove. Current practice relies on time and chemical fining agents. Fining agents release gases such as oxygen that combine with bubbles of other gases. This produces larger, faster diffusing bubbles that shorten the refining time but also can contribute to air pollution. Fining agents are expensive and can alter glass chemistry, so their application is limited. Time can be turned into a refining ally by using a thin film or 'fining shelf' that shortens bubble distance to rise. Fining shelves are employed in some furnace designs, but care must be taken to maintain temperature uniformity and to minimize heat loss from the large surface of molten glass.

The NGMS process requires rapid conditioning to produce high quality glass from the high-intensity SCM unit. The most promising approaches will be modeled and analyzed in this project. The project team includes experts in water refining (Tomazawa), sonic refining (Spinosa), and other approaches such as vacuum (Wooley). Each rapid refining approach takes advantage of one or more variables in Stokes Law to accelerate the conditioning process. A list of the rapid conditioning approaches to be modeled and analyzed in this project is shown in the table below.

Rapid Conditioning	**Basis for Accelerated Conditioning**
Helium (inert gas)[3]	High solubility and high diffusion leads to scavenging of small bubbles into larger bubbles and fast bubble rise to surface (d_b is larger)
Water (steam)[4]	High solubility and high diffusion leads to scavenging of small bubbles into larger bubbles and fast bubble rise to surface (d_b is larger)
Sonic[5]	Vibrations lead to bubble consolidation and faster rise to the surface
Vacuum[6]	Decrease pressure leads to bubble expansion and fast rise to the surface
Centrifugal[7]	Gravitational constant changed from g to $r\omega^2$ which can greatly increase velocity

Status – Work This Quarter

Experiments have shown that refining of glass from a high-intensity melter such as the SCM can productively be carried out in two stages. They can be referred to as the coarse refining stage and the fine refining stage. To study the coarse refining stage, the project team constructed a forehearth channel to allow continuous refining of SCM product glass for periods up to several hours at various temperatures.

Construction of the forehearth channel was completed and results from the first continuous tests with E glass have been presented in earlier quarterly reports. Several important conclusions have been drawn from the test results

- The SCM product glass is readily refined, with refining accelerated by the uniform distribution of small, medium, and large bubbles in the glass

- The short channel can effectively refine SCM product glass to the quality levels specified for insulation fiberglass and some continuous fiberglass. Higher quality targets for other glass products are expected to require a different refining approach
- The next tests with the short channel for refining will focus on collecting better data inside the glass being refined (temperatures and flow patterns), widen the residence time range studied, and improve sampling to prevent product deterioration from the sampling process

Work this quarter was carried out in the following areas:

1. Determination of means to improve understanding of the short channel refining process
2. Development of concepts for improved refining approaches
3. Early-stage testing of a next generation SCM oxy-gas burner
4. Completion of a pilot-scale SCM test with preheated air instead of oxygen. This test was conducted to gain a better understanding of SCM energy balances

Additional Refining Channel Tests. The project team plans to continue refining tests using the short residence time channel. These tests will start next quarter when warmer weather will allow testing to be conducted safely. The short residence time channel tests have shown that SCM glass can be refined from 30% voids to 0.3% voids. The next tests (with the same E glass) will focus on improved control of the process, understanding the refining process better, and improved refined glass sampling. Improved control will involve better insulation and flow control from the SCM to the refining channel and better means of sampling the refined product glass from the end of the refining channel. Better refining process understanding will be achieved through visual observations and by placing a series of thermocouples in the glass being refined so temperature profiles, stratification, etc. can be studied. Also, sampling will be improved. Instead of sampling from a falling stream of glass leaving the refining channel, samples will be collected directly from the quiescent glass at the end of the refining channel.

These changes are already underway for implementation in tests in the next quarter. The project team will include engineers from GTI, Owens Corning, and Johns Manville. The glass will again be an E glass batch supplied from the same Johns Manville plant.

Other Refining Approaches. The project team continues to evaluate potential rapid refining approaches that are compatible with high intensity melters such as SCM and that are industrially robust. Many rapid refining approaches have been proposed over the years, and the general outlines of the classes of refining methods were presented in a paper given at the 2009 Glass Problems Conference.

By the end of this quarter, the project team had identified three promising refining approaches for 'fine' refining. These approaches are in attention to the ongoing work on 'coarse' refining being evaluated with the short refining channel. The three promising 'fine' refining approaches include:

- An enhancement of the short refining channel to improve the level of refining that can be achieved. This method can be readily evaluated by the project team. Efforts early in the next quarter will include CFD modeling, surrogate liquids testing at ambient conditions, and finally, molten glass testing with the pilot SCM

- A completely innovative process under modeling evaluation. This approach holds promise for being very fast and very compact. Once modeling work is complete in the next several months, the project team will determine the best means to conduct physical testing
- The high surface area refining approach submitted as a patent application by the project team and already evaluated in cold flow tests. This approach has been assigned as the third approach to be further pursued because the other two approaches are more promising for scale-up and operation at an industrial scale.

The project team is planning to conduct tests of at least one other, and hopefully all three, 'fine' refining approaches in the third and fourth quarters of 2010.

Next Generation SCM Oxy-Gas Burner Testing

A series of test stand tests were conducted with the existing SCM oxy-gas burner and an advanced new oxy-gas burner. The new burner is designed to release heat lower in the melt bath and to have a stiffer flame that will not touch the burner body. The shorter flame is expected to improve overall SCM efficiency. The stiffer flame and new guidelines on water cooling are designed to increase burner body life. Figures 1 and 2 below show the two burners firing at the same natural gas rate and same oxygen to fuel ratio.

Figure 1. Standard SCM Oxy-Gas Burner
0.5 MMBtu/h, 10% excess O2

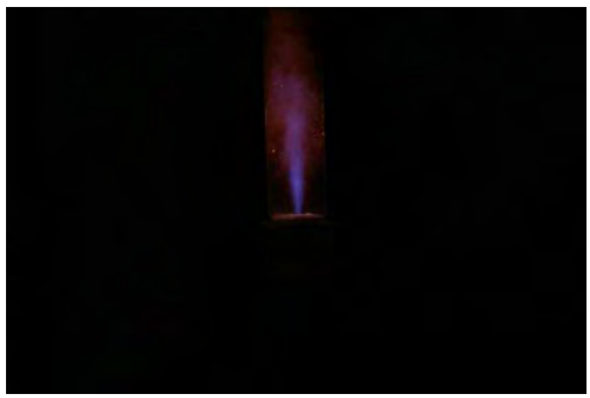


Figure 2. Advance SCM Oxy-Gas Burner
0.5 MMBtu/h, 10% excess O2

Test results were encouraging. The new burner has a flame that is approximately one third shorter. The flame is also not as bushy and is clearly more focused and 'stiffer'. Also, the new protocol developed for water cooling flow rate has proven successful in operations by GTI and IMM (both are using the same burner built from the same drawings). Work will continue on improve burner designs through both testing and modeling.

Pilot-Scale SCM Test With Preheated Air

A pilot-scale SCM test was conducted with preheated air. The objective was to better understand energy balances around SCM. A low temperature glass batch was used so the melt bath temperature could be kept below 2200°F. New air-fired burners were fabricated that matched the two burners already available. The melter floor was replaced with a new floor panel, and four air-gas burners were installed. New castable refractory was poured on the floor and cured. Four of the natural gas flow meters were used. New air flow meters and flow control valves were installed to meter and control air flow. Natural gas and air flow were set on ratio and controlled by the SCM flow control system. An air compressor was rented and used to supply air. The air was metered through the control valves and then sent through electric heaters to simulate preheating. The air was preheated to as high as 750°F before being sent to the burners.

The test went well operationally. Despite the greatly increased gas volume and velocity, batch entrainment was not severe. The high exhaust gas volume prevented the operation of the melter at high pull rates. Pull rate was limited to approximately 350 pounds per hour. Product glass was found to have void fractions similar to those of SCM oxy-gas melted glass. However, the large volume of gas may have contributed to a lower density melt bath. This resulted in a lower mass of glass in the bath and a shorter than expected residence time.

This test was conducted late in the quarter, so full analyses are not yet available. The Figures below show how the SCM input energy is distributed between exhaust gas, walls, and gas as a function of glass pull rate.

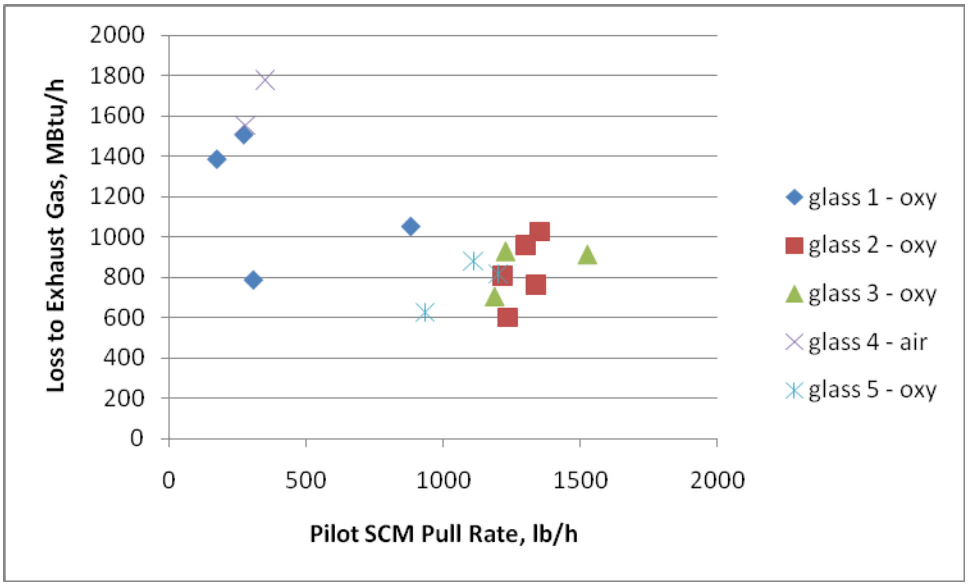


Figure 3. Energy to Exhaust Gas for a Wide Range of Glasses and a Wide Range of Pull Rates in the Pilot-Scale SCM

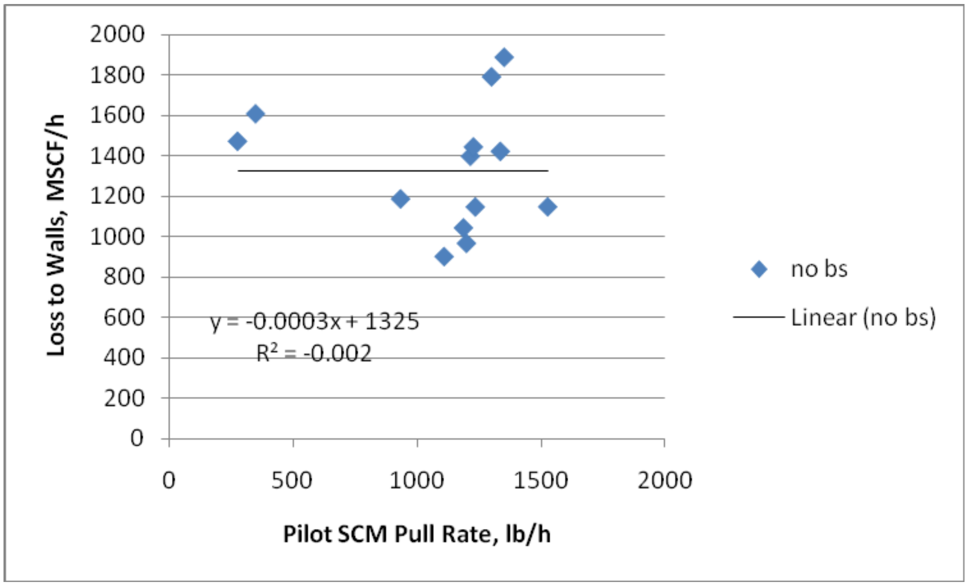


Figure 4. Energy to the Walls for a Wide Range of Glasses and a Wide Range of Pull Rates in the Pilot-Scale SCM

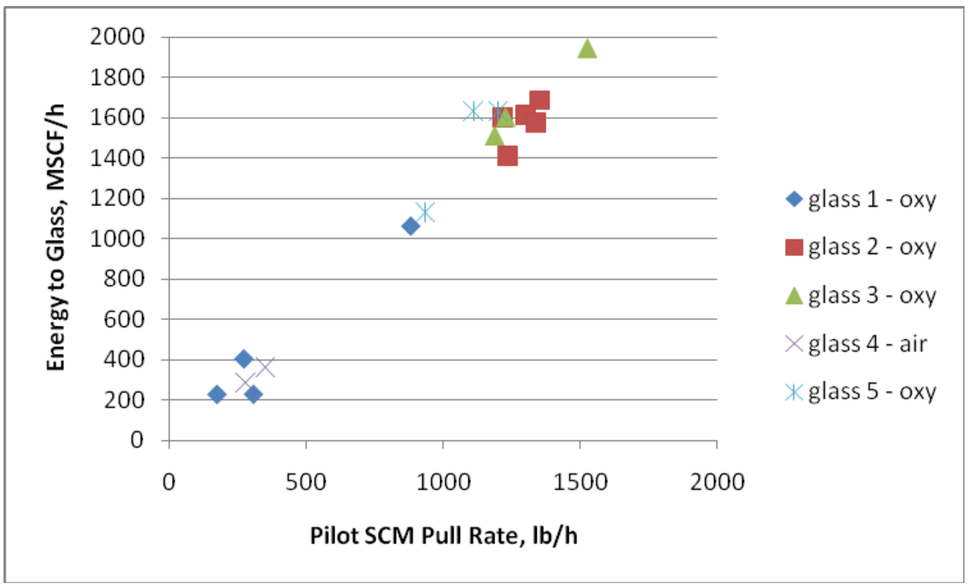


Figure 5. Energy to the Product Glass for a Wide Range of Glasses and a Wide Range of Pull Rates in the Pilot-Scale SCM

Combining data from a wide range of pilot-scale SCM tests covering melt temperatures up to 2900F shows strong correlations on energy distributions. The energy to the walls is relative constant in Btus per hour excluding the high temperature borosilicate glass test. The energy to the exhaust gas declines slightly with increasing pull rate. This happens because higher charging rates provide colder batch and melting glass to absorb heat. Therefore energy to the exhaust gas and exhaust gas temperature decrease as pull rate increases. Note that the test with preheated air loses significantly more heat to the exhaust gas than the oxygen-gas tests. This confirms that overall efficiency for preheated air operation will be lower than the overall efficiency for oxygen-gas firing. This is an expected result and similar to the trend seen in other oxy-gas melters relative to preheated air firing.

The energy to the product glass is a strong linear correlation with the pull rate. As pull rate increases, the energy to the glass increases linearly, leading to higher overall efficiencies. This trend holds across all glasses, across all melter temperatures, and across firing with oxygen or air.

Plans for Next Quarter

Work will be carried out next quarter primarily on Task 2 activities. The first continuous refining tests were carried out in 2009. Results were analyzed and previously presented. Results to date are encouraging. Analyses from the Sept. 30, 2009 test showing the void fraction of SCM product glass can be reduced from 30 to 0.3 percent with a short residence refiner with a residence time of less than a couple of hours. The project team plans to make additional refiner modifications, and additional continuous refining tests will be carried out next quarter. Additional work will focus on determining potential glass quality based on control of independent variables including melter temperature, channel temperature, channel depth, residence time. Potential modifications include

- Adding in-glass channel thermocouples to monitor and control glass temperatures during refining
- Optical monitoring of product glass from the channel to observe temperature in real time and to observe bubbles and seeds before samples are collected. This is desired because the sampling process can add bubbles to the molten glass
- Better control of the melt discharge system from the pilot SCM unit. The new gate worked well in the last test, but components such as hoses, piping, and cables need to be moved to provide better access, improved operating characteristics, and even better melt flow control. These improvements will allow more precise residence time control and a wider range of channel residence times
- Optical monitoring of the foam layer in the conditioning channel
- Variations of temperature in both the SCM and conditioning channel to relate refining to temperature and viscosity
- Variations in conditioning channel depth to better understand refining quality to time provided for bubbles to rise to the surface. This has been calculated and measured experimentally by earlier researchers, and those results will be compared with results obtained for SCM glass with our size and concentration range of gas inclusions.
- Better method of sampling gas from the discharge of the conditioning channel. The current method of taking hand samples in a graphite mold from the falling melt stream likely adds bubbles to the glass. At higher levels of refining, these added bubbles will interfere with our ability to determine the glass quality achieved in the conditioning channel.

The approach followed to date is promising for removing the great majority of bubbles in SCM product glass. SCM product glass typically is around 30% voids by volume. The refining channel, with a reasonable residence time appears to reduce the bubble content to well under 1%.

With further improvements and better control, that is likely to be reduced to under 0.1% voids by volume. This level of voids is acceptable for a number of applications including wool insulation fiberglass and the coarser continuous strand fiberglass. However, this approach may not be able to meet the quality needs for fin continuous strand fiberglass, container glass, tableware, lighting glass, flat glass, etc. With this in mind, the project team will focus Task 2 efforts in two directions in the coming months. These include:

1. Continuing work with the conditioning channel to improve the level of refining that can be reached and to better characterize the glass and the process
2. Pursuing other approaches for 'fine' refining to enable glass to be refined to a higher quality levels. This third step will also need to be a rapid step of refining, and this step will be tailored to the conditions created by SCM glass followed by short residence time refining.

Based on study and development this quarter and in earlier quarters, three promising approaches to higher levels of refining have been identified. Each of these approaches holds promise to both work and to be industrially robust. The project team intends to explore each of these approaches to the level possible in this project. Plans for next quarter include the following for these approaches:

The first 'fine' refining approach is a modification of the refining channel already under investigation. This method will be modeled mathematically by CFD and with viscous liquids at room temperature. Promising results will then be followed by refining tests with molten glass.

A second 'fine' refining approach is highly innovative but presently only conceptual. Work will continue with a consultant to explore the potential for this technique. If modeling and computational results are promising, this approach will then be studied after evaluation of the first 'fine' refining approach listed above (the method involving a modified refining channel).

The third 'fine' refining approach is the approach developed by GTI and covered by the existing patent application. This approach has been studied with simulated high viscosity liquids. This method will be considered either second or third based on developments and technique maturity.

Other approaches to a 'fine' refining step to reach fully clarified glass continue to be studied and the most promising approaches will be tested if possible. Work will involve reading, discussions with industry experts and consultants, modeling if required, and testing with surrogate liquids such as high viscosity silicone oils. If a promising approach if identified, efforts will be made to explore the approach, and the results will be presented in project Technical Progress reports.

Additional SCM burner tests are also planned for next quarter. These tests were begun this quarter and will be completed early next quarter. The goal is to improve burner long-term service life in industrial use. The current research version of the burner has proven effective, but engineers have learned that some burners show wear problems under certain operating regimes. Testing on a stand will allow engineers to identify ways to prevent excessive wear, improve performance, and provide guidance regarding fabrication methods.

Publications/Presentations

The first presentation related to this project was presented in October, 2009 at the 70th Glass Problems Conference. Also, a patent application has been prepared and submitted to the U.S. Patent Office. This patent application covers one approach being developed for refining of glass from high-intensity melters such as the SCM.

Presentations were made in person in mid-2009 and this quarter to Mr. Glenn Strahs at DOE Headquarters in Washington, DC. These presentations covered the technology concept and history as well as the work that has been supported by DOE. The goal of these presentations was to provide Mr. Strahs with background on the SCM and NGMS technologies and to bring him up to date regarding the key role DOE is playing in their development.

The paper presented in October, 2009 at the Glass Problems Conference was authored by David Rue, Walter Kunc, and John Wagner (GTI), Bruno Purnode (Owens Corning) and Aaron Huber (Johns Manville) and titled “Rapid Refining of Submerged Combustion Melter Product Glass”. This was the first public presentation on project approach and status. Data from tests conducted to date and on refining approaches was discussed. Non-proprietary results were included that showed the short residence refining approach can remove 99% of bubbles to lower the void fraction of SCM product glass from 30% to under 0.5%. Conference papers will be published in spring 2010 by the American Ceramic Society.

Milestone Status Table

This project is divided into three Tasks over a five-year period (extended from the original three-year period). The Year 4 effort is currently underway. Work in Year Four is focused on refining tests with the pilot SCM unit and the new refining section that is now assembled. The project is divided into two Budget Periods. Funding from DOE is now in place for Budget Period Two.

Budget Data

The DOE contract was signed in June 2006 with an effective start date of July 1, 2006. DOE has approved an increase in project budget and extension of work into the planned fourth year and Phase 2. The paperwork was completed, and the added $935,000 in funding was put in place by DOE. The NYSERDA contract for co-funding has been revised. With the increase in DOE funding, NYESERDA has agreed to increase their cost sharing to $200,000, but a change in Scope of Work and Budget must be completed and was submitted this quarter. Planned funding allocation from NYSERDA is expected in the second quarter of 2010. Gas industry co-funding through GTI's SMP program is in place. The glass industry partners will be providing in-kind support to the project. The overall project budget, and spending to date, is shown below. Only cash funding is shown. In-kind cost-sharing by subcontractors and the two glass company partners is not shown.

			Approved Spending, $K			Actual Spending, $K		
Phase / Budget Period			DOE Amount	Cost Share	Total	DOE Amount	Cost Share	Total
	From	To						
Year 1	7/06	6/07	109	100	209	15	0	15
Year 2	7/07	6/08	257	100	257	173	50	223
Year 3	7/08	6/09	6	75	156	184	148	332
Year 4	7/09	6/10	467	100	567	235	98	333
Year 5	7/10	6/11	468	100	568			
Total			1307	475	1782	607	296	903

Work will continue next quarter with refining tests with both surrogate liquids and molten glass. The pilot-scale SCM unit will be used for continuous melt tests focused on refining.

Index of Award CID Numbers

Index of Award CID Numbers