Proceedings of the

FY 2003 Glass Industry Project Review

Industrial Technologies
Glass Research Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

In association with the Glass Manufacturing Industry Council

September 8-10, 2003
Golden, Colorado

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FY 2003 Glass Industry Project Review

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National Renewable Energy Laboratory
Golden, Colorado

Coordinated by
Elliott Levine
U.S. Department of Energy
Energy Efficiency and Renewable Energy
Industrial Technologies Program

Prepared by
Energetics, Inc.
Columbia, Maryland

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***E**nergy Efficiency Opportunities in Glass and the Role of Public-Private Partnerships*
***E**nergy Efficiency Opportunities in the Glass Manufacturing Industry (ACEEE)*

C Attendees

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Agenda

FINAL AGENDA

DOE GLASS PROJECT REVIEW

September 8, 2003

6:30 - 9:00 pm	**WELCOMING RECEPTION at Denver West Marriott**

September 9, 2003

National Renewable Energy Laboratory
Golden, Colorado

Time	Activity	Speaker(s)
7:30 - 8:00 am	**REGISTRATION**	
8:00 - 8:30 am	Welcoming Remarks and Introductions	Elliott Levine Department of Energy Michael Greenman Glass Manufacturing Industry Council Richard Truly National Renewable Energy Laboratory
8:30 - 9:10 am	*Development and Validation of a Coupled Combustion Space/Glass Bath Furnace Simulation* Questions and Answers	Mike Petrick Argonne National Laboratory
9:10 - 9:40 am	*In-House Recovery and Recycling of Glass from Glass-Manufacturing Waste* Questions and Answers	Ed Daniels Argonne National Laboratory
9:40 - 10:10 am	*Development/Demonstration of an Advanced Oxy-Fuel Fired Front-End System* Questions and Answers	Christopher Jian Owens Corning
10:10 - 10:25 am	*GPLUS Update*	Peter Angelini Oak Ridge National Laboratory
10:25 - 10:40 am	**BREAK**	
10:40 - 11:10 am	*Improvement of Performance and Yield of Continuous Glass Fiber Drawing Technology* Questions and Answers	Phil Sanger Cleveland State University Simon Rekhson Cleveland State University
11:10 - 11:30 am	*Modeling of Glass Processes Update*	Tom Seward Center for Glass Research
11:30 am - 12:10 pm	*Process Optimization Strategies, Models and Chemical Databases for On-Line Coating of Float Glass* Questions and Answers	Mark Allendorf Sandia National Laboratories Jill Troup PPG Industries
12:10 - 1:25 pm	**WORKING LUNCH**	

September 9, 2003 (Continued)		
12:55 - 1:05 pm	*Next Generation Melting System Technical and Economic Evaluation Update*	Warren Wolf
1:05 – 1:25 pm	*Demonstration: Glass Resources CD-ROM*	Kristi Theis National Renewable Energy Laboratory
1:25 - 1:55 pm	*Energy-Efficient Glass Melting - The Next Generation Melter* Questions and Answers	David Rue Gas Technology Institute
1:55 - 2:25 pm	*Diagnostics and Modeling of High-Temperature Corrosion of Superstructure Refractories in Oxy-Fuel Glass Furnaces* Questions and Answers	Mark Allendorf Sandia National Laboratories
2:25 - 3:05 pm	*Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulates and Crown Corrosion* Questions and Answers	Linda Blevins Sandia National Laboratories
3:05 - 3:20 pm	**BREAK**	
3:15 - 3:30 pm	*Advanced Process Control and Auto Glass Process Control Update*	Moe Khaleel Pacific Northwest National Laboratory
3:30 – 3:45 pm	*OIT Clearinghouse*	Gil McCoy Washington State University
3:45 - 4:25 pm	*Measurement and Control of Glass Feedstocks* Questions and Answers	Robert De Saro Energy Research Company Arel Weisberg Energy Research Company
4:25 - 4:55 pm	*High-Intensity Plasma Glass Melter* Questions and Answers	Ron Gonterman Plasmelt Michael Weinstein Plasmelt
4:55 - 5:10 pm	*Development of an Energy Assessment Protocol*	Brian Kauffman Mississippi State University (DIAL) Cheryl Richards PPG Industries
5:10 - 5:20 pm	*Low-NOx Burner Update*	Dan Wishnick Eclipse/Combustion Tec
5:20 - 5:30 pm	Wrap-Up: Comments and Recommendations	Elliott Levine Department of Energy
6:45 pm	**RECEPTION and DINNER at Table Mountain Inn** Dinner Speaker: Buddy Garland, Department of Energy	

September 10, 2003

Time	Activity
7:30 am	**DEPART Denver West Marriott for Johns Manville**
8:30 - 11:30 am	Tour at Johns Manville Technical Center
11:30 am	**DEPART Johns Manville for NREL**
12:00 - 1:00 pm	**WORKING LUNCH at NREL**
1:30 - 4:00 pm	Tour at NREL
4:15 pm	**ARRIVE Back at Denver West Marriott**

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List of Reviewers

Reviewers
Glass Manufacturing Industry Council

CORE MEMBERS

CertainTeed Corporation
Terry Berg
Robert Butler

Corning Incorporated
Fred Quan

Johns Manville
Aaron Huber

Longhorn Glass
Susan Jones

Osram Sylvania
Bill Anderson

Owens Corning
Manoj Choudhary
Tom Huff
Christopher Jian

PPG Industries
Jim McCamy
Cheryl Richards
Jill Troup

Saint-Gobain Containers
Marvin Gridley
Erik Helin

Society for Glass Science and Practices
Tom Fenton (Fenton Art Glass Company)

Schott Glass Technologies
Carsten Weinhold

Visteon
Ed Boulos

ASSOCIATE MEMBERS

BOC Gases
Neil Simpson

Center for Glass Research
Thomas Seward

Cleveland State University (CAMP)
James Leonard
Philip Sanger

Diagnostic Instrumentation and Analysis Laboratory
Brian Kauffman

Eclipse/Combustion Tec
Dan Wishnick

Gas Technology Institute
David Rue

Praxair
Frank Dumoulin

U.S. Borax
Bob Smith

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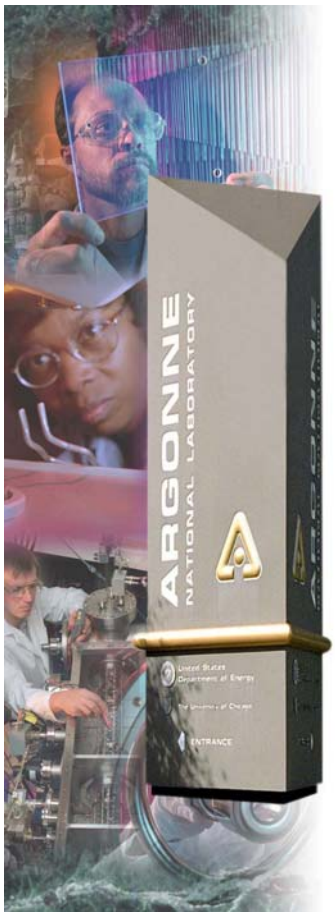
Ongoing Project Evaluation Results and Presentations



Development and Validation of an Advanced Multiphase Gas Furnace Model

Presenters: Brian Golchert, Michael Petrick – ANL

Argonne National Laboratory

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Presentation Outline

- **Program Overview**
  - Goals, Technical Approach, Program Description
  - Program Status
    - *Program will be completed by 12/31/03 as scheduled*
- **Technical Progress/Accomplishments**
  - Brief Overview of Accomplishments of Last Year
  - Final Validation Studies
  - Results from Parameter, Sensitivity, and Optimization (PS&O) Studies
  - GFM 3.0 Multiphase Flow Analytical Capabilities in Melt
- **Technology Transfer of GFM Code to Industry**
  - Strategy Finalized
  - To Be Initiated in FY04

Program Overview

and

Status

Program Goals

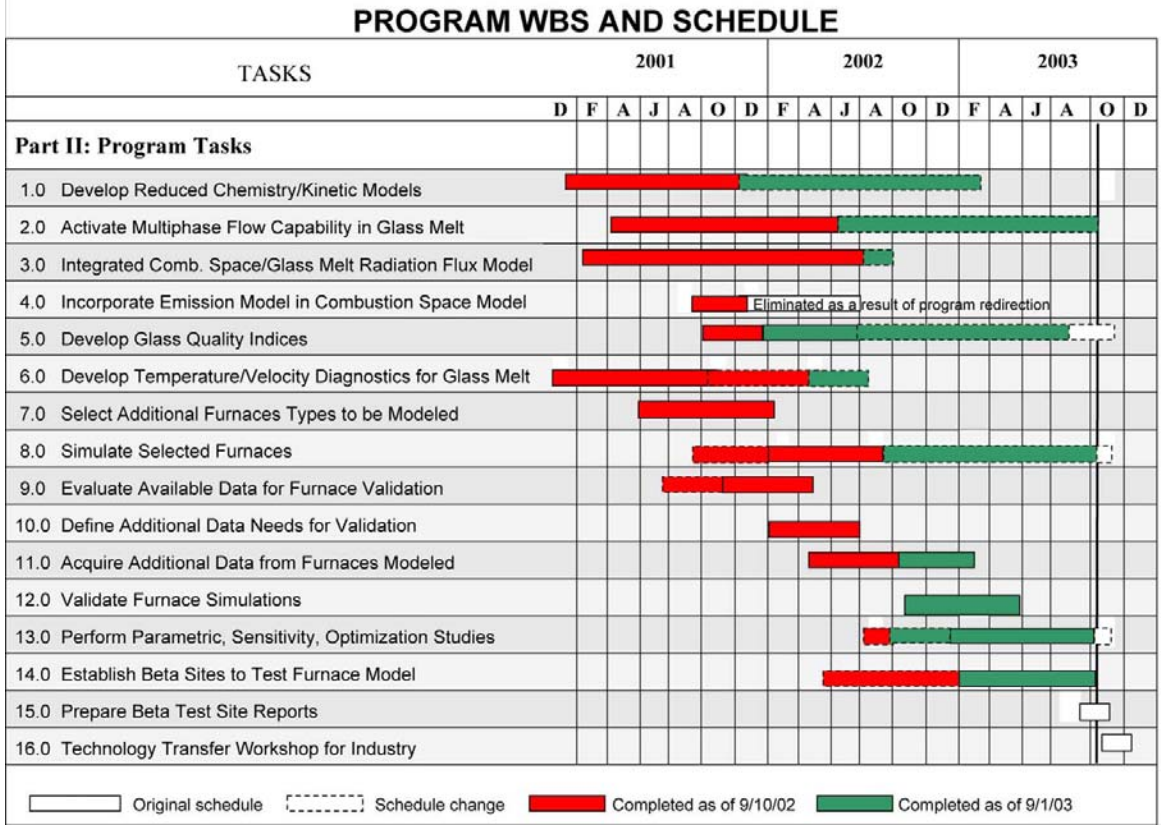
- **Advance the "State of the Art" in Glass Furnace Modeling/Simulation**
- **Provide Industry with a Validated Furnace Model that Can be used to Analyze Different Types of Furnaces**
- **Make the Validated Code (Executable and Source Codes) Readily Available to Industrial Users.**

Program Description

- **Two Part Program Initiated in 1998**
- **Supported by Industrial Consortium**
  - Techneglas, Inc. Libbey, Inc. Visteon
  - Owens Corning Osram Sylvania
- **University Participants**
  - Purdue University
  - Mississippi State University
- **Five-Year Program Schedule**
  - Part I Program completed; Part II Program to be completed at end of CY 03
- **Deliverable: User Friendly, Validated, Glass Furnace Model for Use by Engineers**
  - A step change in modeling capability
  - Technical Support Provided to User

Technical Approach for Achieving Program Goals

- **ANL's Multiphase Reacting Flow CFD Codes (ICOMFLO, ICRAKFLO) used to Develop a Coupled Glass Furnace Model (GFM)**
  - Incorporate advanced phenomenological models for spectral radiation heat transfer, batch melting, foam layer formation, etc.
- **Construct Simulations of Selected Furnaces**
- **Develop/Install Diagnostics in Selected Furnaces to Acquire Data for Code Validation**
- **Validate Furnace Models with Data Acquired**
- **Demonstrate the Utility and Benefits That Can Be Derived From the Use of GFM Code**
  - Conduct extensive parametric, sensitivity and optimization studies to identify opportunities to improve furnace performance



Technical Progress

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Accomplishments

Accomplishments During Past Year

- **Initial Workshop Held at OSU to Introduce GFM to the Industry**
  - Capabilities of early version of GFM 2.0 demonstrated
    - *Demo code given to attendees*
  - 32 attendees
- **Code Validation Data Obtained from Two Additional Furnaces with Different Operation and Design Characteristics**
  - Regenerative end port fired and a recuperative fiberglass furnace
- **Advanced Version of GFM 2.0 Developed and Validated with in situ Data from Three Furnaces**
  - More robust preprocessor
  - Spectral radiation computed throughout furnace volume

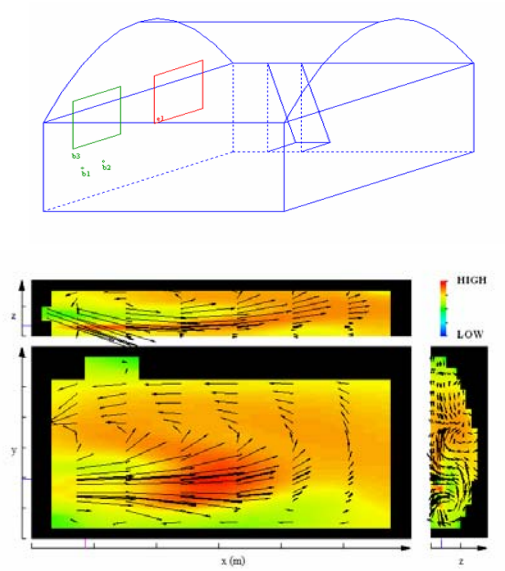
Accomplishments During Past Year (cont'd)

- **GFM 2.0 Beta Tested by Industrial Participants**
- **Simulations of Five Furnaces Selected by IPs Developed with GFM 2.0**
- **Simulations Developed Used to Conduct Parametric, Sensitivity, & Optimization Studies**
  - Parameters varied specified by IPs
  - Studies conducted jointly by IPs and ANL
- **Multiphase Analytical Capabilities of GFM 3.0 (Final Version of Code) Operational**
  - Key solid, gas, and liquid species can be computed and tracked throughout glass melt

Validation Studies

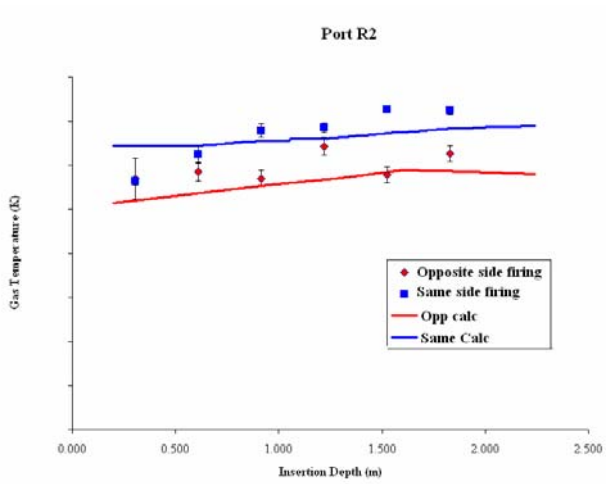
- **Two comprehensive measurement campaigns were mounted by Mississippi State University to obtain validation data**
  - Libbey end-fired regenerative furnace
    - *Measurements made:*
      - Gas Temperature, velocity, and composition
      - Glass surface temperature
      - Radiation heat fluxes
  - Owens-Corning recuperative furnace
    - *Measurements made:*
      - Gas Temperature, velocity, and composition
      - Glass temperature profiles
      - Radiation heat fluxes

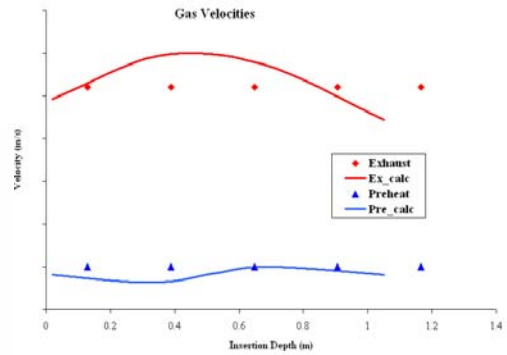
Libbey Furnace Validation Studies



- **Small, end-fired regenerative furnace with one side charger**
- **Needed to use time averaging technique to account for furnace cycling**
- **Grid sensitivity study shows relatively coarse grid is sufficient for validation studies**

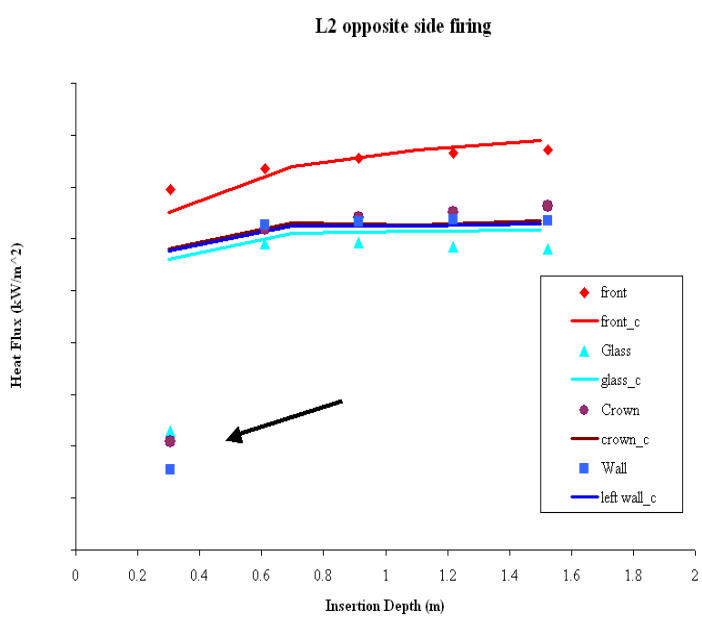
Libbey Furnace Validation: Good Agreement between Measured and Calculated Gas Temperature/Velocities





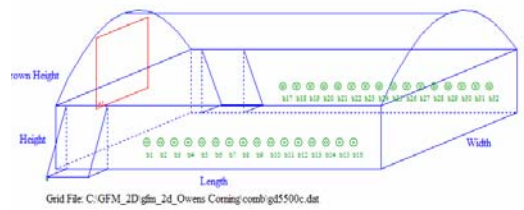
Libbey Furnace Validation: Calculated directional radiation heat fluxes compare very well with measurements both in magnitude and in trend

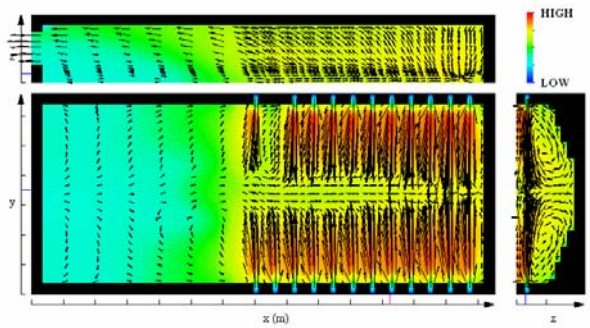
- **Discrepancy in the lower left hand corner of the chart is due to the local effect of the peephole**
  - cooler walls and infiltration air lower measured heat fluxes
  - not explicitly modeled in simulation



Owens Corning Recuperative Furnace Validation

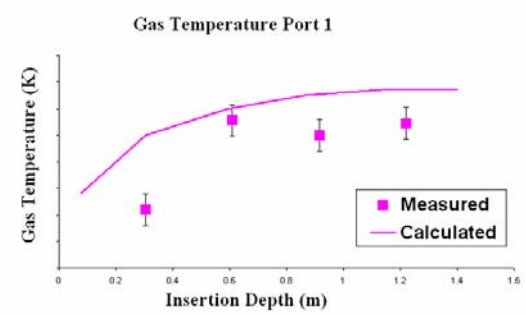
- Recuperative furnace with many burners on both sides of the furnace
- Very clean combustion space; no visible flames
- 'Hard' to melt glass composition
- Extensive electric boosting in the melt
- Many burners on both sides creates relatively uniform temperature field



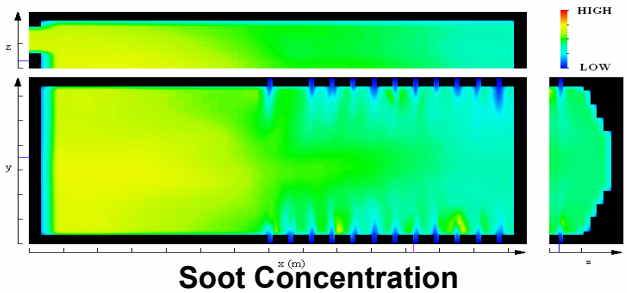


Temperature and Velocity Fields

Owens Corning Recuperative Furnace Validation: Comparison of Calculated and Measured Gas Temperature

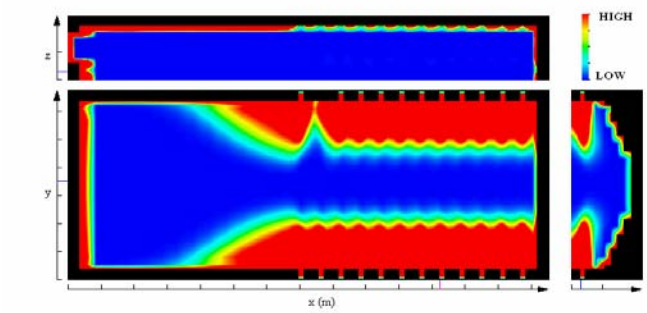


- Measured temperatures lower than the calculated temperatures due to gases released from batch/melt
- Gas release not accounted for in GFM2



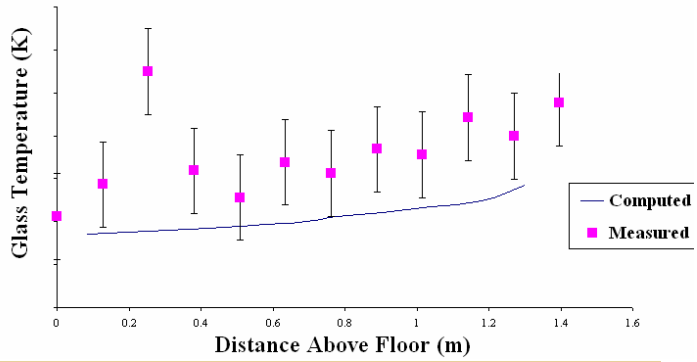
Soot Concentration

Owens Corning Furnace Validation: Heat Flux/Glass Temp.



Calculated surface heat flux

Comparison of Measured and Calculated Glass Temperature-->computed values within 50 K of measured values



Parametric, Sensitivity, and Optimization Studies

- **The industrial participants, with assistance from ANL, are using GFM2 to develop simulations of furnaces they selected**
- **Simulations are being used to conduct parametric, sensitivity, and optimization studies to identify adjustments in operating/design parameters that would improve furnace performance**
- **Personnel conducting the studies have widely varying CFD modeling skills**

Parametric, Sensitivity, and Optimization (PSO) Studies Underway

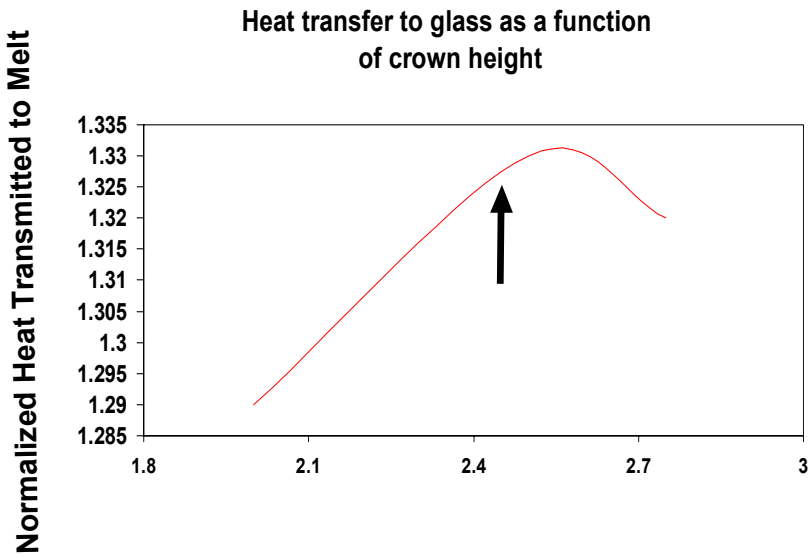
- **Libbey, Inc.**
  - Comprehensive analysis of combustion space
  - Investigating the effects of refiner shape on glass flow field
- **Techneglas**
  - GFM2.0 being used to diagnose some operational difficulties in one of their furnaces and to identify changes in operating parameters to improve performance
  - Investigated the effect of burner type (flattened tube-in-tube versus staged combustion)
- **Osram Sylvania**
  - Evaluating the effect of various heat transfer options (electric boost and combustion space firing patterns) on the melting rate (and hence the mixing) of the batch constituents

PSO Studies Underway (cont.)

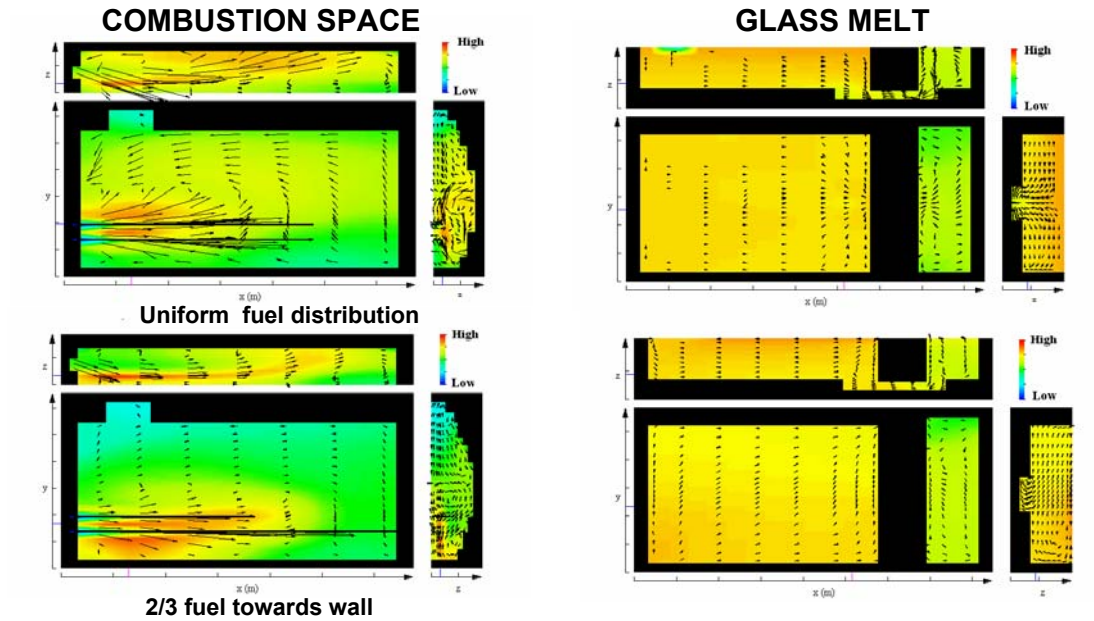
- **Owens-Corning**
  - Investigating firing patterns in the combustion space to enhance heat transfer
  - Evaluating different electric boosting patterns
  - Investigating various doghouse designs and their effect on melt flow
  - Investigating the conversion of a recuperative furnace to an oxy-fueled furnace
- **Visteon**
  - Investigating the effect of bubbler location and flow rates on the glass melt flow
  - Investigating charging pattern to determine if there can be energy savings

Libbey Furnace Parametric Studies: Impact of Crown Height on Heat Transfer

- **Several different crown heights were simulated**
- **Furnace currently running very near the optimal height**
- **An optimal crown height exists**
  - 1-3% impact on the energy transferred to the melt over the range studied



Libbey Study of Adjusting Fuel Firing Pattern



- **Study results indicate that pull could be increased by adjusting fuel firing pattern, while maintaining constant total fuel consumption**

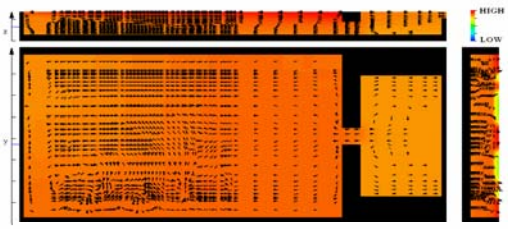
Techneglas Parametric Studies

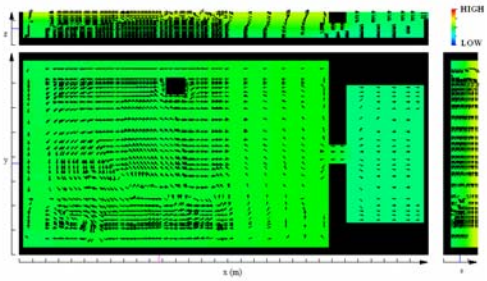
- **A Techneglas melter developed an operational problem due to the need to insert a large amount of refractory material into the melt.**
- **Insertion of this refractory material caused a significant decrease in quality thus causing the operators to reduce the pull**
- **PSO studies are being conducted to help:**
  - Identify the cause of the reduction in quality
  - Determine if operational parameters can be adjusted to allow increasing the pull without sacrificing quality

Techneglas Parametric Studies: Impact of Blockage in the melt on the Flow Field

- **The significant difference in the flow fields gave an indication as to why the quality dropped**
- **Currently modeling studies are being pursued to determine if different heating patterns could increase pull without reducing quality**

Computed flow: no blockage



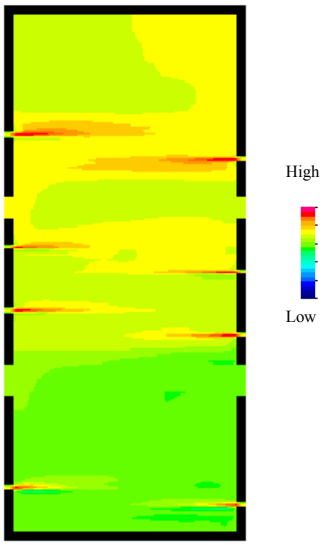


Computed flow: with blockage

Techneglas Parametric Studies (cont)

- **Techneglas has used the GFM to evaluate the effect of burner type on furnace performance**
- **PSO studies were conducted to determine the effect on the combustion space flow field of replacing flat flame burners with staged burners**
  - Objective: To obtain a more uniform temperature distribution

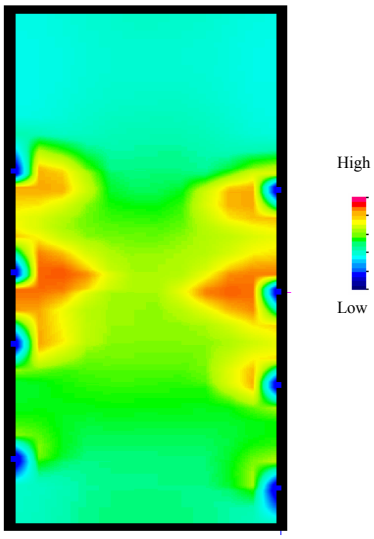
Simulation of Techneglas Furnace with Flat Flame Burners



- **Distinct flame shapes present**
- **More localized areas of heat transfer on glass surface**
- **Soot confined to flame regions**

Gas Temperature in the plane of the burners

Simulation of Techneglas Furnace with staged burners



- **Flames spread out more**
- **More uniform heat transfer to load**
- **Significantly increased soot production, not completely confined to flame regions**

Gas Temperature in the plane of the burners

Multiphase Capabilities of the GFM3.0

- **The melt model in GFM3 can currently handle**
  - Liquid glass species transport
  - Batch/cullet particle size groups
  - Bubble size groups generated from
    - *Batch reactions*
    - *Glass reactions*

- **The focus of this years work was on developing/incorporating models into the GFM3 that compute the bubble flow field in the melter**

Bubble Flow in a Glass Melter

- **Bubbles are created as a result of batch/glass reactions**
- **Required code input parameters to compute bubble transport in the melt**
  - Percent of gas released from batch reactions/melting that is entrained into the liquid glass
  - Average diameter and size distribution of bubbles entering the melt
- **As a bubble is transported throughout the melt, it can grow or shrink depending upon the local conditions (temperature and species concentration)**
  - species concentrations computed from fining reaction kinetics
- **The buoyancy force causes the bubbles to rise towards the melt surface where they can escape and/or create foam**

ASSUMPTIONS MADE RE BUBBLE SIZE/DISTRIBUTION OF GAS RELEASED FROM BATCH TO DEMONSTRATE GFM 3.0 MULTIPHASE ANALYTICAL CAPABILITIES

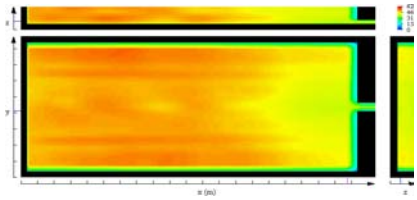
1.0 INITIAL BUBBLE SIZE DISTRIBUTION

	Group 1 Average Radius (mm)	**Group 2** Average Radius (mm)	**Group 3** Average Radius (mm)
Case 1	0.25	0.50	1.00
Case 2	0.35	0.75	1.25
Case 3	0.50	1.00	1.50

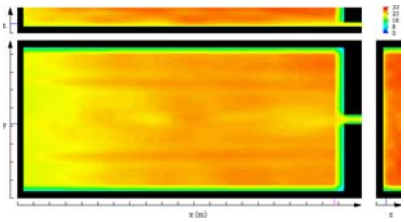
2.0 GAS DISTRIBUTION: 1/3 OF GASES ENTRAINED IN THE MELT FROM BATCH ARBITRARILY ASSIGNED TO EACH GROUP SIZE

Bubble Number Density for Three Size Groups in the melt

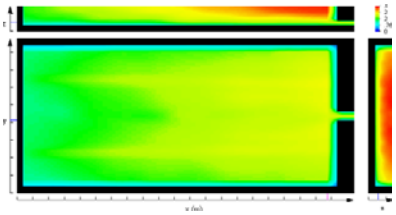
(Note: There are different color key scales for each size group)



Smallest size group



Medium size group

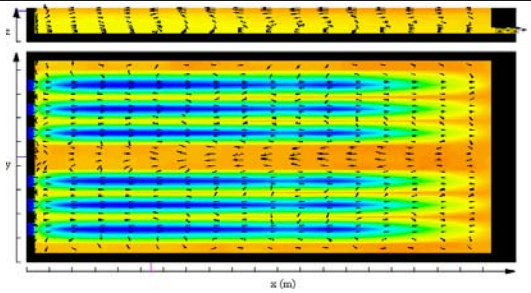


Largest size group

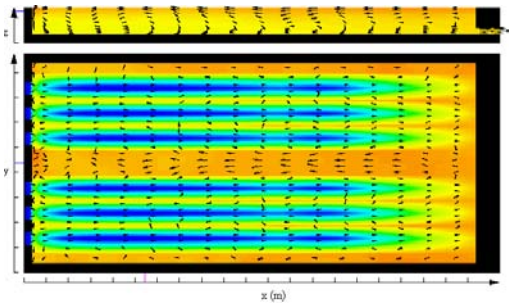
Calculated Bubble Number Density at Throat Exit can be Correlated with Glass Quality

Effect of gas bubble radius on melt temperature and velocity fields

- **Code structured to allow user to prescribe the initial bubble radius and size distribution of gases released from batch**
- **For the parameter range studied a relatively small impact on the melt temperature and flow field was found**

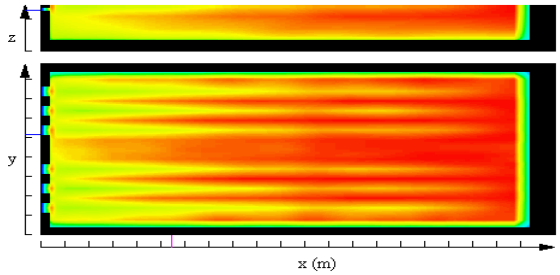


Smallest Initial Bubble Size

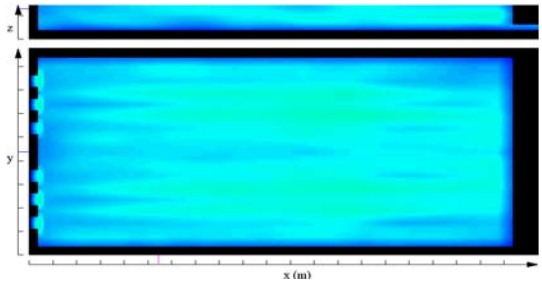


Largest Initial Bubble Size

Effect of bubble radius on gas volume fraction distribution in the melt



Smaller Initial Bubble Size

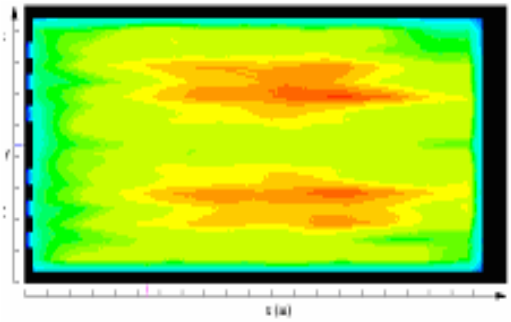


Larger Initial Bubble Size

- **Local melt bubble volume fraction distribution is very sensitive to the initial average bubble size**
- **The figures show that fewer bubbles per unit volume exist throughout the melt and at the surface for the case of the larger initial bubble diameter**

Foam Coverage

- **Model developed by Purdue correlates the foam thickness directly with the surface bubble flux and several thermo-physical parameters**
- **GFM3 can calculate the surface bubble flux and thus the foam coverage**



Computed foam coverage for a generic furnace configuration

Glass Furnace Model Technology Transfer (GFM-TT) Strategy

GFM – TT Objectives

- **Disseminate and Promote Widespread Use of the GFM Code in Glass Industry**
- **Provide Requisite Long Term Technical Support**

Issues Impacting the Transfer of GFM Code to Industry

- **GFM Code is Relatively Complex**
  - Testing of code will not be complete prior to end of program
  - Problems will be encountered by initial code users
- **Users Must Make Commitment to Master Use of Code**
  - Reluctant to do so until benefits from use proven
  - Costs associated with using code must be minimized for widespread application
- **Long Term Technical Support Essential if Code is to Become Widely Used**

Technical Support Must be Provided if Code is to Achieve Widespread Use

- **Any User will Initially Need Some Level of Training in its Use**
- **Use of Code to Simulate Different Furnace Geometries will Undoubtedly Lead to Situations Where Code Initially will not Converge**
  - User will need technical support to resolve problems
- **Additional Bugs in Code Will Surface as its Use Becomes More Widespread**
  - Code is complex
  - Code has undergone relatively limited testing

All Commercial Codes are Supported and Customization Services are Provided to Users

GFM-TT Objectives Will be Achieved By

- **Dissemination of Information on GFM Code to Industry**
- **Making GFM Code Readily Available to Interested Users**
- **Establishing a Technical Support Mechanism for GFM Code Users**
- **Implementation of Long Term Technical Support for GFM Code**

Dissemination of Information on the GFM Code to the Industry

- **A Brochure will be Prepared that Provides a Description of**
  - Code and its capabilities
  - How interested users can license code
  - How technical support will be provided
- **Brochure will be Mailed to Companies Throughout the Industry**
  - Will also be available from GMIC and other industry groups

Mechanism for Licensing GFM Code to Interested Users

- **GFM Code will be Placed in ANL Software Shop**
  - Accessible via internet
  - Site maintained by ANL Office of Technology Transfer
    - *Handles all licensing for ANL*
  - Allows interested users opportunity to license code online
  - Terms, conditions, and procedures for licensing code clearly outlined
- **Code Operating Manual and Example Problems will be Available to be Downloaded**

GFM Code Release Schedule

- **Planned Release Date for GFM 2.0 is 10/30/03**
  - Assumes IPs alpha & beta testing completed
  - Capabilities of GFM 2.0 demonstrated at 10/21/02 Glass Problems Conference Workshop
- **GFM 2.0 Release Motivated by**
  - Potential user interest expressed at workshop
  - Desire to promote early interest in and transfer of code to industry
- **Licensor of GFM 2.0 Will Automatically Get GFM 3.0 (Final Version of Code) at No Charge**
  - Full multiphase reacting flow capabilities
  - To be released during 2nd quarter of 04

Mechanism for Providing Technical Support to GFM Code Users

- **A GFM Code User Group (CUG) Established After Release of GFM 2.0**
  - Each licensee is automatically a member
  - Each member entitled to technical support services
- **Technical Support Services That Will Be Available to CUG Members**
  - Individual instruction on use of code at ANL
    - *Expect average user will require 3 days*
    - *User will create and run furnace simulations*
  - Additional support provided on an as needed basis
    - *Hours available will depend on number of users (CUG members)*
    - *Estimated minimum of 40 hours/year*
  - Customization services will be provided within allowable hour limits
    - *Modification of code when applied to unique/unusual geometries*
    - *Source code expected to evolve & be improved*
- **CUG Members Periodically will be Issued Improved Versions of GFM as They Evolve**
- **Technical Support will be Provided at No Cost Over 18 Month Period**
  - Levels to be compatible with resources provided by DOE

CUG Member Roles/Responsibilities

- **Meet Periodically (~ 4 month intervals) to**
  - Exchange information & share experiences from use of GFM code
  - Discuss strategies/opportunities identified for improving furnace performance
    - *Focus on reductions in energy use*
- **Based on Code Use Experience Identify/Prioritize Further Code Development Needs**
  - ANL will pursue code improvements consistent with available resources
- **Promote GFM Code use Within Their Companies and Across Industry**

Long Term Technical Support

- **Need and Mechanism for Continuing Support to Be Determined by CUG Membership**
  - At conclusion of 18 month DOE Support Period

- **CUG Could Evolve into a "Permanent" Industry Organization**
  - Support continued development/improvement of the GFM codes
    - *Funding provided by membership dues and possibly DOE*
  - Continued technical support available from ANL if needed on a fee basis
  - Ensure "state of the art" modeling capability for the industry

Improvement of Performance and Yield of Continuous Glass Fiber Drawing Technology -*"Breaking Through the Glass Fiber Drawing Barrier"*

Dr. Phillip A. Sanger and
Dr. Simon Rekhson
Cleveland State University
Cleveland, OH

Outline

Part 1

- Project Definition and Team
- Energy and Economic Benefits for Solution
- Tasks and Schedules
- Milestone Accomplishments
- Project Funding Profile

Part 2

- Process Design and Validation

Outline

Part 1

- Project Definition and Team
- Energy and Economic Benefits for Solution
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Part 2

- Process Design and Validation

This State IOF project aims to demonstrate a breakthrough four-fold reduction in downtime and un-recyclable waste, 20% yield increase, 15% throughput increase, and 20% reduction in fiber diameter variation.

•A Initiative on Cooperative Programs with States for Research, Development and Demonstration

Prime: Ohio Department of Development
Office of Energy Efficiency

Lead Organization: Cleveland State University through The High Performance Glass Forming Consortium

Participating Industrial Partners:
PPG Industries
Johns Manville
Schott Glas

Supporting Companies:
U.S. Borax

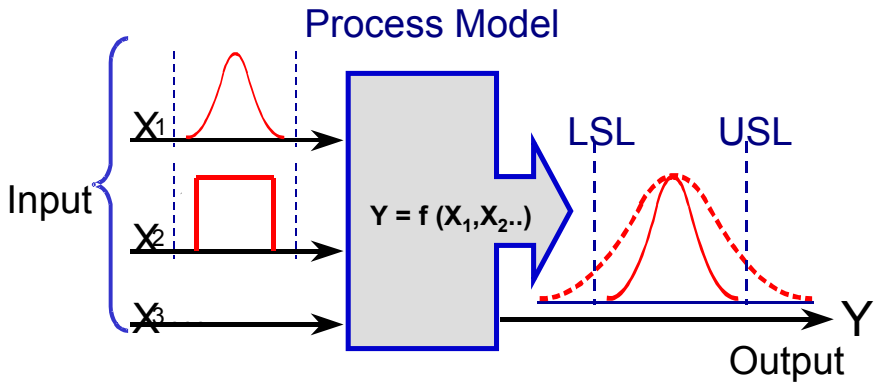
Converting Scrap into a Higher quality, Salable product Saves Energy

•Reducing breakage by 50% reduces scrap by 67,000 tons per year

•Energy thrown away in the scrap is presently 460-740 BBTU annually which is saved by realizing good product from waste

•Sales of saved product estimated at greater than $500M annually

Applying advance glass science and 6σ quality methodology, we attack fiber breakage and the waste that results



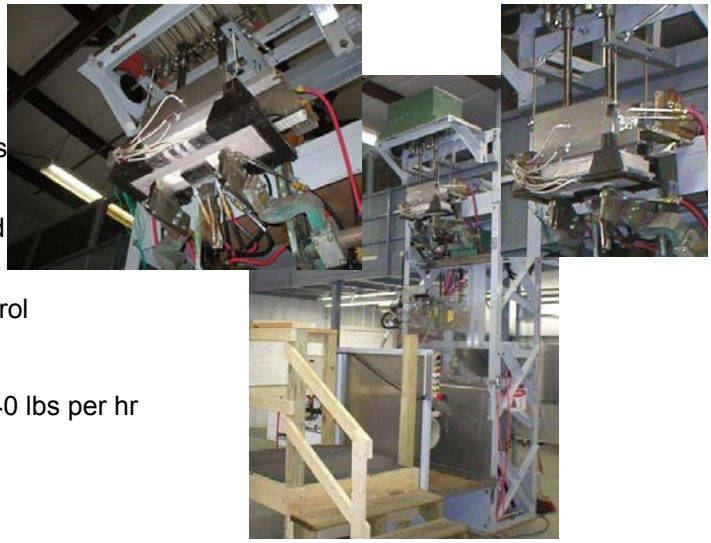
- Develop model from first principles
- Define key variables (x)
- Allocated tolerances to control output
- Validate

Milestones are being achieved according to the project plan

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
1	**Build and Install Drawing Tower**			
1.1	Install tower	1/10/03	3/20/03	First glass melting on March 27, 2003
1.2	Complete debug process	05/15/03	4/20/03	
1.3	Install new design of bushing	11/15/03	9/5/03	Planned for mid Aug
2	**Develop diagnostic instrumentation**			
2.1	Install IR and high speed photo system	03/01/03		Prototype testing completed, final instruments being assembled
2.2	Implement dimensional characterization process	09/15/03		
3	**Develop simulation models**			
3.1	Initiate testing of models	12/20/02	11/30/02	
3.2	Complete transfer function	04/16/03	4/30/03	
4	**Optimize process**			
4.1	Validation	07/30/03		Data being collected at partner site
4.2	Demonstrate improved process	03/15/04		
5	**Disseminate technology**			
5.1	Hold first tech transfer training session	10/30/02	10/30/02	
5.2	Start final partner implementation	05/30/04		

Drawing Tower is entering phase II with next iteration of bushing and melter design

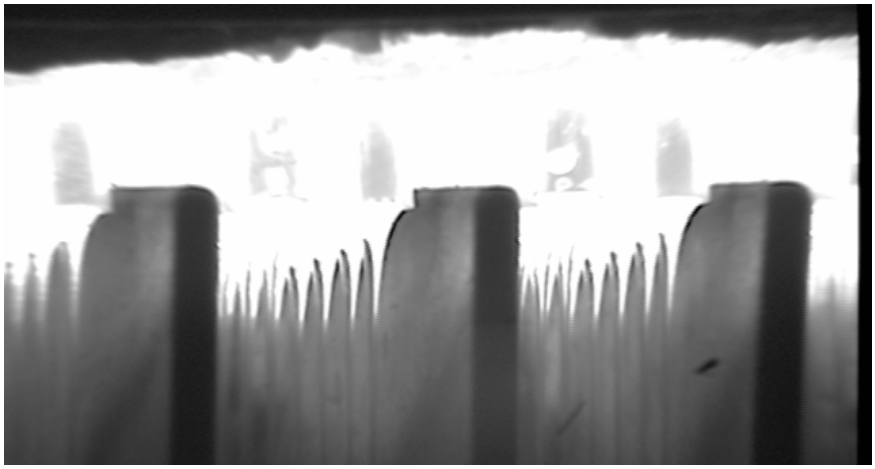
- >175 operational hours
- >1500 lbs of glass drawn
- Focused on instrumentation debugging and defining process region
- Installation of new bushing and melter completed
  - Independent melting control
  - ~1 hr residence time
  - Increased throughput to 40 lbs per hr
- Debugging initiated



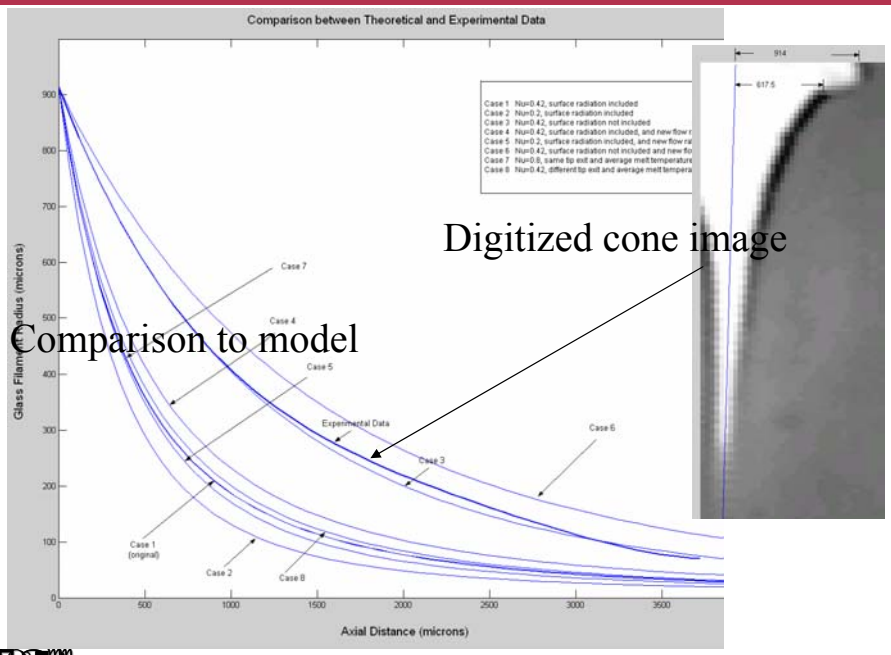
Diagnostic instrumentation should fill in the major data holes by end of September

- **Tension**- manual, three wheel
- **Speed** -laser doppler on the bundle continuous
- **Cone Imaging** – photography with 1 D traverse on edge cones, semi continuous scanning
- **Temperature Profile** – pyrometer at 45°, 2D scan on tip and plate, semi continuous scanning
- **On-line Filament Diameter** – high resolution digital scan, continuous, combined with off line diameter confirmation
- **Nuclear Level Gauge**- continuous, feedback to melter
- Plus experimentation with mm-Wave temperature and viscosity measurement with PNNL and MIT

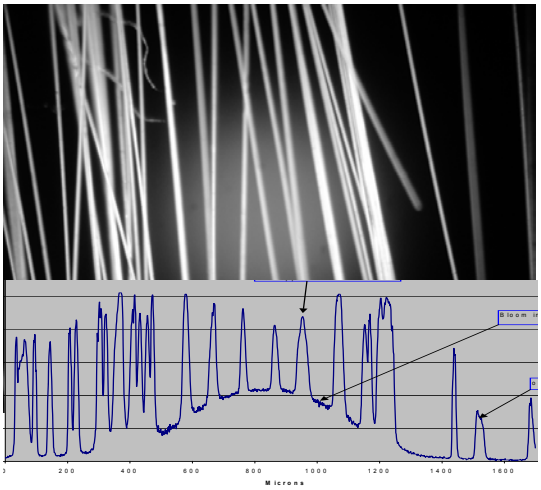
Dimensional monitoring of Cone shape and length – a key parameter linked to breakage- permits model validation and process control



Cone photography is a key element in model validation



An in-line diagnostic for fiber diameter measurement links directly to bushing temperature uniformity



The project is on track and entering the exciting part of the program

			Approved Spending Plan			Actual Spent to Date		
Phase / Budget Period			DOE Amount	Cost Share	Total	DOE Amount	Cost Share	Total
	From	To						
Year 1	July 11, 2002	July 30, 2003	$554,014	$166,070	$720,084	$519,404	$295,539	$814,942
Year 2	August 1, 2003	July 30, 2003	$419,935	$122,525	$536,410	0	0	0
Totals			$967,899	$288,595	$1,256,494	$519,404	$295,539	$814,942

The Project TEAM is on target, on schedule and on budget making great progress

- We processed over 1500 lbs of glass in over 175 hours of running
- We have installed the next generation bushing for testing
- New types of instrumentation are being employed and developed to control the process
- The project team has expanded to include Johns Manville and USBorax.
- And now……the rest of the story!

Process Design and Validation

Outline

Physics of Glass Fiber Drawing

Breaking a liquid

Validation

Acknowledgements

Model… validation @ CSU… industry implementation = a team effort of

Jim Leonard, Paul Lin and Sridhar Ungarala, CSU

Chi Tang, Sameer Talsania, Mark DeLong, Jim Koewing and Terry Love, PPG

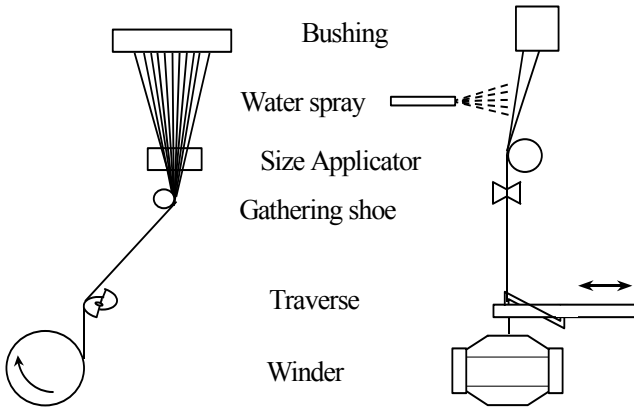
Jerry DeMott and Terry Hanna, Johns Manville

Ulrich Fotheringham, Schott Glas

John Simon and Bob Smith, US Borax

Last but NOT least - thanks to our hard working students Uma Sistu, Rick Bartel and Li Xiaolong

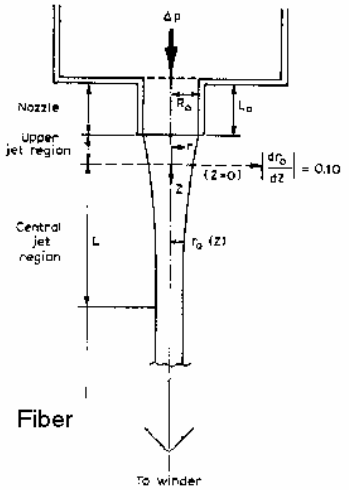
Glass Fiber Drawing - Process



Schematic of a continuous glass fiber drawing machine

Glass Fiber Drawing - Basic Physics

- Viscosity of molten E-glass at ~2150 F (~1180 C) is 1000 P; sour cream at R.T. = 1000 P, honey = 100 Poise
- Flows through the channel (bore) of 1.7 mm (~1/16 inches) driven by pressure $\Delta P = \rho g H$ (hydrostatic head)
- @ tip (nozzle) exit V = 7 m/hr; several cm below → V ~ 80 - 120 km/hr
- Typical bore/filament diameter ratio = 1720/12 (microns) = 140, the ratio of areas (~ratio of d^2) = 20,000
- 0.1 mm-thin sliver of jet (paper sheet) → ~ 2000 mm long fiber

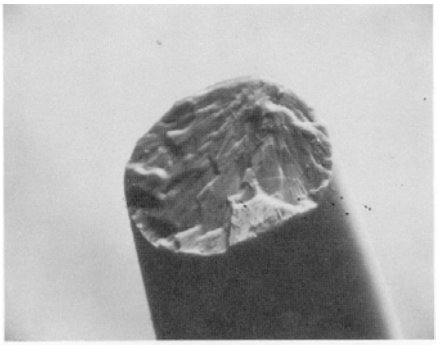


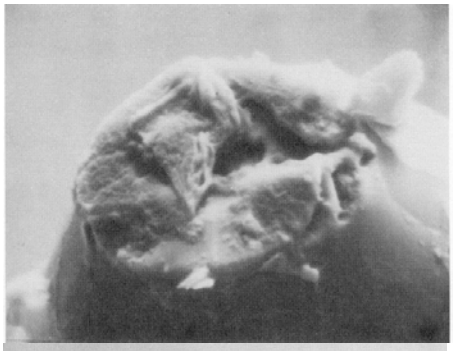
Schematic of attenuating glass jet (adopted from Gupta)

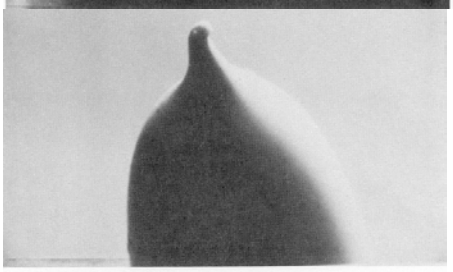
Basic Physics, cont'd: Melter/Former Relationship

- **"Lazy" tip vs. "hungry" winder**
- **Tension !!! → "Instron" testing machine**
- **Ten times around the globe testing a one-inch part at a time - statistics!**
- **Brittle fracture of liquid**

Three Modes of Failure in our 1982 Research

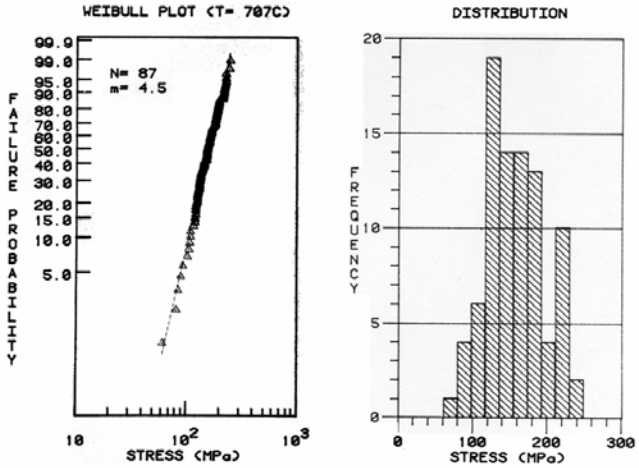






Three modes of failure for soda-lime glass at 580°C, η = 6.3 10^{10} poises (SEM photomicrographs of ~350 mkm fibers)

100 MPa Breaks 5% of Pyrex Fibers just above their Glass Transition Temperature Range



Strength distribution for Corning 7740 (Pyrex) at 707°C, η = 3.2 10^9 poises

Transfer function from first principles

KPIV

Head

Set Point

Winder speed

⇨

Transfer Function

⇨

KPOV

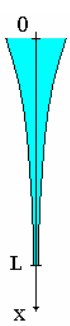
Filament diameter

Tension

Run time

Goal: define KPIV's to achieve a specified filament diameter (customer) and low breakage level (manufacturer)

Quasi-one-dimensional model, Glicksman '68



Conservation equations:

$$\frac{\partial S}{\partial t} + \frac{\partial (vS)}{\partial x} = 0, \qquad \text{- mass}$$

$$\frac{\partial}{\partial x}\left(3\mu \frac{\partial v}{\partial x} S\right) = 0, \qquad \text{- momentum}$$

$$\frac{1}{v}\frac{\partial T}{\partial t} + \frac{\partial T}{\partial x} = -\frac{1}{\tau_T}(T - T_a) - \frac{1}{\lambda} r\left(T^4 - T_a^4\right) \qquad \text{- energy}$$

Boundary conditions:

$$S = S_0, \quad v = v_0, \quad T = T_0, \quad x = 0$$

$$v = v_L, \quad x = L$$

where S is the jet cross section, v is the axial velocity

$\mu(T)$ is the viscosity, T and T_a are the temperature of glass and air

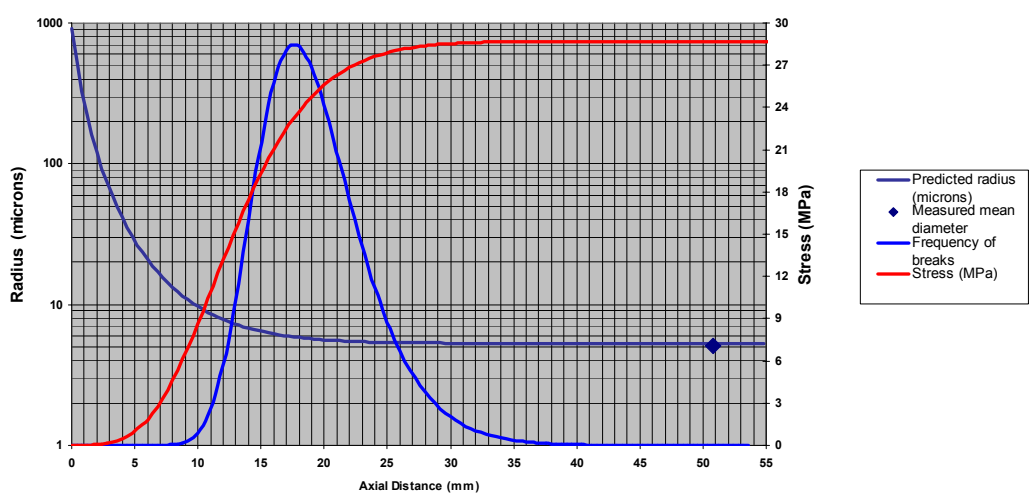
$\tau_T = \frac{C_P W}{\pi k_a Nu}$ and $\lambda = \frac{C_P W}{2\pi\sigma\varepsilon}$, k_a is the air thermal conductivity, Nu is the Nusselt number $= h\,D/k$

σ is the Stefan – Boltzmann's constant and ε, the emissivity of glass.

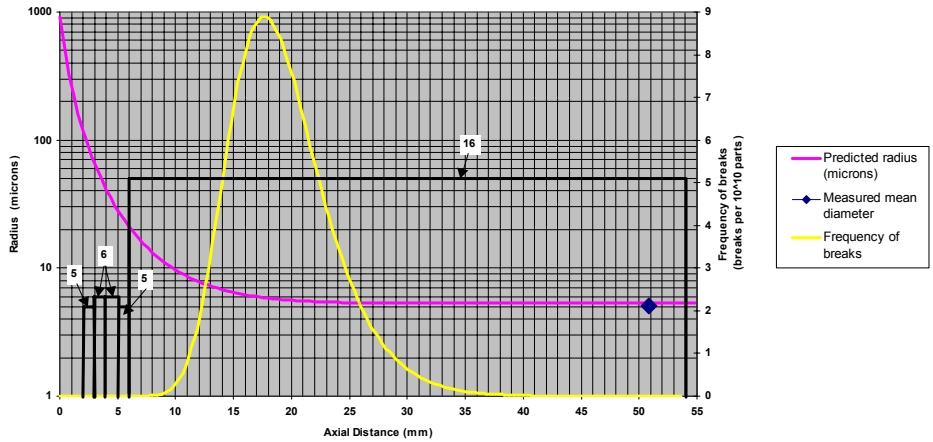
Input

Input variables:			
Tip temperature	T_0	2150	F
Mass flow rate	W	1.00E-05	Kg/sec
Tip radius	r_0	0.001	m
Winder speed	V_L	49.16	m/s
Filament Radius	r_L	5	microns
Process and material constants:			
Density of glass	ρ	2590	kg/m^3
Nusselt number for convective heat transfer	Nu	0.42	
Glass heat capacity	C_P	1340	J/kg/K
Emissivity of glass	ε	0.3	
Ambient air Temperature (K)	T_a	293	K
Thermal conductivity of air	K_a	0.0254	W/m/K

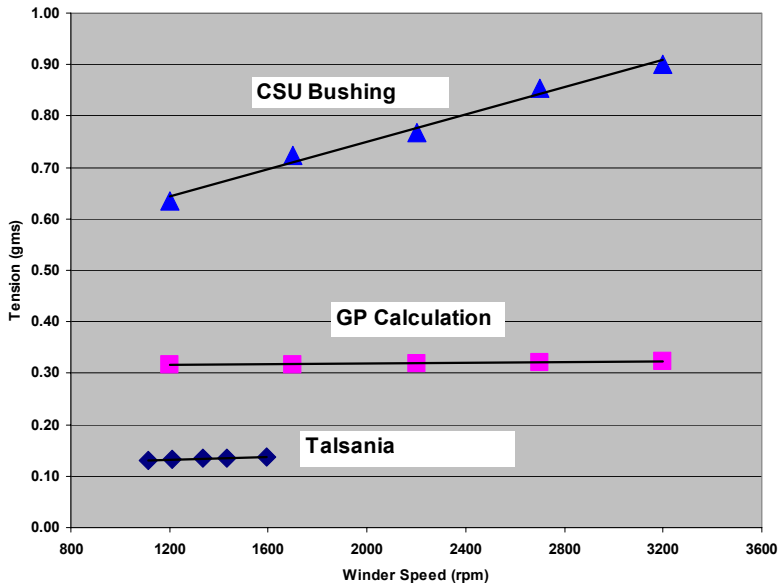
Radius, Stress and Probability Density Function for Filament Breakage



Plant Validation



Tension in gms (1 filament) at different winder speeds

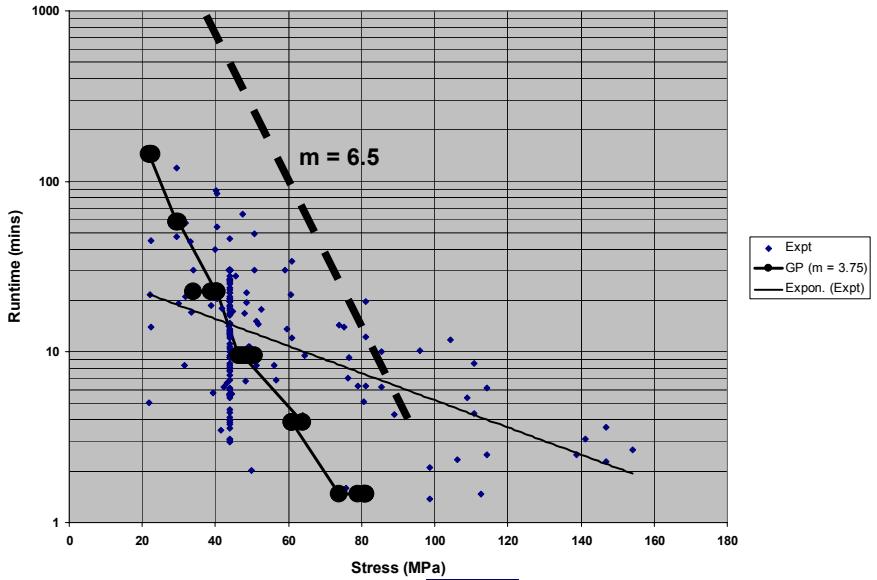


SU Bushing data
$y = 0.0001x + 0.4848$
$R^2 = 0.9881$

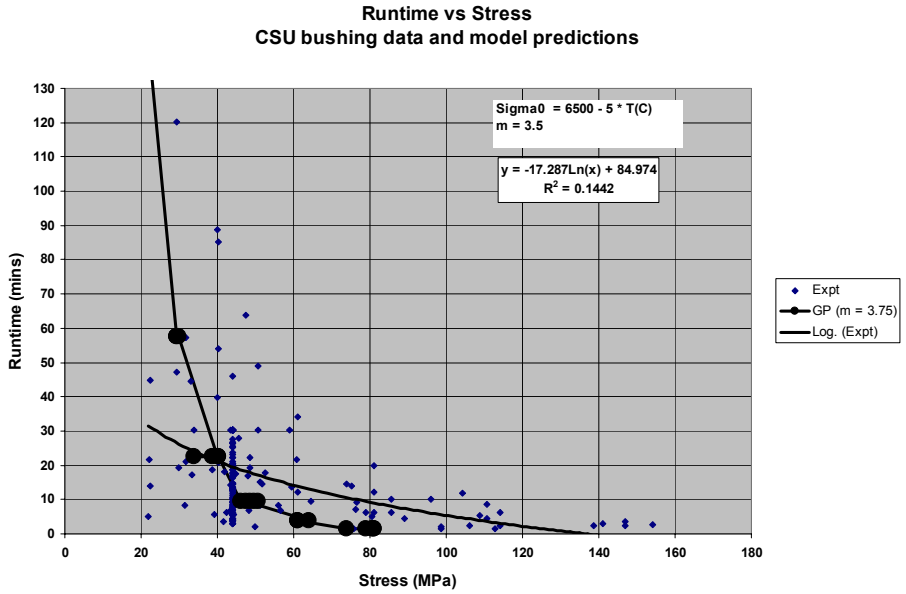
GLASSPRO
$y = 3E-06x + 0.3113$
$R^2 = 0.9897$

Sameer's calculations
$y = 1E-05x + 0.1161$
$R^2 = 1$

Validation - Run Time Prediction



Validation - Run Time Prediction



Summary

The model predicts run time

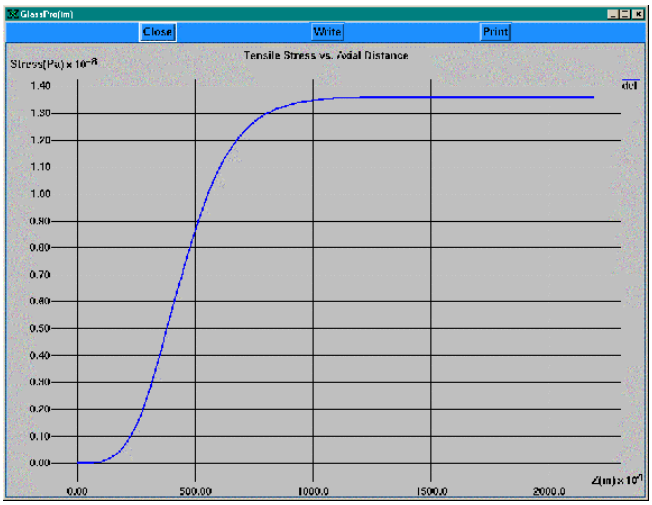
GEN1 data helped to set up procedures

GEN2 starts running next week to continue validation

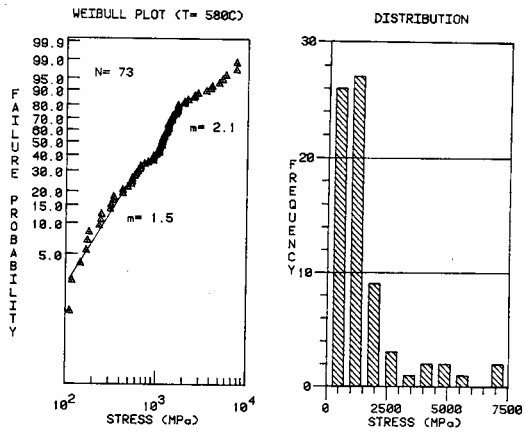
Our partners are on a fast "teach-'n-learn" track

The Pulling Force Imposes 100 MPa (14.5 kpsi) Stress onto a Glass Fiber

A numerical solution of mass, momentum and energy equations for a tip operating at 2062 F, mass flow rate = .8 10^{-5} kg/s, r_0 = 1. m m, r_L = 4 microns, Nu = 0.42, and V_L = 64 m/s.



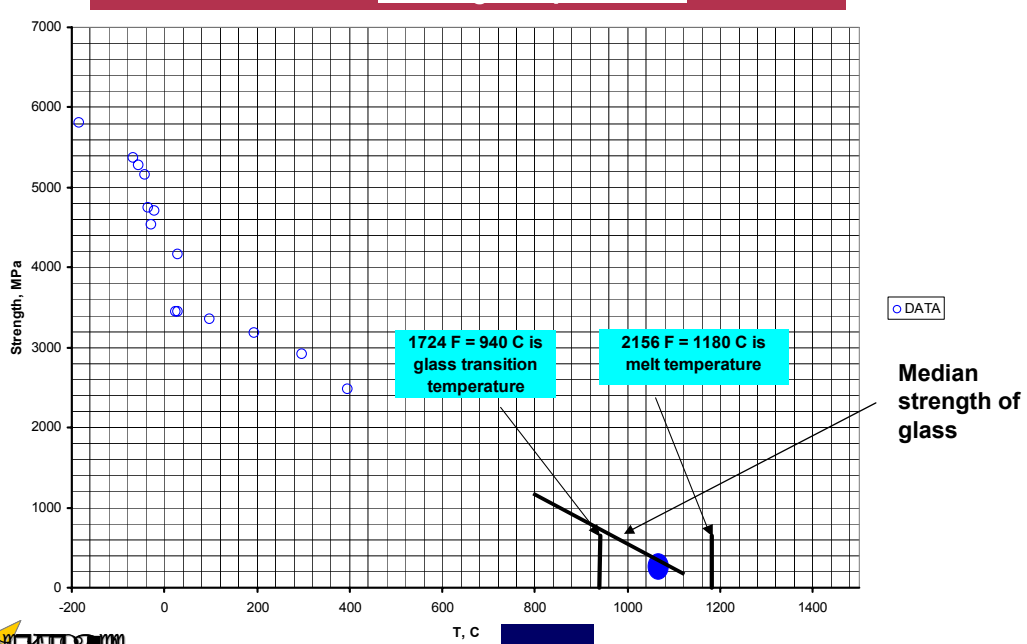
100 MPa Breaks ~2% of Soda-Lime Fibers just above their Glass Transition Temperature Range



Strength distribution for soda-lime glass at 580°C, η = 6.3 10^{10} poises

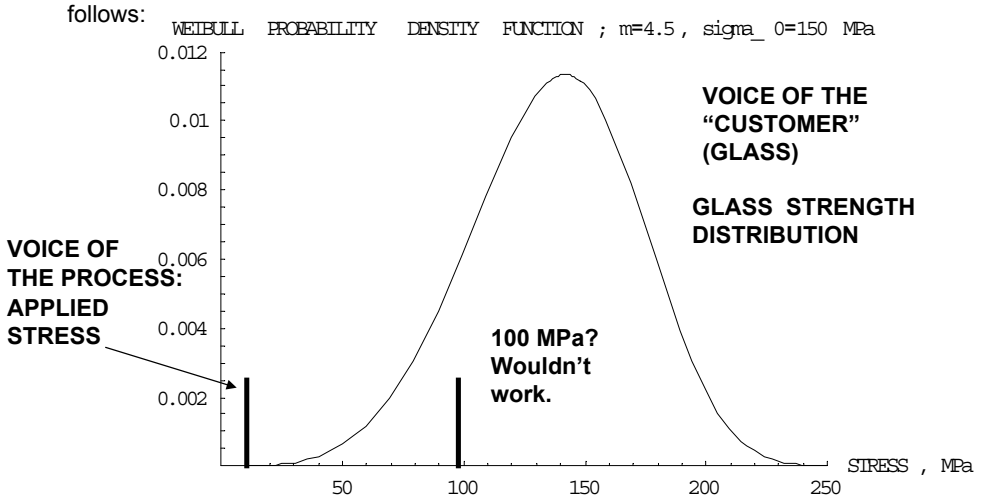
Note a very broad distribution, from 100 to 7,000 MPa.

How does 100 MPa compare with Strength of Glass Fiber at a Forming Temperature ?



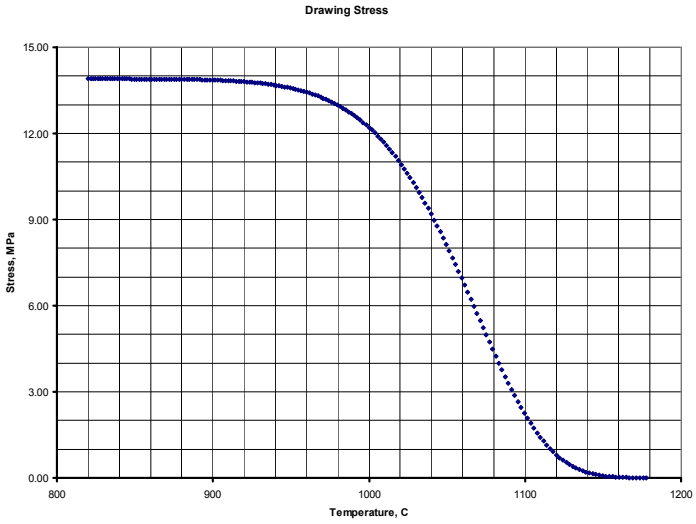
Fiber Drawing Process Design
(Voice of the "Customer" vs. Voice of the Process)

Suppose we work with Corning 7740 (Pyrex) fiber whose Weibull distribution function is as follows:

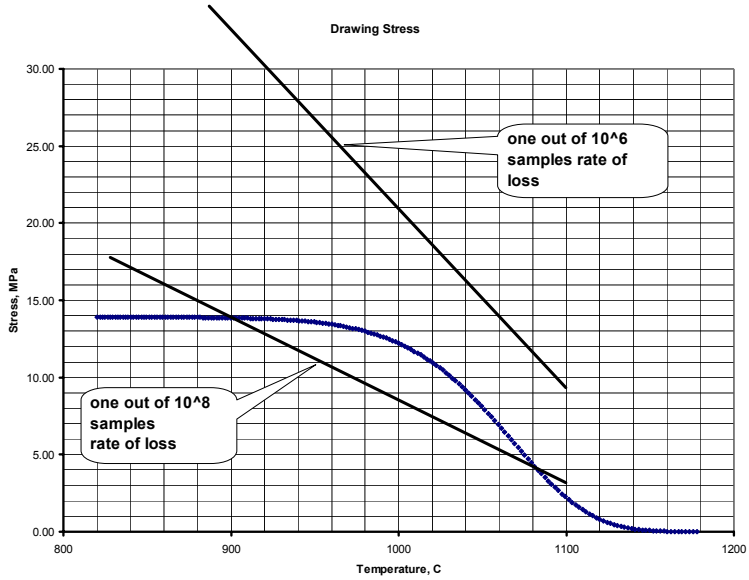


Fiber Drawing Process Design, cont'd

Decrease pulling force by raising melt *T* by 60 F



Predicting breaks - the approach



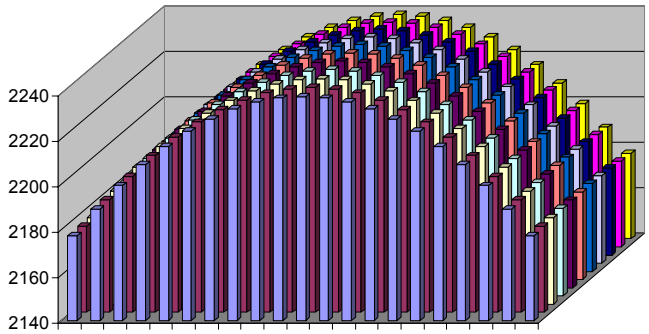
Excel:

Weibull(stress,alpha,beta, cumulative=true)

The process imposing 14 MPa stress breaks one out of 10^8 glass "parts". The process imposing ~30 MPa stress breaks one out of 10^6 glass "parts". . What is the "part's" length? - about four inches.

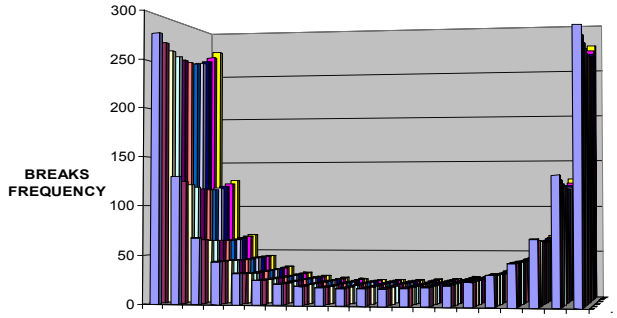
Predicting breaks - order of magnitude test

ASSUMED TEMPERATURE PROFILE OVER THE TIP PLATE IN A 231 TIP BUSHING



Predicting breaks - test, cont'd

FREQUENCY DISTRIBUTION OF BREAKS IN THE 231 TIP BUSHING

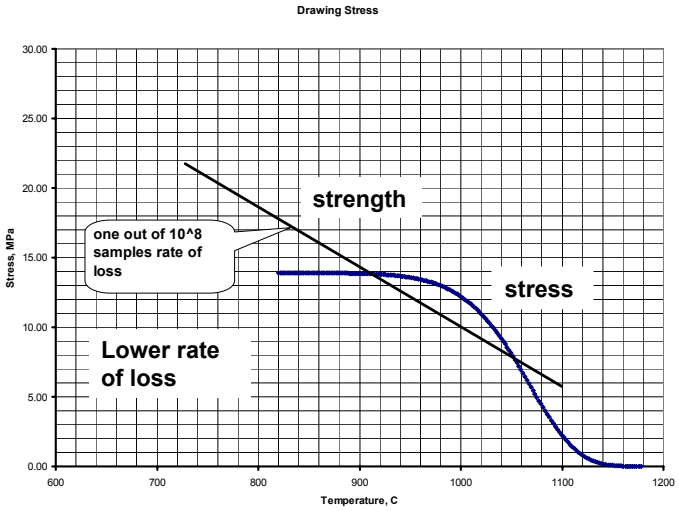


♦

14000 breaks per 2×10^{12} "parts" ♥ assuming the "part" length = 10 cm, one break per 14,300 km of filament pulled through 200 tips at 90 km/hr results in one break per 48 mins.

Conclusion: this process runs at one out of 10^8 samples rate of loss

But what is the definition of our "sample" the glass filament being continuous?



Below 800°C strength goes up and probability of failure drops. From 1100 down to 900°C the stress increases along the curve of one out of 10^8 "samples" rate of loss.

The temperature equal to 900 C is reached at 10.7 cm (~ four inches) below the tip - this is our "sample."

Our process breaks one sample out of 10^8 samples, whose cumulative length is 10.7E-2(m) * 10^8=1.07E7 m of filament that is being pulled at 49 m/s. Hence we have one break per 1E7m/(49m/s*3600s/hr)=56.7 hours.

Questions

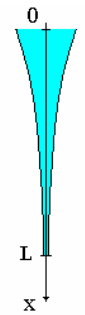
1. Why do we need to know the radius?
2. How do we control/monitor it?
3. Voice of the process! (Process data)

A numerical solution of mass, momentum and energy equations

T_0 = 1180°C, mass flow W = 1. 10^{-5} kg/s, V_0 = 1.23 10^{-3} m/s, $\langle V_L \rangle$ = 49.16 m/s, r_0 = 1. 10^{-3} m, r_L = 5 10^{-6} m, Nu = 0.42

Quasi-one-dimensional model

Conservation equations:



$$\frac{\partial S}{\partial t} + \frac{\partial (vS)}{\partial x} = 0, \qquad \text{- mass}$$

$$\frac{\partial}{\partial x}\left(\mu \frac{\partial v}{\partial x} S\right) = 0, \qquad \text{- momentum}$$

$$\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial x} = -\frac{1}{\tau_T}(T - T_a) \qquad \text{- energy}$$

Boundary conditions:

$$S = S_0, \quad v = v_0, \quad T = T_0, \quad x = 0$$

$$v = v_L, \quad x = L$$

where S is the jet cross section, v is the axial velocity

$\mu(T)$ is the viscosity, T and T_a are the temperature of glass and air

$\tau_T = \frac{c_p \rho S_0 v_0}{\pi k_a Nu}$ is the characteristic length that correlates with cone length

k is the thermal conductivity, Nu is the Nusselt number $= h\,D/k$

Effect of stress, temperature and filaments number - a semi-quantitative discussion

To recap:

The single-filament process building **14 MPa** pulling stress runs for 1E7m/(49m/s*3600s/hr) **~57 hours without a break**.

Now, suppose the process runs at **100 MPa** pulling stress as we had it in our earlier calculation.

Weibull (x = 100, alpha = 4.5, beta = 850, true) = 6.5E-5 → ~ 7 broken parts per 100000 good parts or ~one broken part per 15000 good parts

10.7E-2 (m) * $(6.5E\text{-}5)^{-1}$ (or 10.7E-2 (m)*15000) = 1646 m of filament that is being pulled at 49 m/s. Hence we have **one break** per 1646/49 = **33 seconds**

Increase in pulling stress by a factor of 7 will cut down the period of uninterrupted performance by a factor of 6,000! (In the exercise, doubling the stress reduces the period of uninterrupted performance by a factor of 20). We seem to have identified a "jugular."

A few "what if's":

Assume a uniform temperature:

A single filament runs for **56.7 hours**

A **200**-filament process will run for 56.7/200 = **17 minutes**

and a **5000** filament will run for 56.7/5000 = **40 seconds**.

This lets one appreciate the progress, particularly because the main barrier to scaling-up is temperature uniformity

In terms of attenuation ratio:

Go from the bore radius of 1 mm to a filament of 5 microns in radius, i.e. attenuation ratio of 40000, with breakage every half-a-minute

Go from the bore radius of 0.5 mm to a filament of 5 microns in radius, i.e. attenuation ratio of 10000, with breakage every 60 hrs.

In terms of temperature and viscosity:

100 MPa is in drawing a 6 micron radius filament from a 0.85 mm radius bore at 2156 F and viscosity of 1900 poises
14 MPa is in drawing a 7.4 micron radius filament from a 0.5 mm radius bore at 2415 F (!?) and viscosity of 150 poises viscosity - unrealistic because of oscillations.

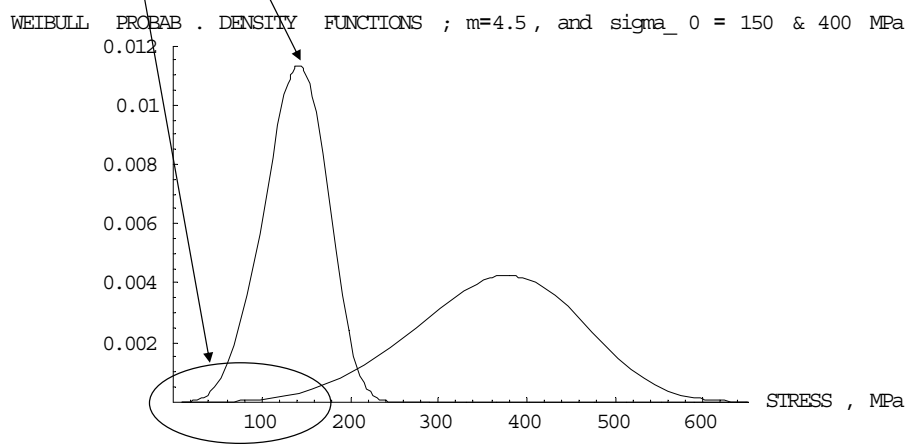
The analysis and optimization effort continue.

Fracture Statistics; Assessing the Industry-Wide Base Line

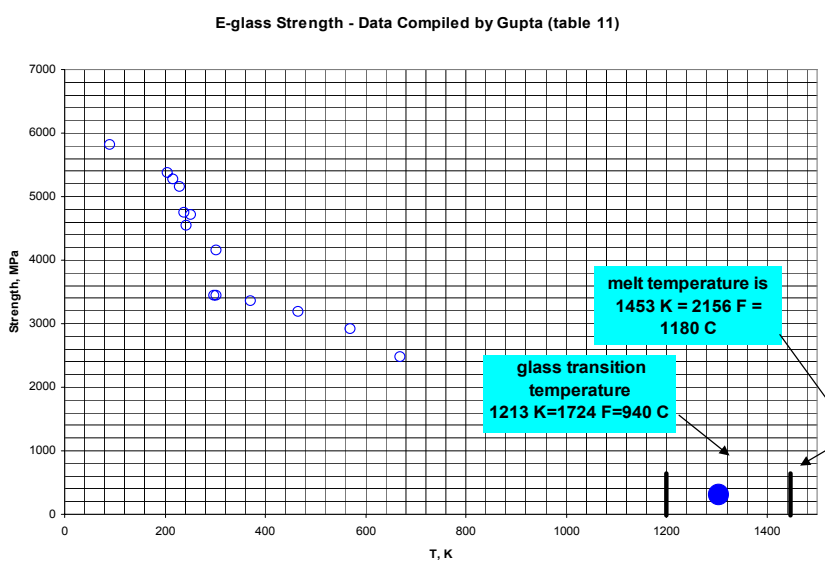
- A one break per hour implies one defective four-inch long "part" of glass filament per (5000 filaments * 100 km/hr *1000 m/km) = 5 10^8 meters = 5 10^9 "parts"
- *Assumption 1: All 5000 filaments are equally likely to break*
- The defect rate of one per 5 10^9, i.e. 2 10^{-10} requires the stress to be controlled within 6 MPa. In normal distribution terms this defect rate corresponds to z = 6.25, i.e. to a 7.75 sigma process. (For procedure click on View/Speaker_Notes)
- *Assumption 2: A single - "coldest" - filament is likely to break*
- The defect rate of one per 1 10^6, i.e. 1. 10^{-6} requires the stress to be controlled within 40 MPa. In normal distribution terms this defect rate corresponds to z = 4.75, i.e. to a 6.25 sigma process.

VOICE OF THE "CUSTOMER", cont'd. Changing *T* from 1140 to 1040°C.

Note that as median strength increases with lowered temperature by 250 MPa the lower strength tail shifts toward higher strength more sluggishly



How does 100 MPa compare with Strength of Glass Fiber at a Forming Temperature ?



In our calc'n in Fig. 18:

initial *T* = 1453 K (1180 C, 2156 F)

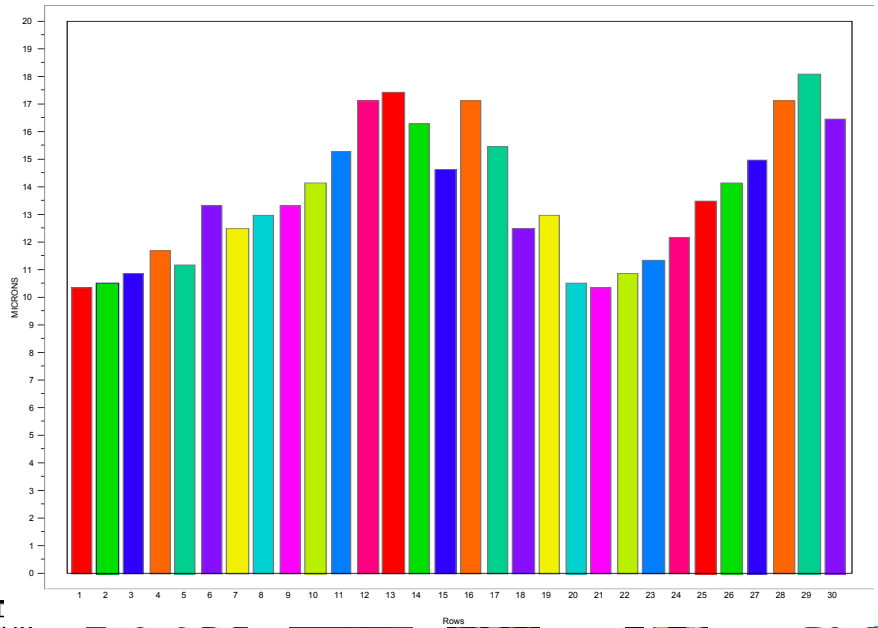
T_g =1130 to 1300 K (or ~850 to ~1030 C) per different estimates by Gupta.

Say, 1213 K (or 940 C, 1724 F)

(vs. 970 K, (or 700 C, 1300 F) for 3 K/min cooling rate)

Our fiber breakage tests were done at ~ 50 to 150 K above T_g i.e. about here

An e-mail from Cheryl Richards of PPG: SINGLE TIP BUSHING PULSATING 2475 F 5 SECOND TRAVERSE 1500 RPMS. MEASUREMENTS TAKEN LEFT TO RIGHT ON MANDREL.

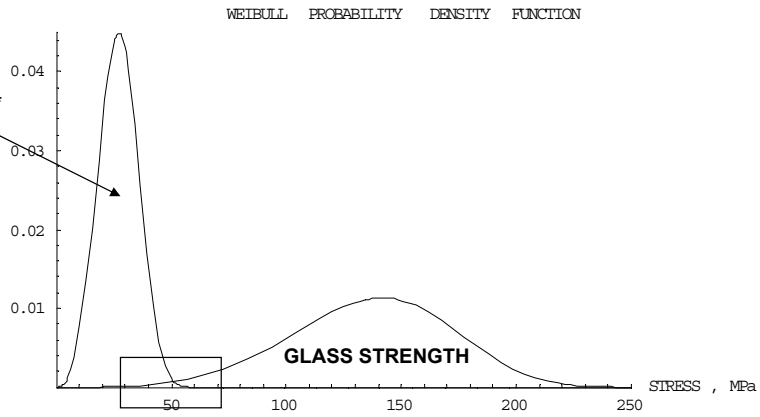


"VOICE" OF GLASS vs. VOICE OF THE PROCESS, cont'd

PULLING STRESS (=3*VISCOSITY*CROSS-SECTION* DRAW VELOCITY GRADIENT)

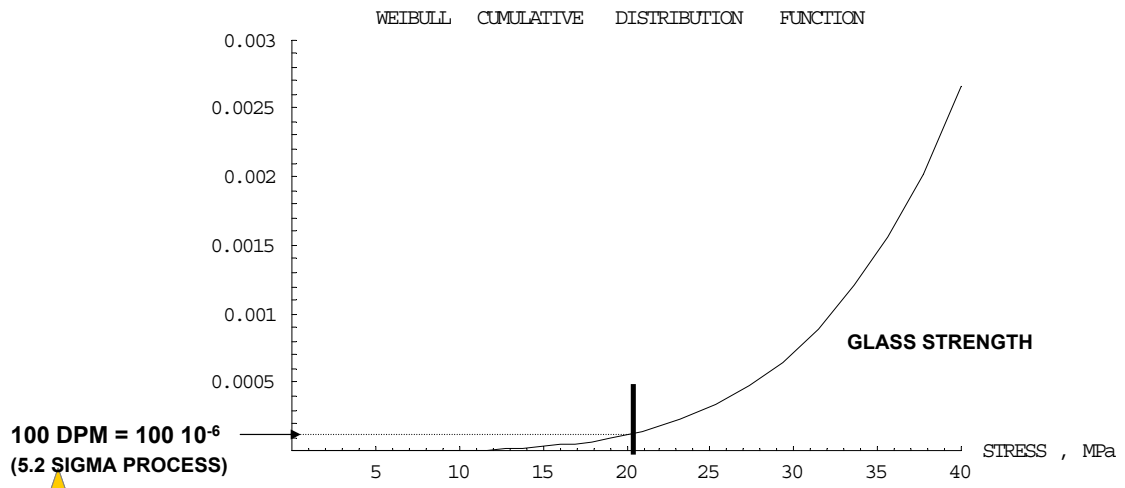
VISCOSITY = *F* (POWER DISTRIBUTION OVER BUSHING)

POWER DISTRIBUTION OVER BUSHING = CTQ (CRITICAL TO QUALITY PARAMETER)



Fracture Statistics - Getting Quantitative

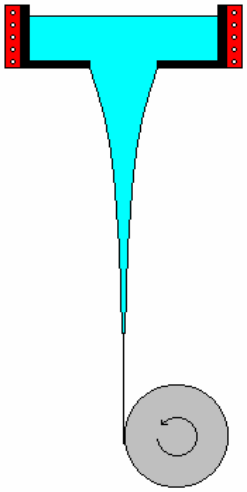
Let's look at the Cumulative Distribution Function (CDF) which shows the fraction of fibers broken at/below a given stress value (still m = 4.5 and σ_0 = 150 Mpa)

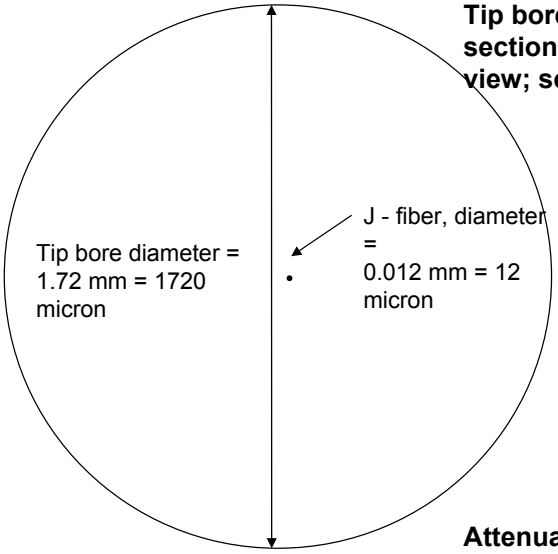


Conclusions

- A tough challenge
- complete a careful analysis of "giants and pygmies" ("critical few vs. noise")
- run further tests in production to validate findings
- current focus: *T* - Variation → diameter attenuation → stress increase → breakage

The Area of Stream "Collapses" into a Point



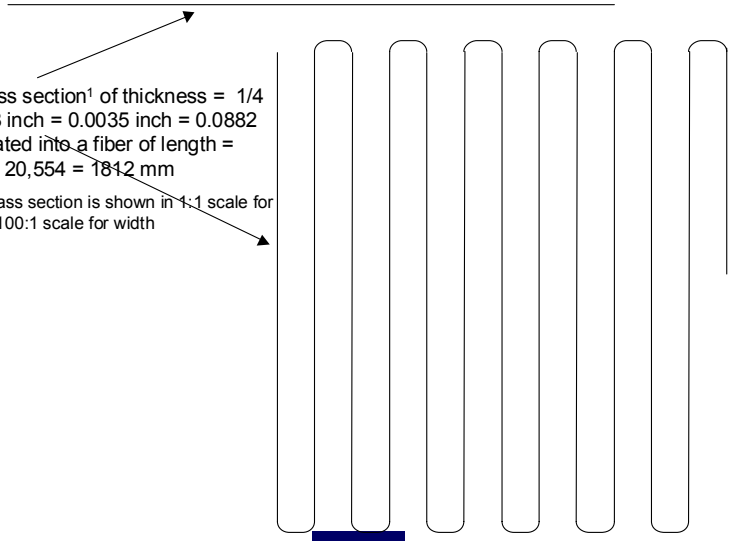


Tip bore/fiber cross-sections - bottom view; scale ~100:1

Attenuation: $1720^2/12^2 = 20{,}544$

A Paper Thin Slice of Glass Stream Elongates into Two Yards of Fiber

Tip bore and fiber - side views.



A molten glass section[1] of thickness = 1/4 point = 1/288 inch = 0.0035 inch = 0.0882 mm is elongated into a fiber of length = 0.0882 mm * 20,554 = 1812 mm

[1]The molten glass section is shown in 1:1 scale for thickness and 100:1 scale for width

Fiber Drawing Process Design - Order of Magnitude Analysis

Hagen-Poiseuille law for flow in a nozzle:

$$v_0 = (\rho g H + \sigma_0) R_0^{\,2} \Big/ \left(8 L_0 \eta_0 \left(1 + \frac{3\pi R_0}{8 L_0} \right) \right)$$

where ρ, g and H are the density, gravitational constant and total fluid height

$\rho g H$ = hydrostatic head

σ_0 is the pulling stress

R_0 and L_0 are the nozzle radius and depth

η_0 is the molten glass viscosity

$$\eta = \mathrm{Exp}[-\alpha(T - T_0)]$$

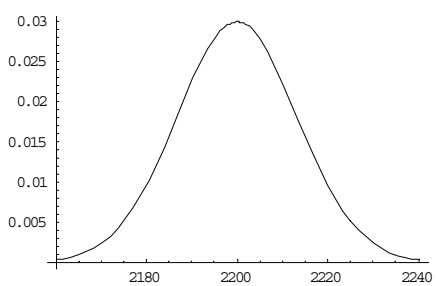
From continuity equation

$$S_L = S_0 \frac{v_0}{v_L}, \qquad r_L = r_0 \sqrt{\frac{v_0}{v_L}}$$

From known process variables and constants - T, R_0, L_0, etc. - and using Eqs. (1)-(3) we calculate resulting radius r_L

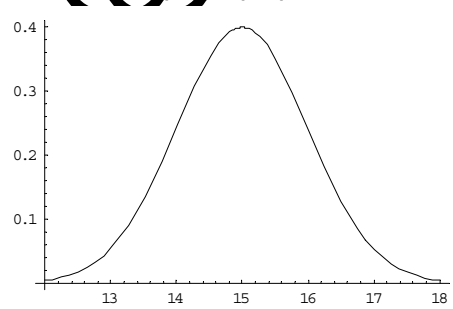
Fiber Drawing Process Design - Order of Magnitude Analysis, cont'd

In[5]:= Plot [redacted] 160, 2240 [redacted]



Out[5]= ..Graphics ...

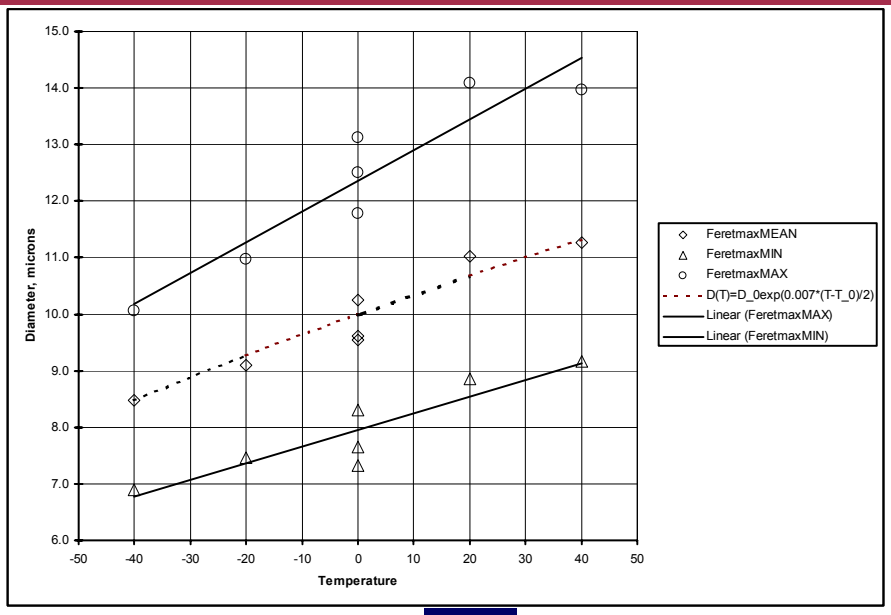
Plot [redacted] 2, 18. [redacted]



..Graphics ...

2160 to 2240°F variation of temperature over the bushing results in 12 - 18 micron variation of filament radius

MAX, MEAN, and MIN Filament Diameters in Seven Tests at Five Temperatures by Koewing, Love and Talsania, PPG



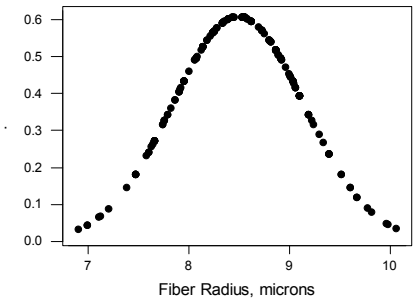
ANOVA: A Significant Effect on Mean Diameter Values

One-way Analysis of Variance

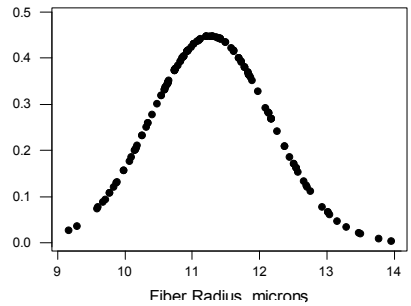
```
Analysis of Variance
Source      DF        SS        MS        F        P
Factor       6   872.852   145.475   198.54    0.000
Error     1049   768.622     0.733
Total     1055  1641.474
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  -------+---------+---------+---------
-40 F      188     8.486     0.628   (*)
-20 F      176     9.090     0.795        (*)
NOM1       183     9.550     0.825           (*-)
NOM2       115    10.256     0.745                  (-*)
NOM3       169     9.614     1.077            (*)
+20 F       88    11.022     0.888                         (-*-)
+40 F      137    11.266     0.992                            (-*)
                                   -------+---------+---------+---------
Pooled StDev =    0.856                 9.0       10.0      11.0
```

Filament Diameter Distributions

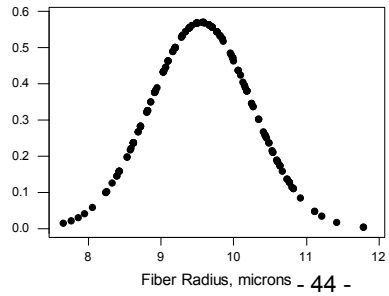
Probability Density Function, -40 F



Probability Density Function, +40 F

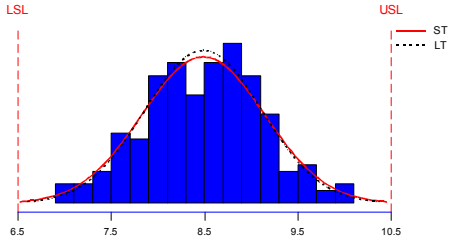


Probability Density Function, NOM 1



4.5 sigma process, 6 sigma process

Process Capability Analysis for -40 F

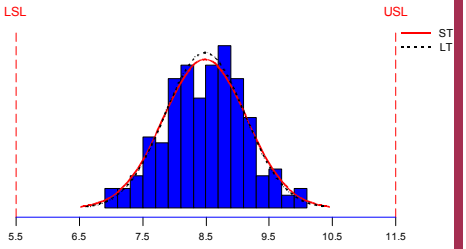


Process Data	
USL	10.5000
Target	*
LSL	6.5000
Mean	8.4857
Sample N	188
StDev (ST)	0.656692
StDev (LT)	0.629119

Potential (ST) Capability	
Cp	1.02
CPU	1.02
CPL	1.01
Cpk	1.01
Cpm	*

Overall (LT) Capability		Observed Performance		Expected ST Performance		Expected LT Performance	
Pp	1.06	PPM < LSL	0.00	PPM < LSL	1247.86	PPM < LSL	798.67
PPU	1.07	PPM > USL	0.00	PPM > USL	1080.10	PPM > USL	683.07
PPL	1.05	PPM Total	0.00	PPM Total	2327.96	PPM Total	1481.75
Ppk	1.05						

Process Capability Analysis for -40 F



Process Data	
USL	11.5000
Target	*
LSL	5.5000
Mean	8.4857
Sample N	188
StDev (ST)	0.656692
StDev (LT)	0.629119

Potential (ST) Capability	
Cp	1.52
CPU	1.53
CPL	1.52
Cpk	1.52
Cpm	*

Overall (LT) Capability		Observed Performance		Expected ST Performance		Expected LT Performance	
Pp	1.59	PPM < LSL	0.00	PPM < LSL	2.73	PPM < LSL	1.04
PPU	1.60	PPM > USL	0.00	PPM > USL	2.22	PPM > USL	0.83
PPL	1.58	PPM Total	0.00	PPM Total	4.94	PPM Total	1.87
Ppk	1.58						

Development of Process Optimization Strategies, Models, and Chemical Databases for On-Line Coating of Float Glass

Jill Troup
PPG Industries, Inc.

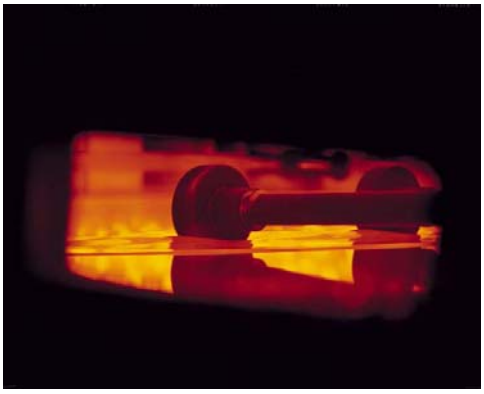
Mark D. Allendorf
Sandia National Laboratories
Livermore, California

Funding from the U.S. DOE/Office of Industrial Technologies
Glass Industry of the Future Team

Program review meeting
Golden, CO
September 8-9, 2003

Atmospheric Pressure Chemical Vapor Deposition (APCVD) In The Glass Industry

- **Approximately 110 million ft^2/year of float glass are coated using APCVD.**
- **Primary uses of APCVD-coated glass:**
  - **low-emissivity and solar-control windows**
  - **solar cells**
  - **computer screens**
  - **automotive glass**
  - **xerography glass**
- **The dual pane window market for APCVD coated glass is nearly $600 million. This is only a fraction of the value of the final product considering the framing.**



Molten glass on on a float line prior to APCVD

Optimizing an APCVD process presents numerous challenges

- Low deposition efficiencies lead to
  - wasted chemical
  - high costs associated with purchase, waste treatment, and disposal of the unconverted chemical ($23 million/year)
  - doubling reaction efficiency from ~11% to ~22% would halve this cost
- Low process yields due to coating defects result in unproductive energy usage for re-melting the glass
  - 4.5×10^{10} BTU per year are used to remelt glass due to coating defects
  - reducing the fraction of coating defects from 15% to 5% would reduce the amount of unproductive energy usage by ~3×10^{10} BTU per year
- Difficulty in scaling new APCVD processes from laboratory to manufacturing facility requires extensive investment of time and money to determine the correct parameters for the manufacturing facility

Project Objectives

- Identify modified/new APCVD coater designs that double the efficiency of reactant utilization Full-scale tests planned for this year
- Develop validated process models and use them to reduce coating defects (non-uniform coating thickness, haze, chlorine pitting, etc.) Model developed; validation by pilot-scale experiments nearly complete
- Generate thermodynamic and kinetic data for chemical precursors needed for modeling Thermodynamics complete
- Provide enhanced understanding of underlying chemistry and physics of APCVD Several published papers with others planned

Project Tasks

- **Task 1: Deposition Mechanism Development (SNL)**
  - Thermodynamic Data
  - Gas-Phase Chemistry
  - Surface Mechanism
  - Defect Formation
- **Task 2: Reaction Rate Measurements (SNL, TNO)**
  - Gas Phase Reactions
  - Surface Reactions
- **Task 3: On-line Coater Effluent Analysis (SNL, PPG)**
- **Task 4: CFD Modeling of Coating Reactors (SNL, PPG)**
- **Task 5: Deposition Experiments (SNL, PPG)**
  - Model Validation
  - Defect Analysis
- **Task 6: Validation of Optimization Strategies (SNL, PPG)**

Tin Oxide Deposition Kinetics and Model Development

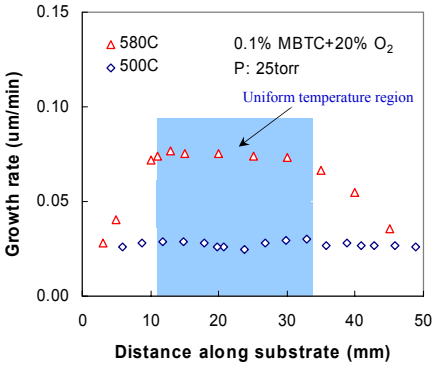
(Tasks 1, 2, & 5)

Objectives:

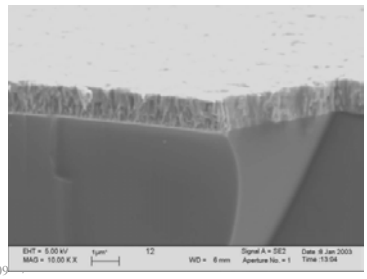
- **Develop validated process model**
- **Generate thermodynamic and kinetic data for chemical precursors needed for modeling**
- **Provide enhanced understanding of underlying chemistry and physics of APCVD**

New Sandia reactor provides an easily modeled environment with quantitative process diagnostics

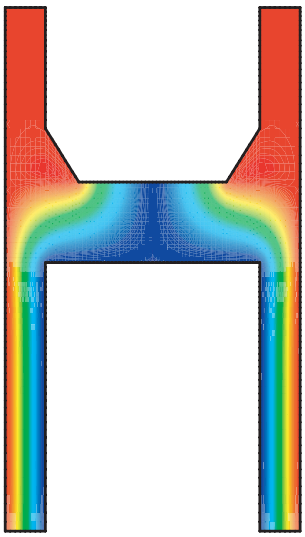
- 1-D flow environment simplifies modeling of complex chemistry
- Flow environment is well behaved
- Deposition rates modeled by the (1-D) SPIN code



Temperature: ± 8 K
Growth rate variation:
- 500 ° C: ± 5.8%
- 580 ° C: ± 3.8%



Streamlines



Flowrate = 5 slpm
Pressure = 100 Torr
Substrate Temp. = 1073 K

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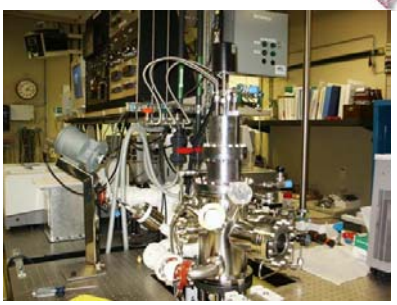
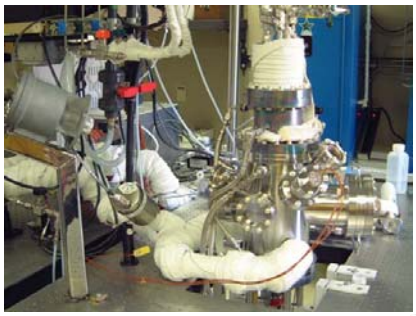
Deposition rates obtained in a stagnation flow reactor (SFR) provide data needed for process modeling

- **Extensive matrix of tin oxide deposition experiments completed this year, including:**
  - 300 – 700 °C
  - 15 – 100 Torr
  - 2,500 – 10,000 sccm total flow
  - MBTC mole fraction 0.05 – 0.5%
  - H_2O mole fraction 0 – 2.0%
- Observations are consistent with PPG pilot-scale experiments
- Results being distributed to industry via publication





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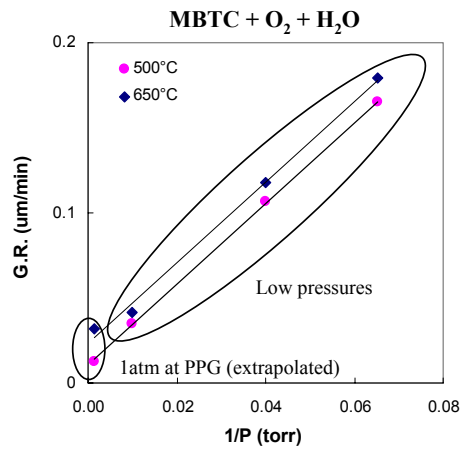
Low-pressure results obtained in the SFR agree with pilot-scale when extrapolated to 1 atm

- Data in stagnation-flow reactor were obtained at 15 – 100 Torr
- Pilot-scale coater operates at 1 atm, as do typical on-line coating operations
- Detailed kinetics obtained in SFR must therefore be extrapolated to higher pressures and reactant concentrations
- Results are in very good agreement when:
  - SFR results extrapolated to 1 atm
  - Pilot-scale extrapolated to low MBTC concentrations



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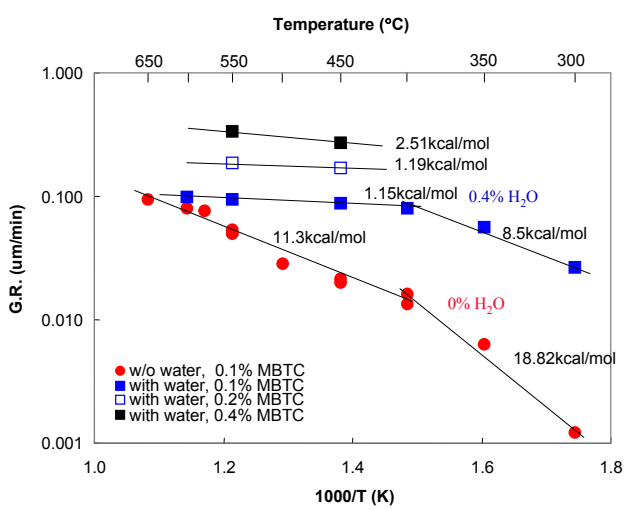
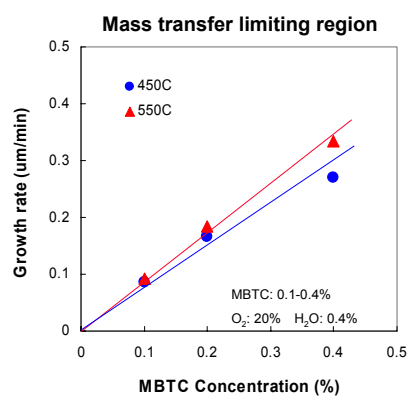
Addition of H_2O to MBTC/O_2 produces a major increase in the tin oxide deposition rate





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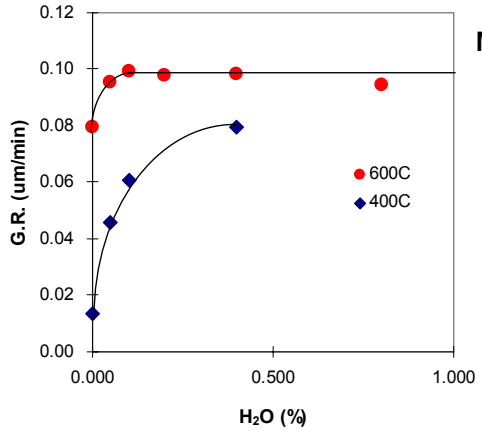
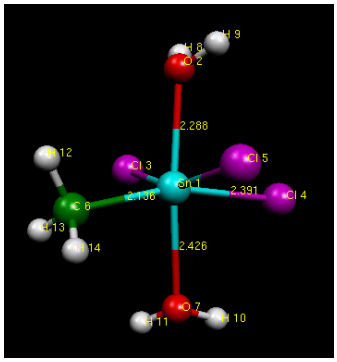
Effect of H_2O concentration on growth rate



MBTC:0.1%, O_2:20%

$Cl_3Sn(CH_3)(H_2O)_2$



T ≤ 400 °C (no gas-phase MBTC pyrolysis):

- **H_2O dramatically increases deposition rate (~3X with 0.1% H_2O)**

T = 600 ° C:

- **Growth saturates quickly (~1:1 MBTC/H_2O)**

Possible mechanisms:

- **MBTC + H_2O complexes**

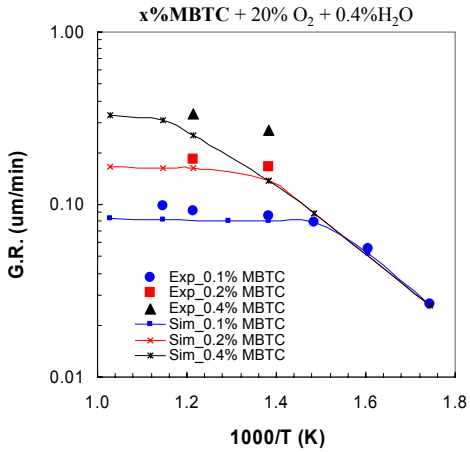
  $Cl_3Sn(CH_3) + 2\ H_2O \rightarrow Cl_3Sn(CH_3)(H_2O)_2\ \Delta H_{reac} = -16.0$ kcal/mol

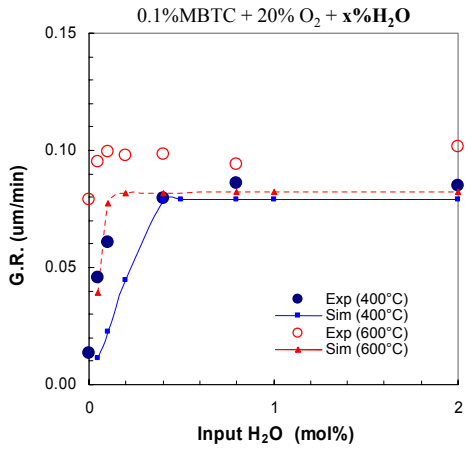
- **H_2O surface adsorption**

Global deposition mechanism by surface reaction for MBTC + O_2 + H_2O

Adsorption: $C_4H_9SnCl_3 + OS(s) \rightarrow C_4H_9SnCl_3(surf)$

Surface Reaction: $C_4H_9SnCl_3(s) + ½\ O_2 + H_2O \rightarrow SnO_2(b) + 2C_2H_4 + 3HCl + O(s)$





CFD Modeling of Pilot-Scale Coater Deposition Experiments (Task 4)

Objective:

Develop validated process model effective for realistic coater designs

Task 4 FY03 accomplishments

- **Modeled PPG pilot-scale coating results to obtain:**
  - **Kinetics for MBTC + O_2**
  - **Kinetics for MBTC + O_2 + H_2O**
- **Used model to predict sensitivity of reactant consumption to process variables:**
  - **Total flow rate**
  - **Coater top-wall temperature**
  - **Precursor concentrations**
  - **Inlet/outlet spacing**
  - **Glass-coater distance**
  - **Glass temperature**

Generalized process optimization strategies were developed as a result of this modeling (Task 6)

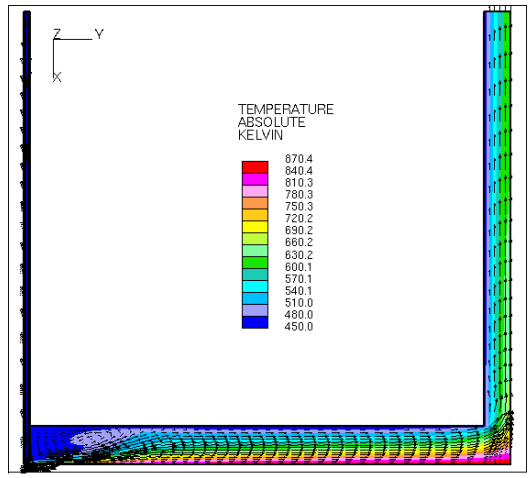
- **Simulated Sandia SFR reactor to guide choice of experimental parameters**
- **Compared full CFD predictions with lower-dimensional codes**

Star-CD kinetics capability for CFD with detailed chemistry

- **2- and 3-D modeling of flow fields**
- **Chemkin interface for incorporating detailed chemical models with multi-component transport**
  - **Homogeneous**
  - **Heterogeneous**
- **Advanced methodologies for solving stiff equations**
  - **Convergence and numerical stability challenging**
- **Use validated models to predict the effects of additives on growth chemistry**

Velocity vectors and thermal profile for pilot coater at initial conditions:

T_{inlet} = 450 K, $T_{substrate}$ = 870 K, $V_{substrate}$ = 0.1016 m/s, F_{inlet} = 85 slpm



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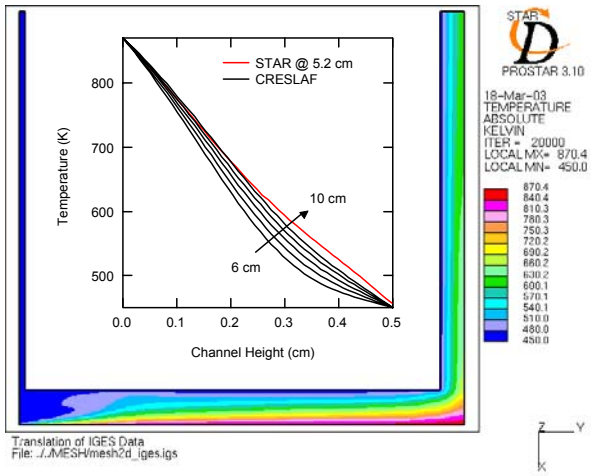
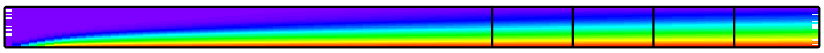
Lower-dimensional models can provide valuable insight into the coating process



STAR-CD 2D CFD model

- **2D boundary layer code adequately predicts behavior downstream of entrance**
- **1D stagnation-flow code may be adequate to predict deposition at the entrance**
- **<u>Conclusion</u>: lower-D codes, which are much faster and easier to use, will be valuable for modeling on-line deposition**

CRESLAF 2D boundary-layer model 6 cm → 10 cm



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Pilot-scale Deposition Measurements at PPG Glass Technology Center (Task 5)

Objective:

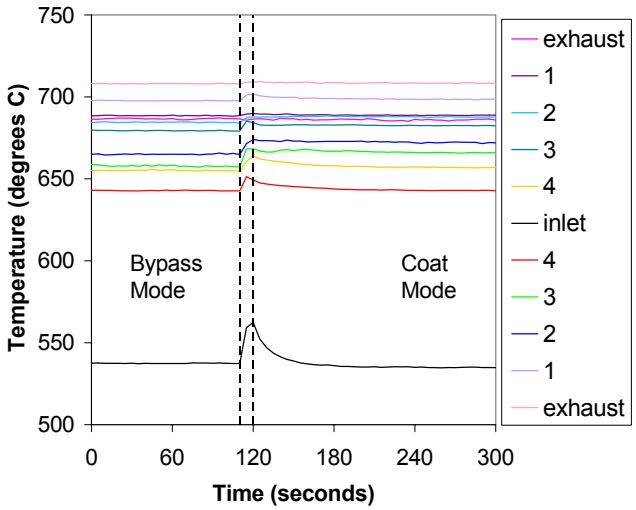
Provide data for model validation under simulated manufacturing conditions

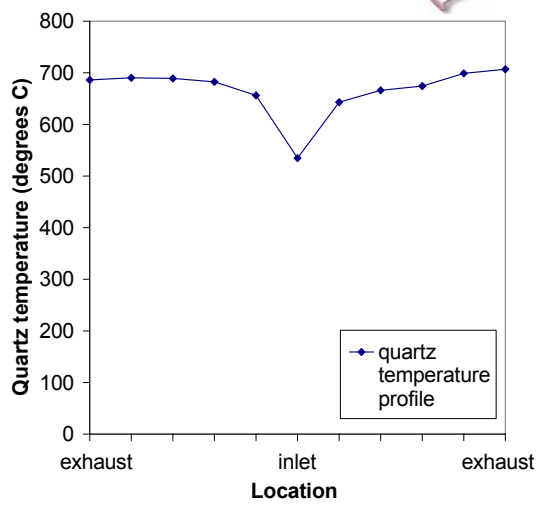
PPG's pilot-scale coater provides a realistic environment for model testing and validation

- **Pilot scale coater has been modified to coat stationary substrates**
  - **Allows steady-state deposition and analysis of exhaust gases**
  - **Stationary heater installed directly under coater face**
  - **New coater face for heat transfer fluid channels for temperature control**
  - **Heat transfer fluid circulation system installed**

Side view of pilot-scale coater interior

Stationary substrate characterization

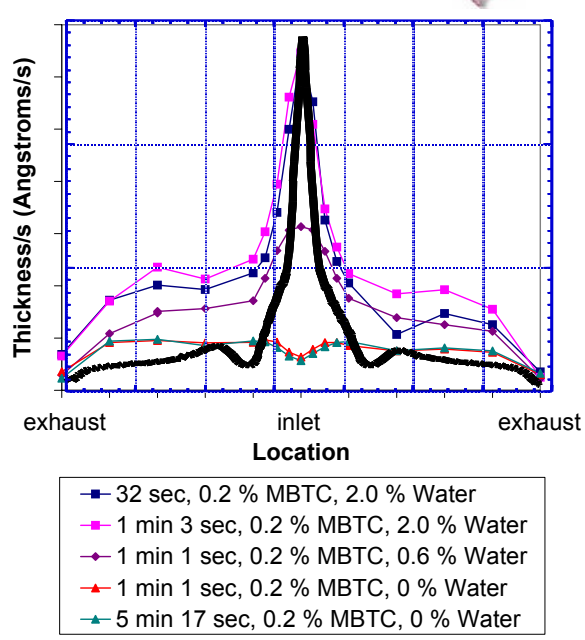




- **Switch to coat mode results in a large (~25-50ºC) temporary (~1 min) temperature increase under the inlet**
- **Substrate temperature is lower under inlet due to flow**

Initial experiments provide dramatic evidence of the effect of H_2O on growth

- **Change in deposition profile when H_2O is added confirms change in deposition mechanism**
- **Data indicate that MBTC/O_2 deposition involves a thermally driven (gas-phase?) reaction**
- **Addition of H_2O initiates either very fast gas-phase chemistry or fast (perhaps mass-transport-limited) surface reactions**
- **Transient temperature underneath inlet has a negligible effect on growth rate and profile**
- **Predicted profile shape using CFD model based on SNL data is in good agreement**



Stationary substrate experiments in progress

- Experiment variables
  - MBTC Concentration
  - H_2O Concentration
  - Glass Temperature
  - Coater Height
  - Inlet Gas Temperature
  - Oxygen Concentration
- Experimental results and CFD modeling results will be compared
- Experimental results will be analyzed to determine the interactions among process variables

Optimization Strategies (Task 6)

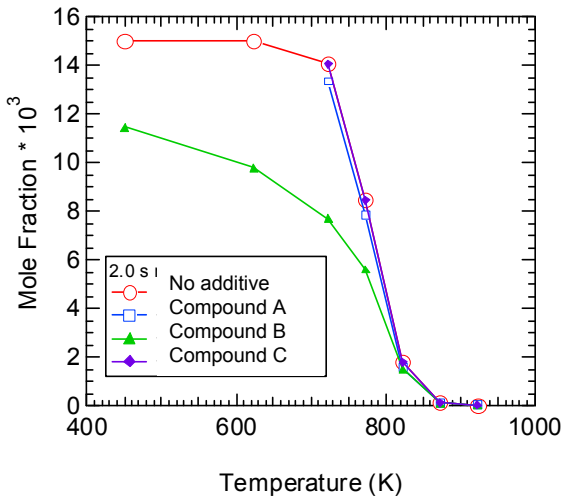
Objectives:

- Identify modified/new APCVD coater designs that double the efficiency of reactant utilization
- Develop strategies to reduce coating defects, particularly non-uniform coating thickness

We used our model to explore the use of additives to accelerate MBTC gas-phase decomposition

- Additives can increase MBTC consumption by opening new decomposition pathways
- Regimes in which they are effective may be temperature dependent
- Stability in transfer lines and premixing are important issues
- SNL is filing a patent disclosure

- We are requesting additional funds from OIT to pursue this aspect of the project



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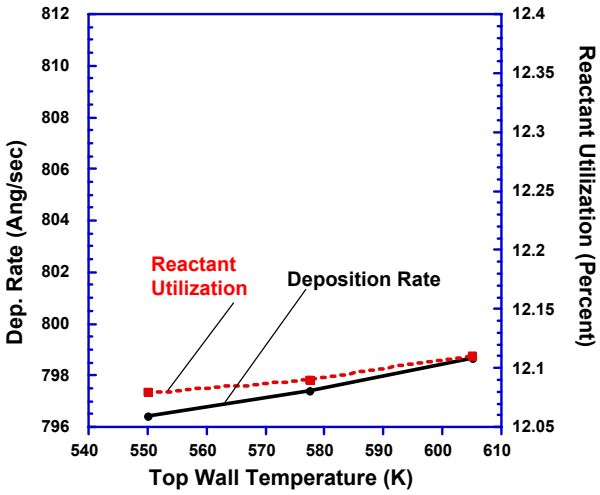
Variations in process variables provide insight into the source of thickness-related defects

- Effect on growth rate predicted by Sandia deposition model
- Deposition rates are insensitive to these variables:
  - Flow rate variations of ± 5%
  - Inlet temperature variations of ± 20 °C
  - Top-wall temperature excursions of ± 30 °C



Effect of Coater Top Wall Temperature On Deposition Rate and Utilization

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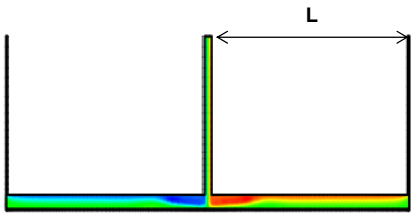
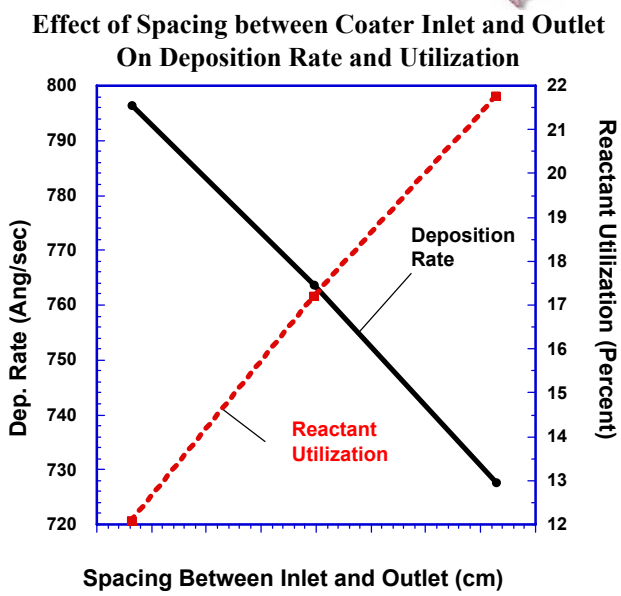
Increasing the distance between the coater inlet & outlets increases the utilization of the reactant gas (MBTC)

- Distance between coater inlet and outlet increased by 50% and 100%.
- Increasing coater inlet-to-outlet spacing increases reactant utilization from 12% to 22%





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Full scale plant trials planned for this year

- Full scale plant trials planned for late September / early October
- Experimental Variables
  - Coater geometry
  - Water concentration

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Significance to glass industry

- Optimization strategies will be tested on a full-scale manufacturing line
- MBTC is a commonly used precursor in flat- and container-glass production
  - Film growth models developed here can easily be extended to other manufacturing processes using this precursor
  - Models are sufficiently robust to cover a wide range of process conditions
- Flow modeling demonstrates that useful insight can be obtained without the need for full-scale CFD.
  - Process engineers using cost-effective, lower-dimensional modeling software can identify strategies to improve efficiency; full-scale CFD model is probably not necessary in most cases
- The use of additives to accelerate conversion and growth rates can be extended across the industry
  - Additional experiments still required, but concept has commercialization potential and is being explored by SNL and PPG

What's up for FY04 (final project year)

- Model enhancements and improvements:
  - Complete validated model of SnO_2 deposition from MBTC/O_2/H_2O
  - Complete analysis of MBTC gas-phase kinetics
- Stagnation-flow reactor experiments (at Sandia)
  - Evaluate effects of additives (funds requested from OIT)
- Process optimization strategies (at PPG)
  - Pilot-scale testing with GC monitoring
  - Field tests of optimization strategies
  - Evaluate effects of additives (cost sharing by PPG)
- Final report

Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulate Emissions and Crown Refractory Corrosion in Glass Melting Furnaces

Linda G. Blevins, Alejandro Molina, Shane M. Sickafoose, and Douglas D. Scott
Sandia National Laboratories
Livermore, CA

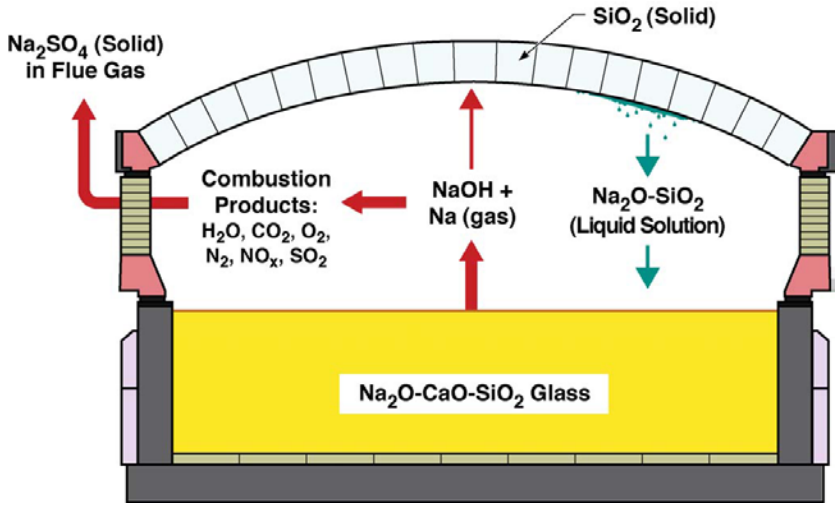
Peter M. Walsh
University of Alabama Birmingham
Birmingham, AL

John W. Neufeld
Gallo Glass Company
Modesto, CA

DOE/OIT Glass Industry Project Review
September 2003

Technical Needs

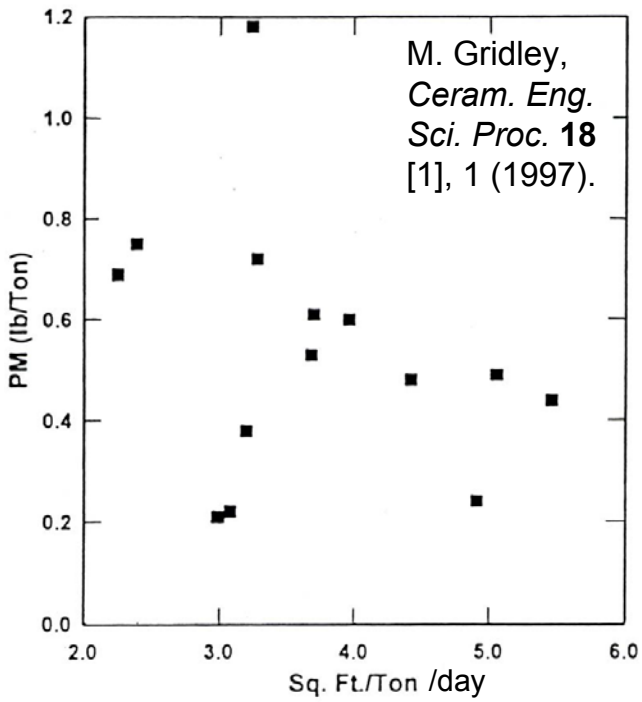
- Control particulate matter emissions, from both volatilization and batch carryover.
- Minimize rates of superstructure and crown corrosion.



Particulate Matter Emissions Highly Variable

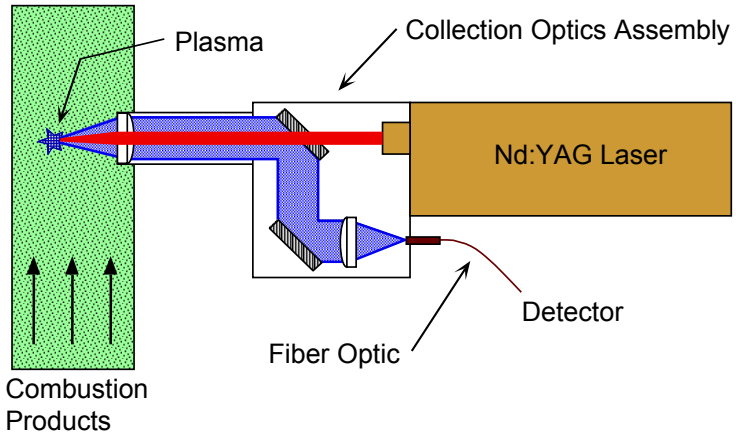
Even disregarding the outlier at the top of the figure, there is still a factor of 4 difference between the best performing and least well performing furnaces.

There are evidently design or operational influences on volatilization that are not well understood.



Laser-Induced Breakdown Spectrometry (LIBS)

- **Elemental signature**
- ***In-situ* measurement**
- **Rapid time response**
- **Transportable**

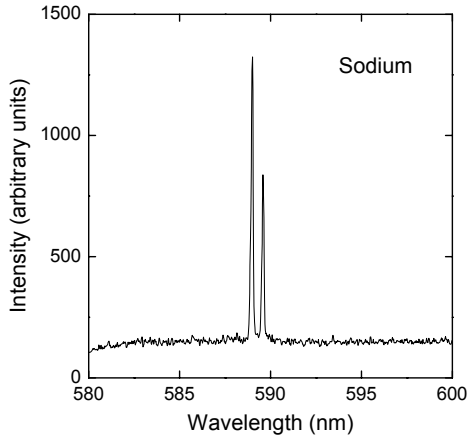


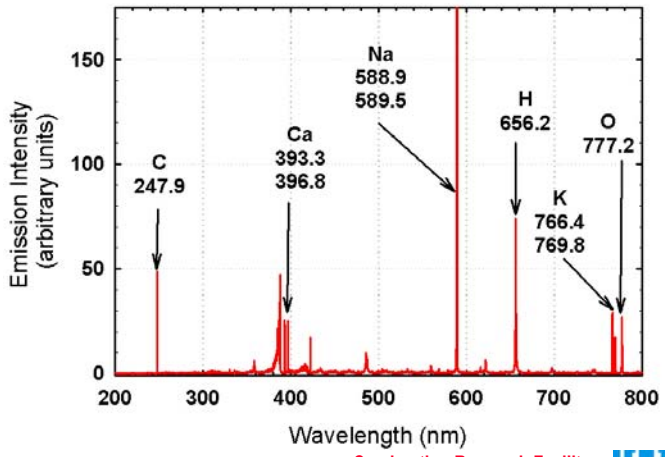
Methods

- 5 Hz LIBS with 2 spectrometers
  - Linear
  - Echelle
- Gas analyzer for NO, SO_2, and CO, and O_2
  - O2 lesson learned
- Thermocouple for gas temperature
- Scanned printouts from plant

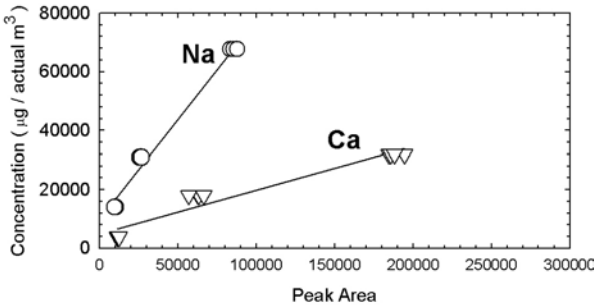
Two LIBS detection schemes

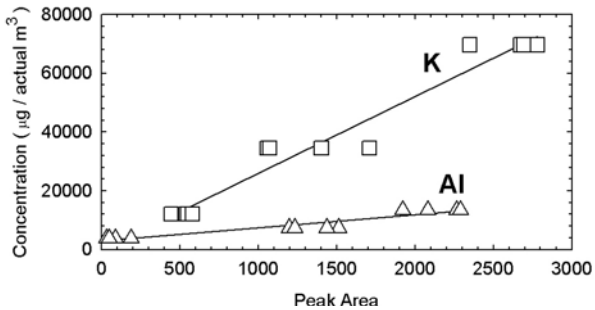
- Linear spectrometer
  - Single shots at 5 Hz
  - Narrow spectral windows
    - 20 nm at 0.05 nm resolution
  - Continuous data collection alternating between Ca & Al, Si & Mg, Na, and K
- Echelle spectrometer
  - 1600, 800, or 500 shot averages
  - Broadband
    - 300 nm – 900 nm
    - Resolution 0.1 nm at 400 nm
  - Multiple elements





LIBS is calibrated in the laboratory

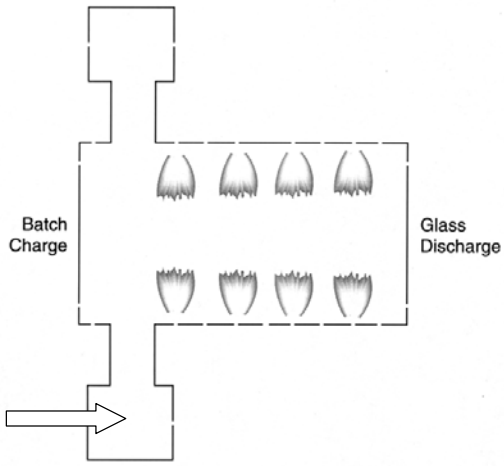




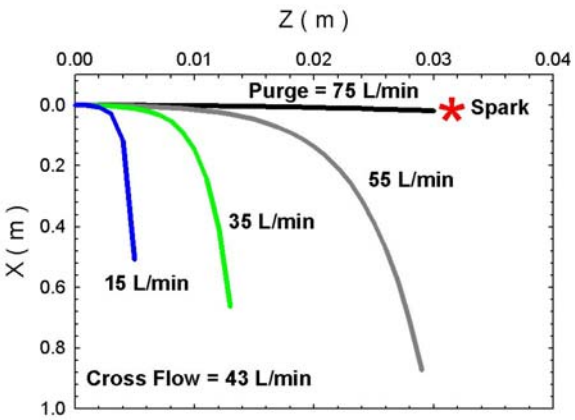
LIBS has been applied in two areas of a container glass furnace

- **Exhaust duct**
  - **Dilution ~3.5**
  - **Low temperature**
    - **620 K (650 º F)**
  - **High velocity**
    - **29 m/s (95 ft/s)**
- **Vertical flue**
  - **No dilution**
  - **High temperature**
    - **1450 K (2150 º F)**
  - **Low velocity**
    - **0.5 m/s (1.6 ft/s)**

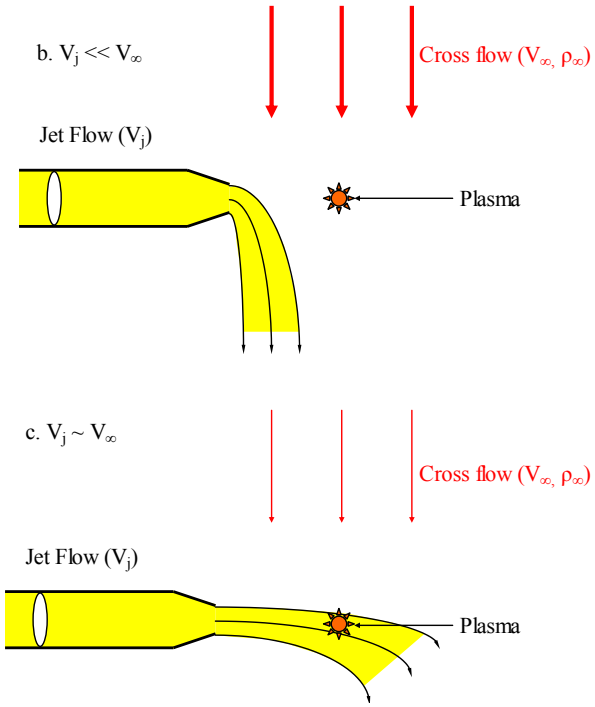
Gallo Glass Company
Tank #1



Purge flow matters in the vertical flue



$$\frac{x}{D} = \frac{0.19}{V_e^{\,2}}\left(\cosh\left(\frac{V_e^2}{0.19D}\right) - 1\right)$$

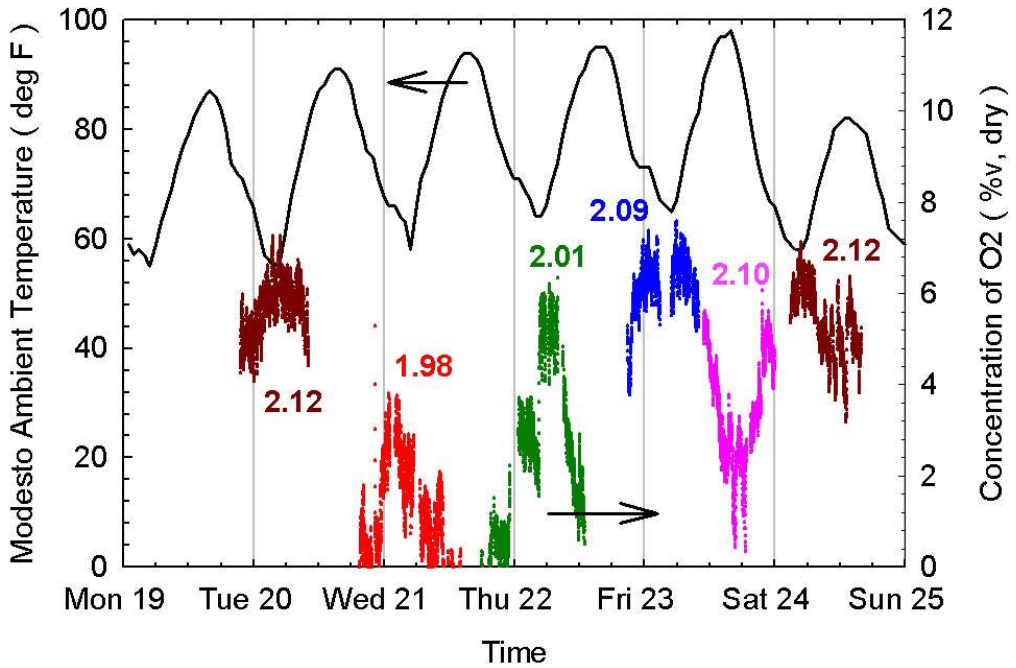


Field Tests to Date

Date	Pull Rate (t/day)	O/G	Heat Release Rate (MW)	% Boost	
Dec 2001	430	2.16	15.2	14.6	**Exhaust**
June 2002	336 435	2.12	12.0 14.9	13.2	**Vertical Flue**
May 2003	322 405	1.98 - 2.18	11.3 - 13.9	13.7 - 15.6	**Vertical Flue**

(40-50 MMBtu/hr)

Ambient temperature affects apparent O/G



May 2003

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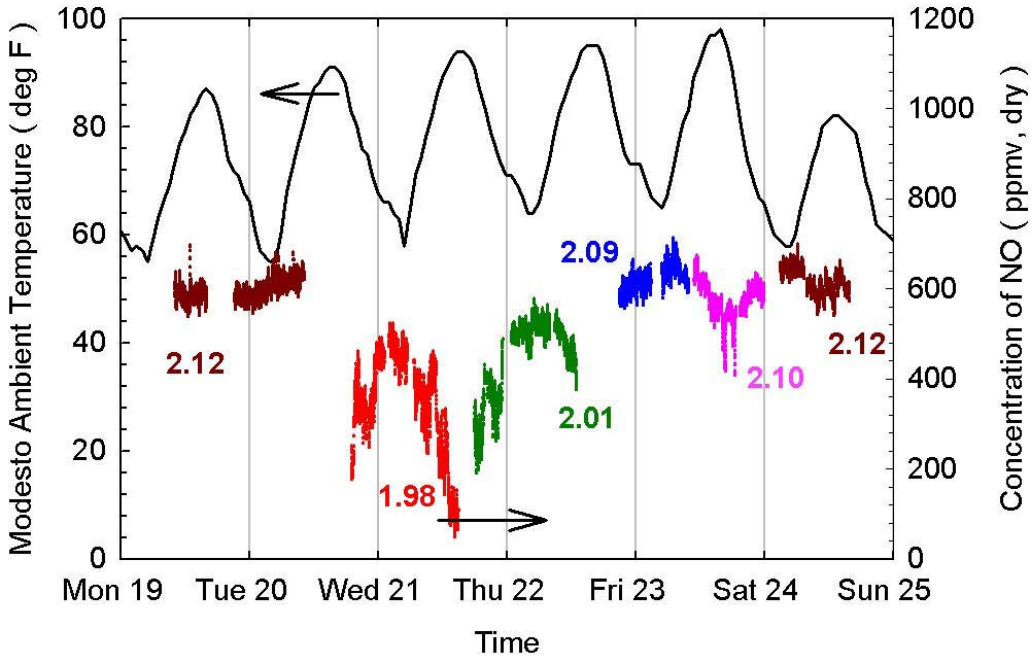
NO responds in kind



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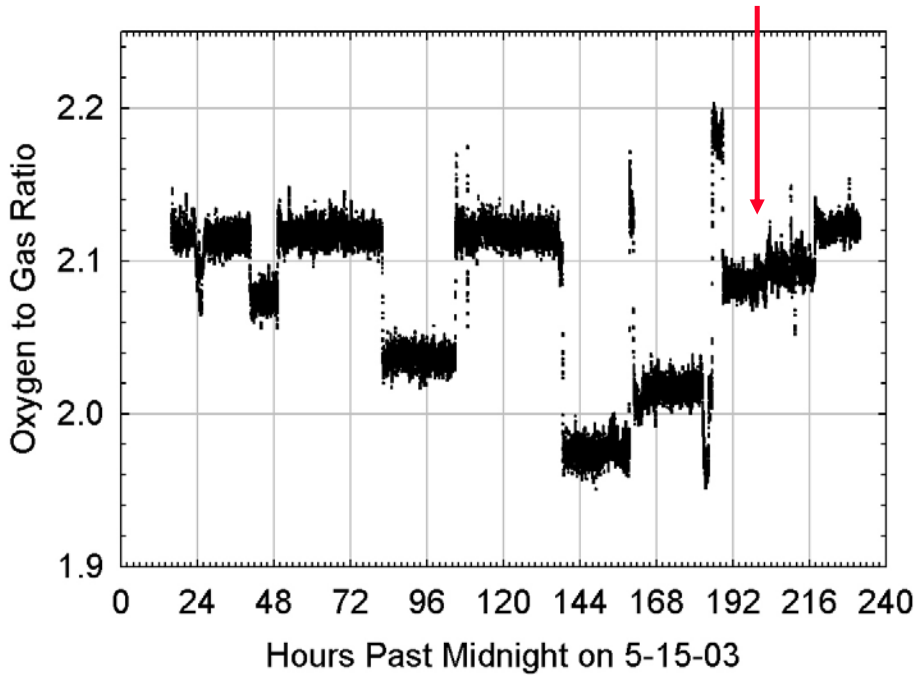
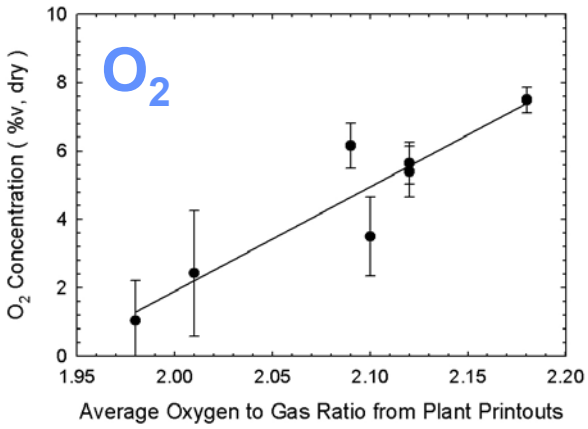
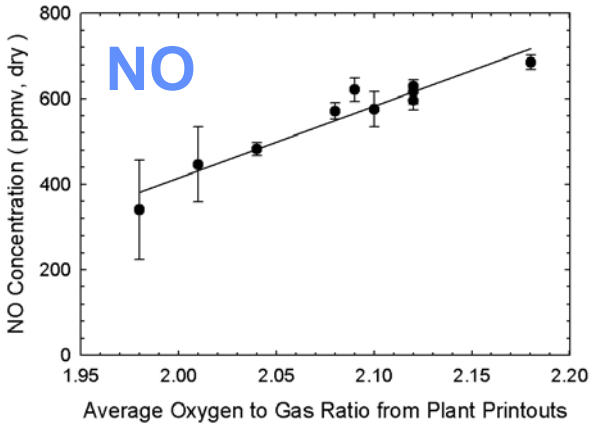
May 2003 Tests



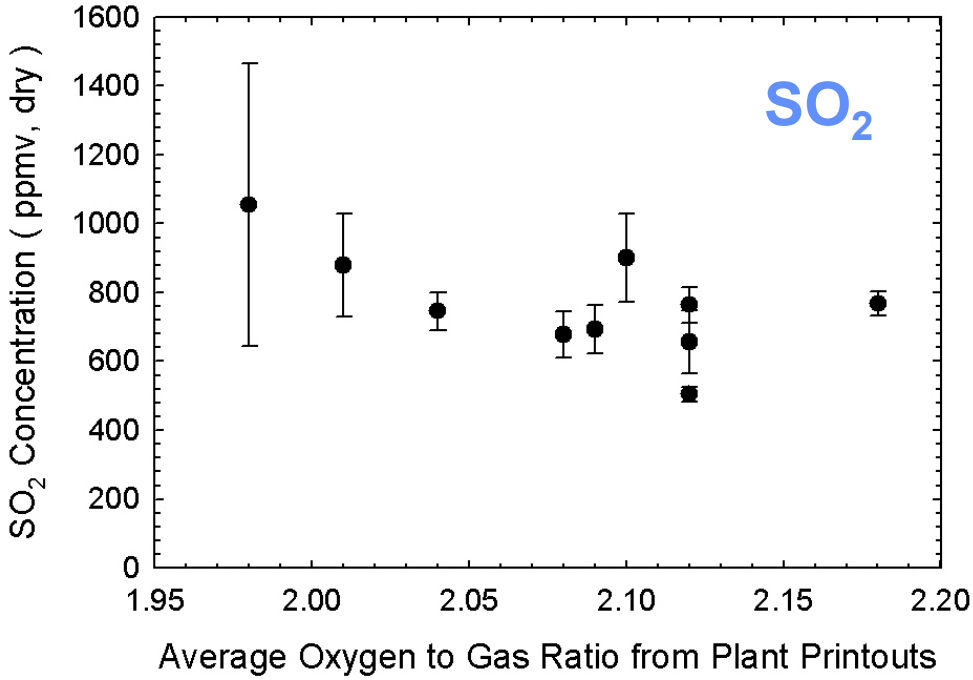
Results

Combustion products depend on O/G

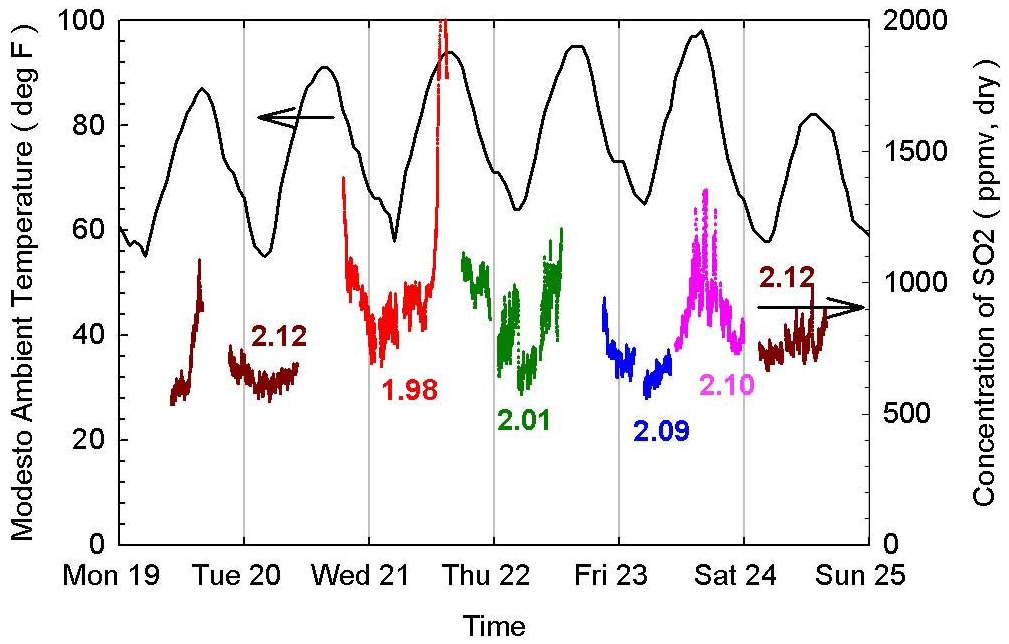




Combustion products depend on O/G



Rich conditions alter SO_2 release



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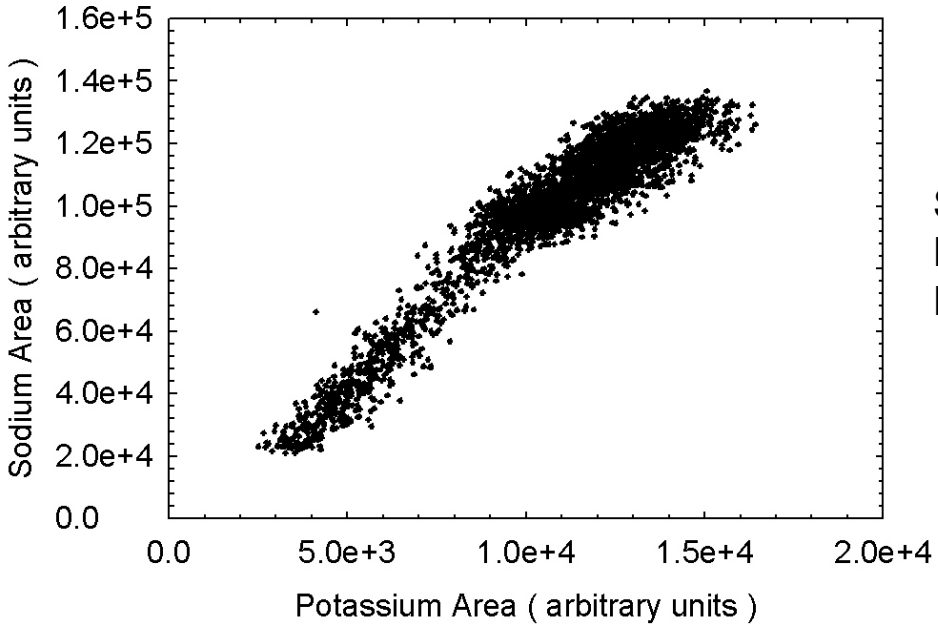
Sodium correlates with potassium



Sodium to Potassium Ratio = ~ 3-6

May 2003

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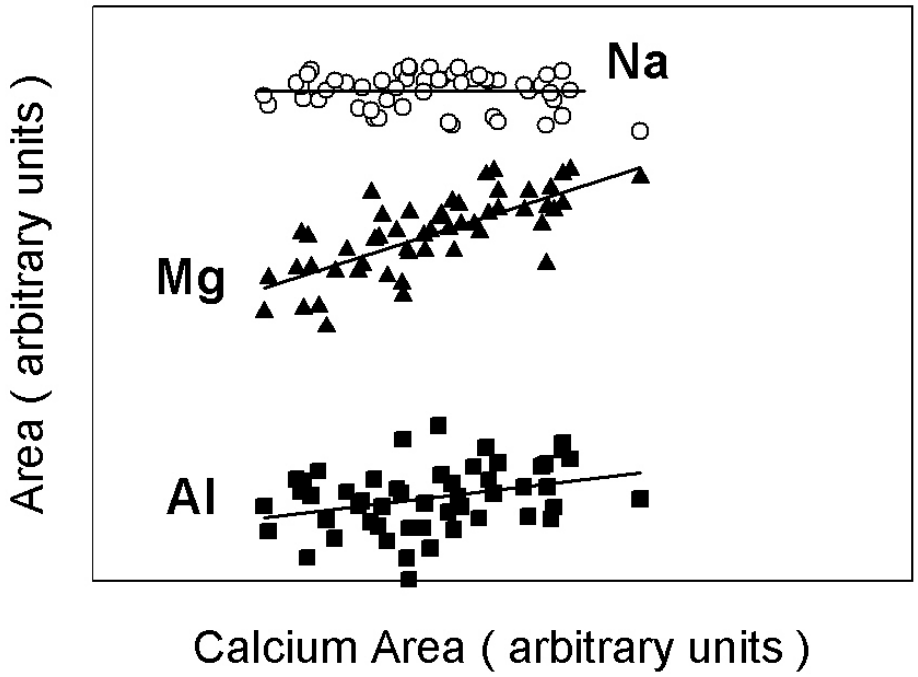
Other metals do not correlate with alkali



K too..

Dec 2001

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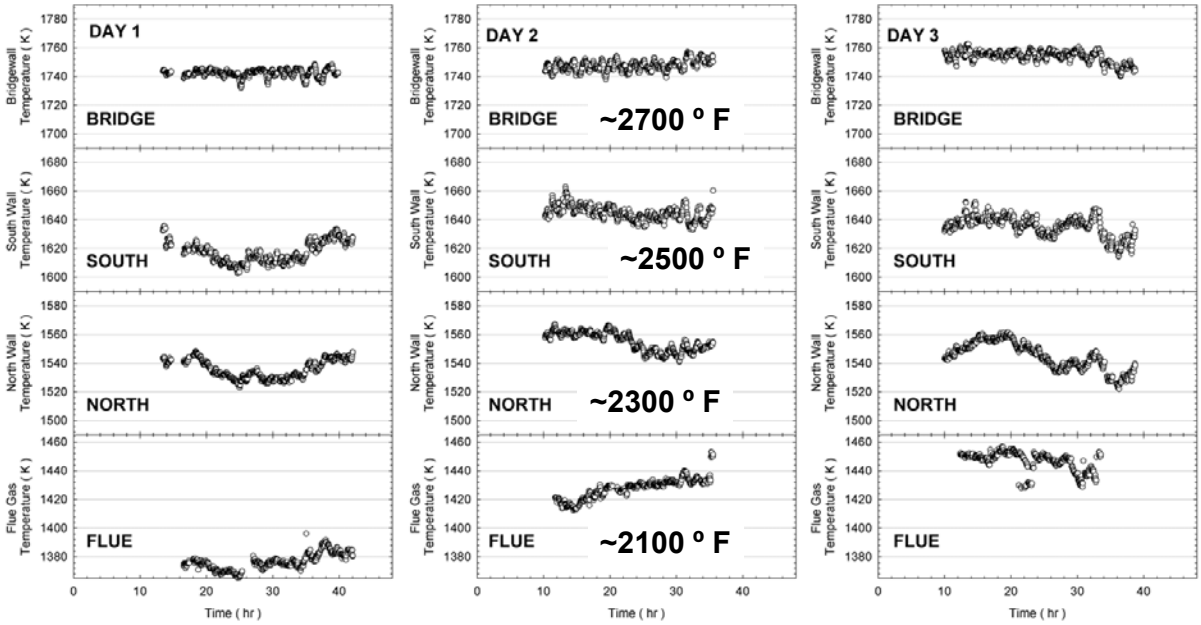
Alkali release depends on temperature



June 2002

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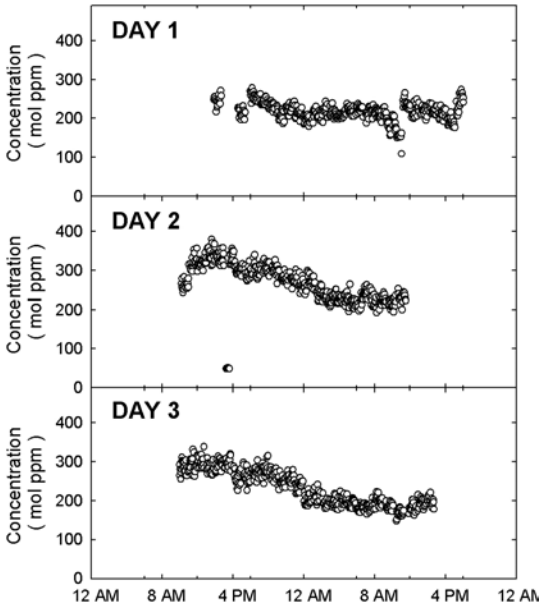
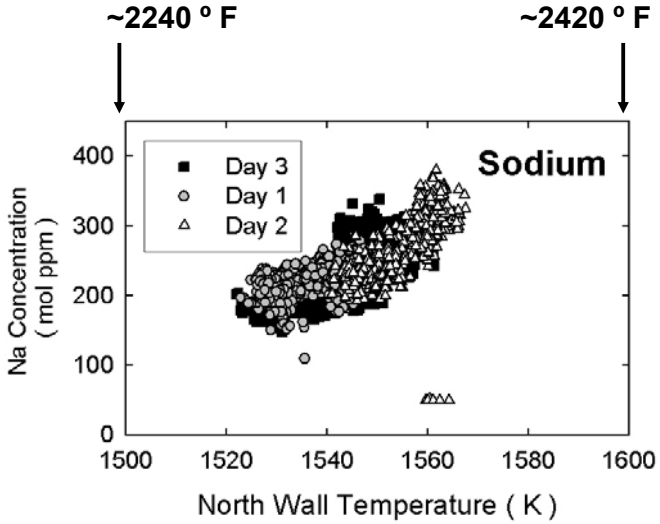
Alkali release depends on temperature





Measurements in North Flue

K too..

June 2002

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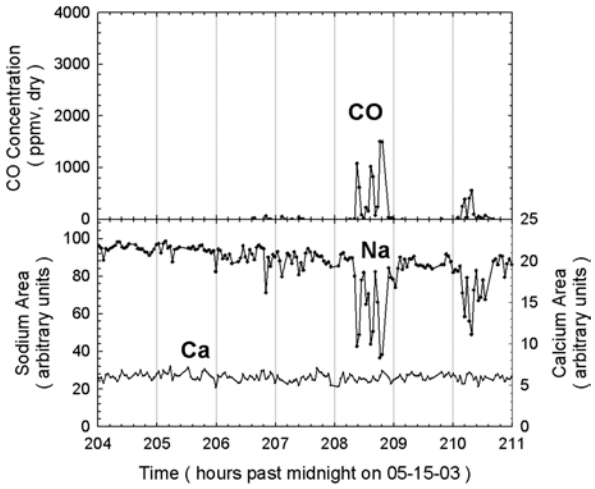
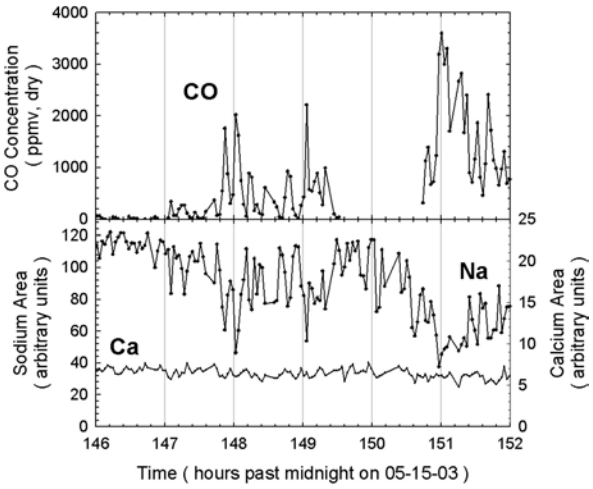
Rich conditions may affect alkali release





K too..

May 2003

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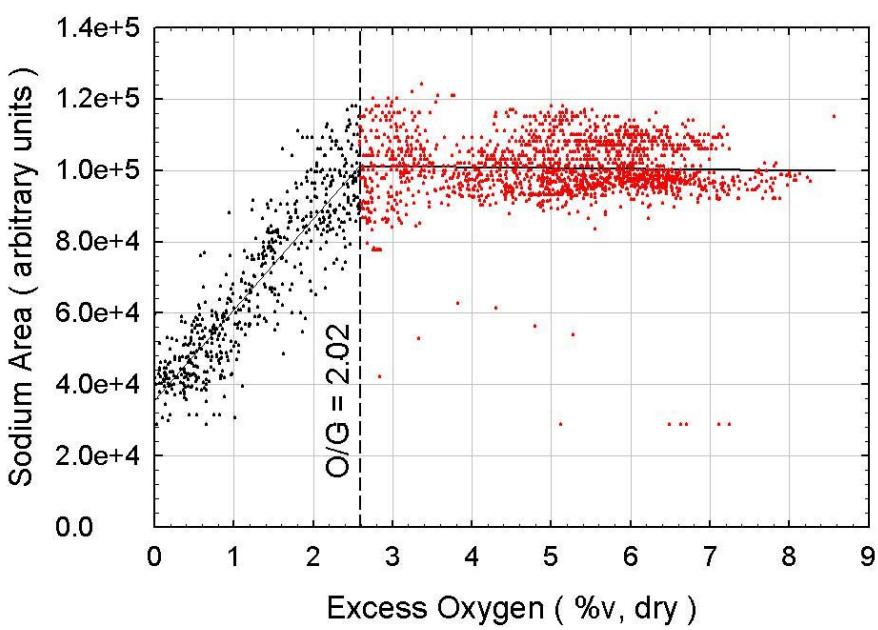
What is expected for rich conditions?

- The presence of CO should increase Na vaporization (Beerkens and van Limpt, 2001)

$$Na_2O_{melt} + CO \Leftrightarrow Na_g + CO_2$$

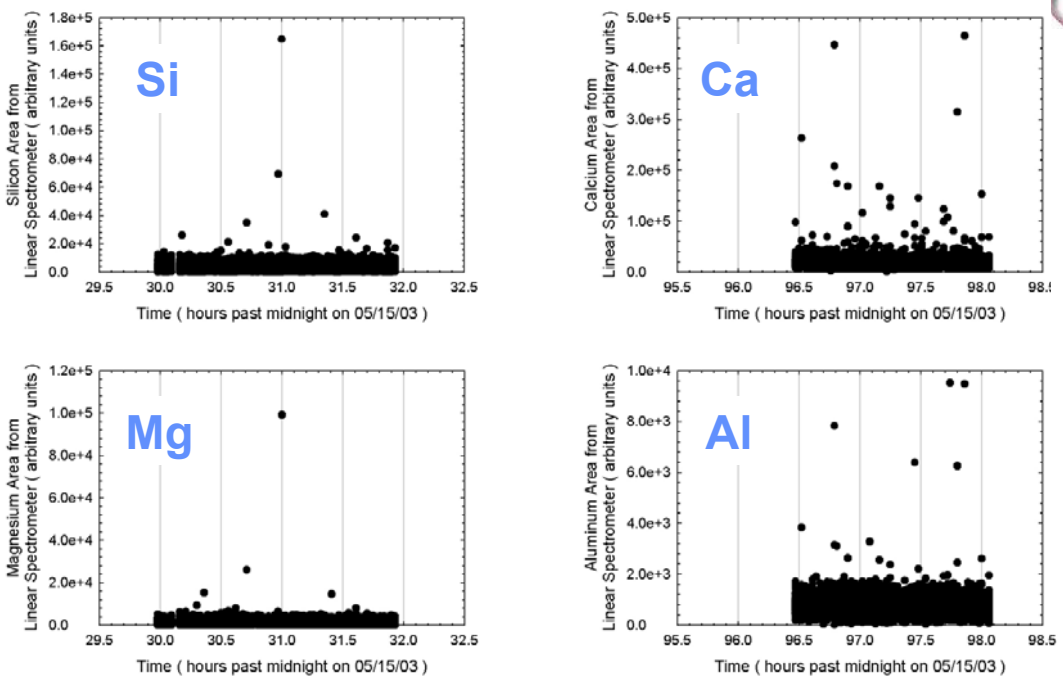
- Allendorf performing equilibrium calculations

Alkali release depends on stoichiometry



(T also…)

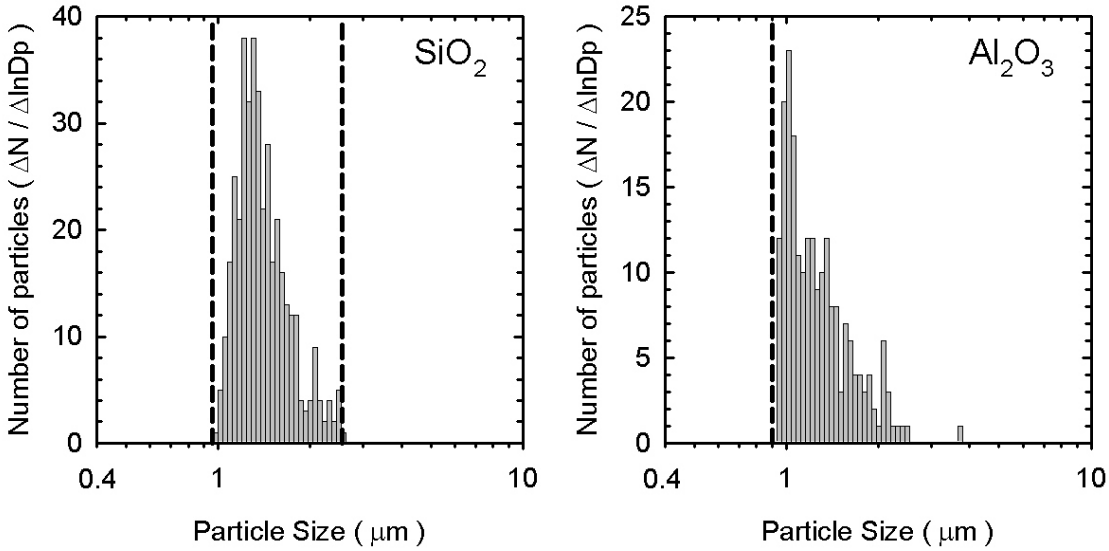
Batch particles can be detected



May 2003 1 Data Point = 1 Spark

Sandia National Laboratories
Combustion Research Facility

Batch particle sizes SiO2 & Al2O3



N = 399 of 662,580
Mean = 1.44 μm

N = 213 of 581,580
Mean = 1.31 μm

May 2003

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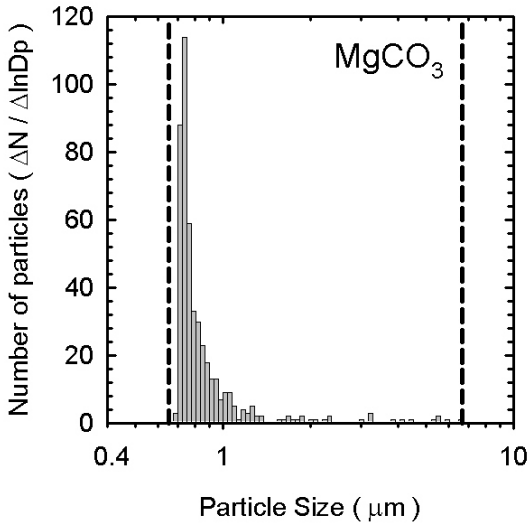
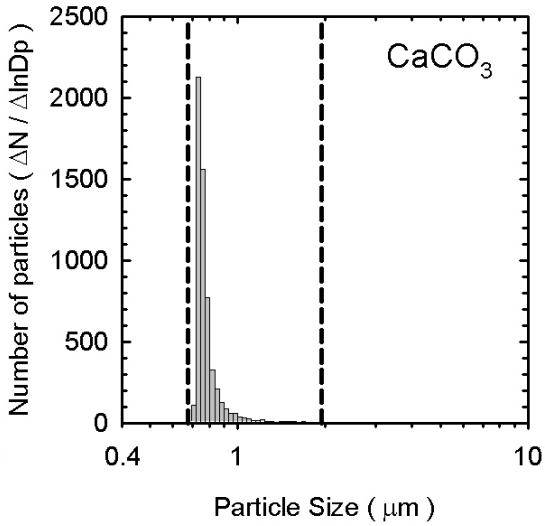
Combustion Research Facility

Batch particle sizes CaCO3 & MgCO3





N = 466 of 662,580
Mean = 0.934 μm

N = 5713 of 581,580
Mean = 0.795 μm

May 2003

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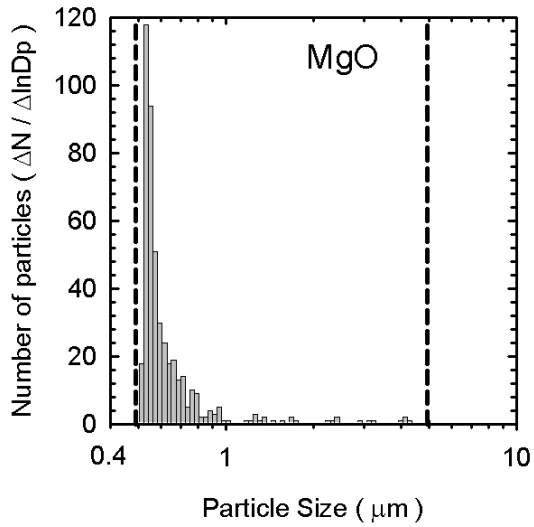
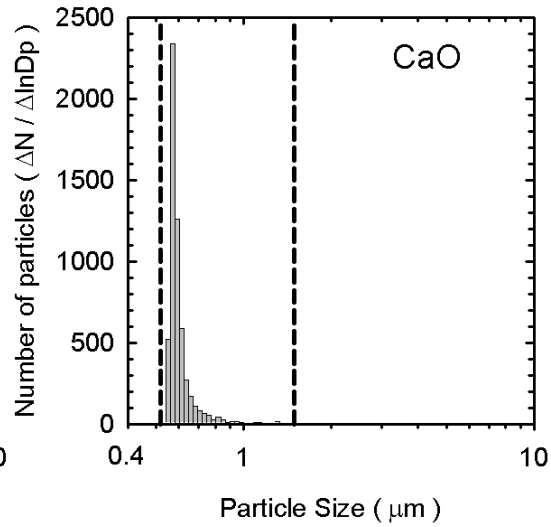
Batch particle sizes CaO & MgO





N = 466 of 662,580
Mean = 0.691 μm

N = 5713 of 581,580
Mean = 0.611 μm

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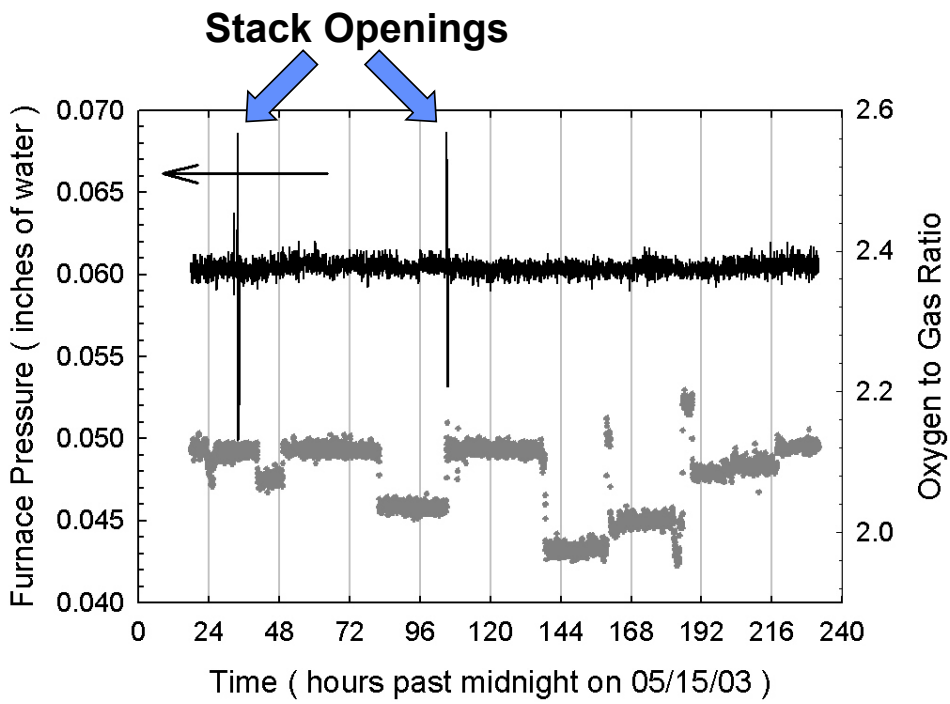
Combustion Research Facility

Batch particles depend on pressure



May 2003

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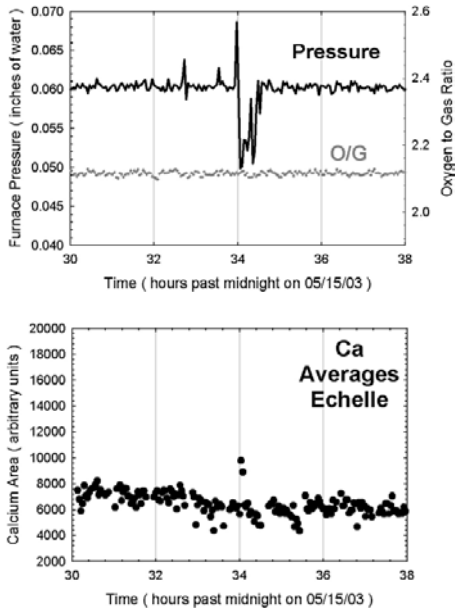
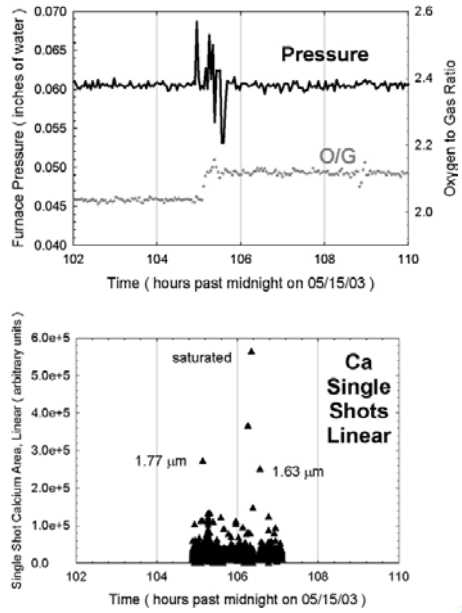
Batch entrains when pressure drops

Stack Opening #1



Stack Opening #2



May 2003

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Combustion Research Facility

Challenges

- Laser power drift during continuous operation
- Applicability of laboratory calibrations in the field
- Oxygen analysis –
  zirconium oxide better than galvanic cell
- Hard to separate effects of pull rate, boost, temperature, and stoichiometry
- Need to understand fuel-rich behavior of Na and K
- Dynamic range of particle size limited
- Broadband spectrometer not useful for single shots

Publications and Presentations

- Blevins, L.G., Shaddix, C.R., Sickafoose, S.M., and Walsh, P.M., "Laser-Induced Breakdown Spectroscopy in High-Temperature Industrial Boilers and Furnaces," to appear, Applied Optics, 2003.
- Walsh, P.M., Blevins, L.G., Sickafoose, S.M., Johnsen, H.A., Molina, A., Ottesen, D.K., Scott, D.D., Steinhaus, R.J., Christy, R.H., and Neufeld, J.W., "Laser-Induced Breakdown Spectrometry: Application to Measurement of Inorganic Particulate Emissions from Combustion in Engines and Furnaces," Third Mediterranean Combustion Symposium, Marrakech, Morocco, June 8-13, 2003.
- Walsh, P.M., Hotbels Seminar, 2003.
- Blevins, L.G., Molina, A., Sickafoose, S.M., Walsh, P.M., and Neufeld, J.W., "Alkali Metal Concentrations in an Oxy-Fuel Glass Furnace Exhaust," 3rd Joint US Meeting of the Combustion Institute, Chicago, Illinois, March 2003.

Tasks/Milestones

No.	Task / Milestone Description	Planned Completion	Actual Completion
1	Data acquisition system	7/31/01	6/20/02
2	CO and O_2 monitors	9/30/01	12/14/01
3	Furnace exit gas temperature	10/31/01	6/20/02
4	Flame and refractory radiation	11/30/01	6/20/02
5	Synchronized records	12/31/01	6/20/02
6	Measurements of sodium	2/28/02	12/14/01
7	Sources of sodium	3/31/02	8/31/02
8	Conditions influencing sodium	4/30/02	8/31/02
9	Maximum furnace efficiency	5/31/02	

Tasks/Milestones

No.	Task / Milestone Description	Planned Completion	Actual Completion
10	Measurements of silicon	7/31/02	12/14/01
11	Measurements of calcium	9/30/02	12/14/01
12	Correlations for metals	11/30/02	
13	Broad-band LIBS instrument	3/31/03	10/31/01
14	Software for LIBS instrument	5/31/03	10/31/01
15	Simultaneous measurements of Na, K, Ca, and Si	7/31/03	12/14/01
16	Relationship between Na and K	8/31/03	06/01/03
17	Optimum stoichiometry	9/30/03	06/01/03
18	Sodium and calcium monitor	1/31/04	
19	Control strategy	3/31/04	
20	Demo in melting research facility	4/30/04	
21	Method for monitoring and control of volatilization and carryover	5/31/04	

Plan for FY04

- Examine temperature and particle effects on calibration
- Add narrow band filters to obtain Ca and Na monitor
- Test monitor at Gallo Glass Company
- Examine effects of pull and boost rates
- Separate temperature and stoichiometry effects
- Determine conditions causing batch entrainment
- Recommend data-based control strategy
- Compile "best practices" for using LIBS to monitor particulates and corrosion in container glass furnaces
- Identify commercialization partner

Budget

Budget Data as of August 2003:

			Approved Spending Plan ($000)			Actual Spent to Date ($000)		
Phase / Budget Period			DOE Amount	Cost Share	Total	DOE Amount	Cost Share	Total
	From	To						
Year 1	6/01	5/02	350	350	700	350	350	700
Year 2	6/02	5/03	350	350	700	350	350	700
Year 3	6/03	5/04	350	350	700	150	150	300
Totals			1,050	1,050	2,100	850	850	1,700

Findings

- As O/G increases, O_2 and NO increase, SO_2 decreases
- Ambient temperature affects actual oxygen to gas ratio
- Na and K correlate with each other; Al, Ca, and Mg correlate with each other; no inter-correlation
  - Suggests different release mechanism for these metals
- Alkali release depends on temperature and stoichiometry in different ways
  - Suggests staged combustion as a strategy
- Decreasing pressure encourages batch carryover

Acknowledgments

- Department of Energy
  - Elliot Levine
- Gallo Glass Company
  - Doug Moore, Plant Technical Staff
- Sandia National Laboratories
  - Bob Gallagher, Jim Wang, Mark Allendorf, Steve Rice, Gary Hubbard, Howard Johnsen, Bob Steinhaus

Measurement and Control of Glass Feedstocks

Arel Weisberg, Ph.D.
Robert De Saro
Joseph Craparo, Ph.D.
Arthur Poulos, Ph.D.
James Simpson, Ph.D.
Energy Research Company

2003 OIT Glass Project Review
September 9, 2003

Silicon and Aluminum in Clay

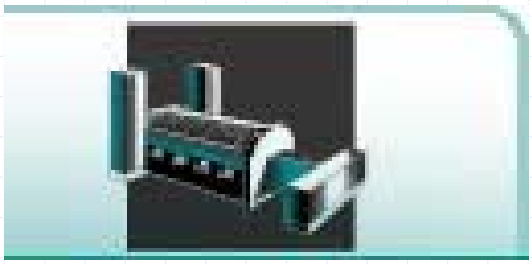
Experiment	Silicon (% error)	Aluminum (% error)
A	0.21	0.10
B	2.64	1.38
C	2.64	0.65
D	2.16	1.42
E	2.37	1.93
Average	**2.00**	**1.10**

Agenda

- Participants
- Brief Summary of Accomplishments
- Problem Statement
- Concept Description
- Experimental Data
- Discussion and Conclusion

DOE's Office of Industrial Technologies

Glass



Participants in Glass Project

- DOE OIT
- Energy Research Company
- PPG Industries (Fiberglass)
- Fenton Art Glass
- Oak Ridge National Laboratory

Two Projects in Glass

- Measure Batch Formulations in Real-Time
  - Measure Oxide Concentrations
  - Determine if Batch is on Spec
- Measure Cullet in Real-Time
  - Identify Cullet Color and Contaminants
  - Remove Contaminants and Separate Color

Accomplishments

- Laboratory Apparatus Operational
- Demonstrated Technology's Utility for Batch and Cullet Analysis
- Development of Advanced Batch Analysis Algorithm Initiated
  - Clay
  - Silica
  - Limestone
  - Ulexite
  - Colemanite

Accomplishments

- Material Sampling Method Developed
- Developed "1-click" Calibrationless LIBS Software
- Host Site Selection Completed
  - PPG Fiber Glass Chester, SC
- Material Choice for Host Site Completed
  - Individual Ingredients - Clay or Ulexite
- Measured Molten Glass Concentrations

Problem Statement

- The Glass Industry Technology Roadmap emphasizes this need for accurate process and feedstock sensors (p. 12):

  "The lack of effective in-process sensors and control systems is the most serious barrier to better production efficiency."

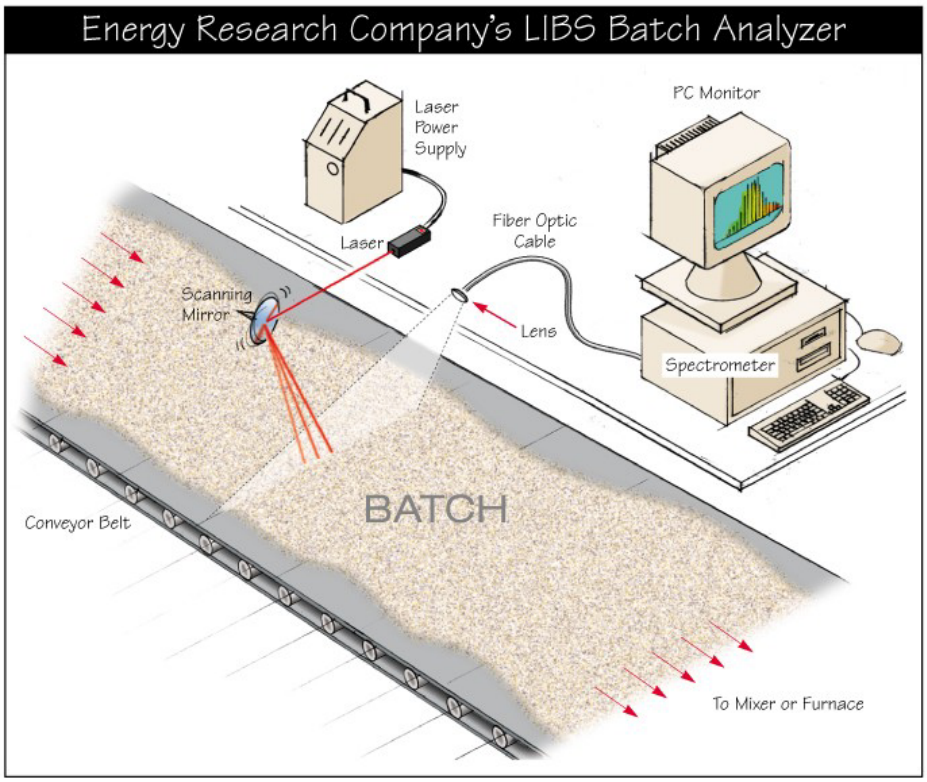
ERCo
Energy Research Company

Problem Statement

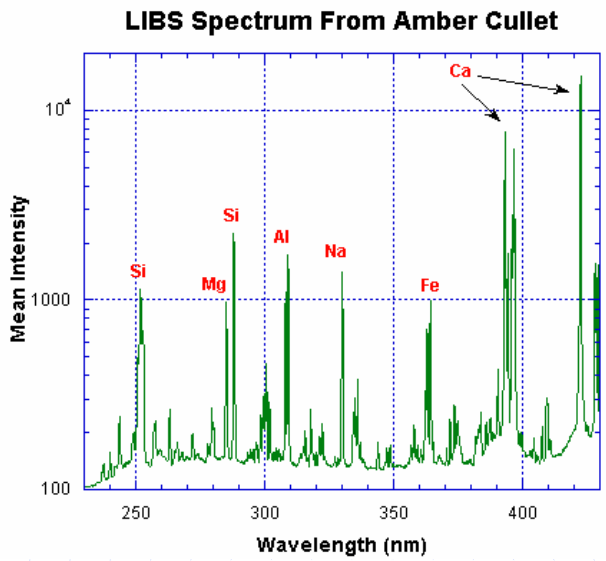
- Lack of Effective Way to Ensure Accurate Batch Oxide Concentrations
- Oxide Fluctuations Lead to
  - Wasted Feedstock
  - Quality Problems
  - Increased Energy Use and Emissions
  - Wasted Product

Goals

- Develop an on-line sensor for rapidly measuring oxides in batch materials



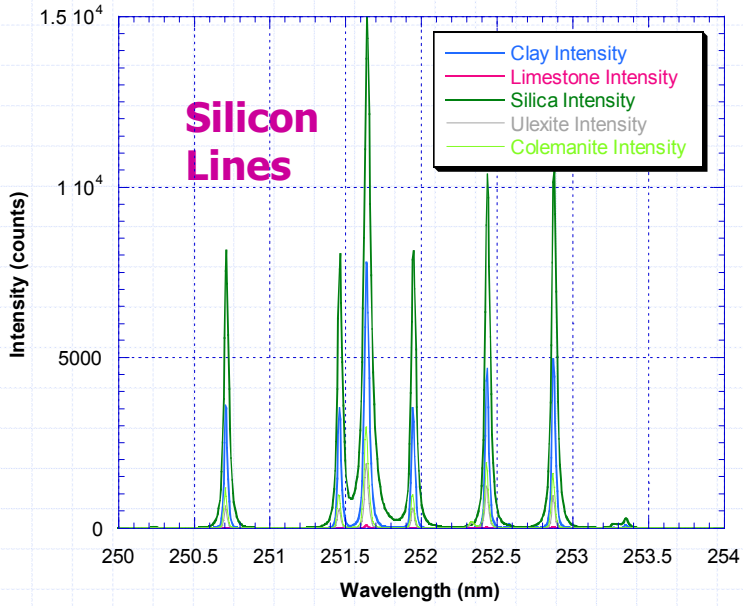
LIBS Technology



Spectrometer gathers the plasma light and spreads it, like a prism, into a spectrum where the contribution of each element can be seen

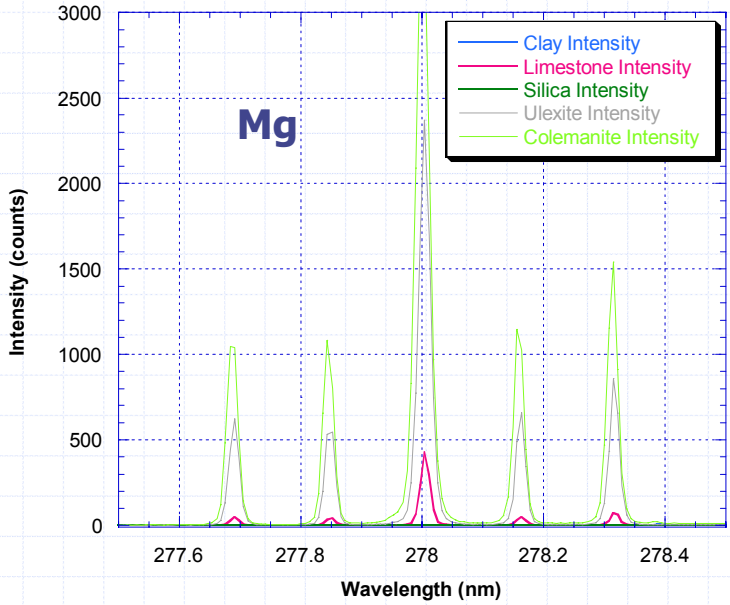
Batch Constituents

- LIBS Spectra Collected from Each Sample



Batch Constituents

- LIBS Spectra Collected from Each Sample



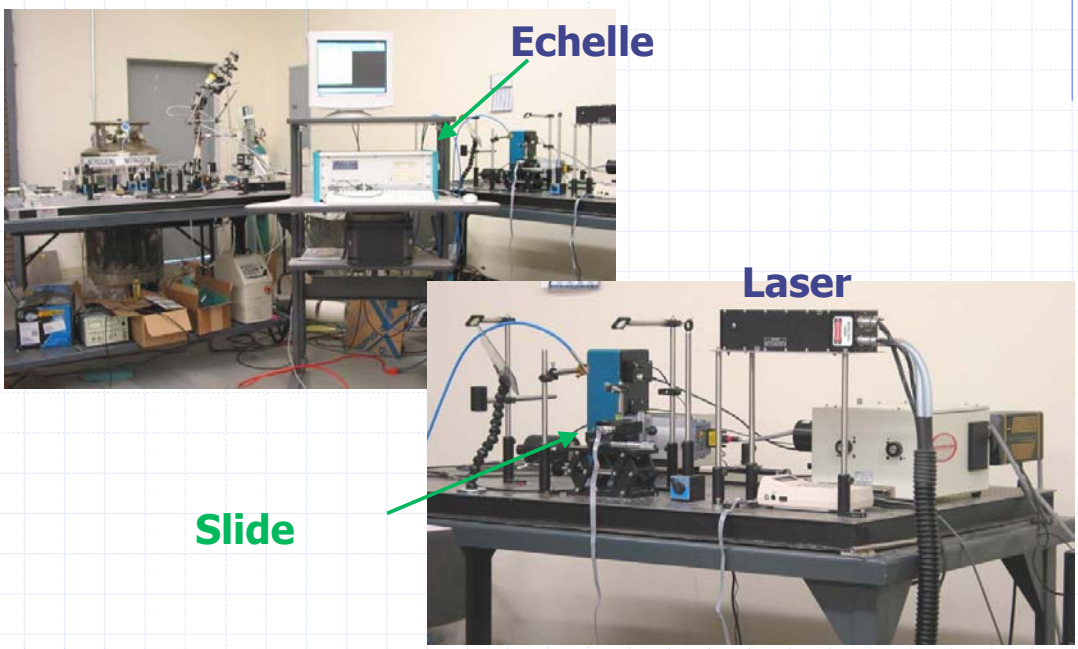
LIBS Advantages

- Fast
  - A few minutes to perform a complete elemental analysis
- Accurate
  - Fractions of a percent to ppm
- Applicable to a wide range of materials
  - Glass, Batch
  - Metals, other solids, liquids, gases
- Proven
  - Extensive literature on use of the process in lab environments
  - **ERCo** installation in aluminum plant production line

Experimental Results

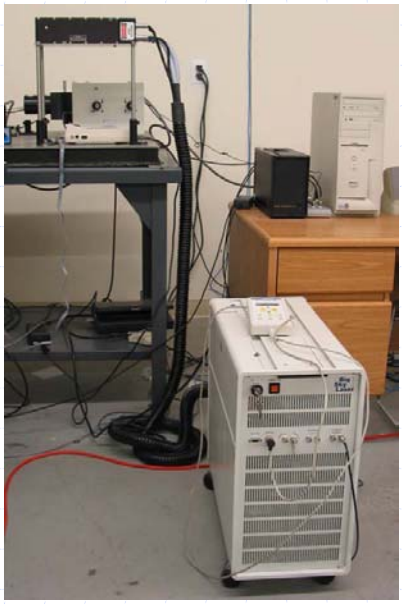
- Apparatus and method
- ERCo's calibrationless LIBS software
- Concentration measurements from PPG samples

ERCo LIBS Facility



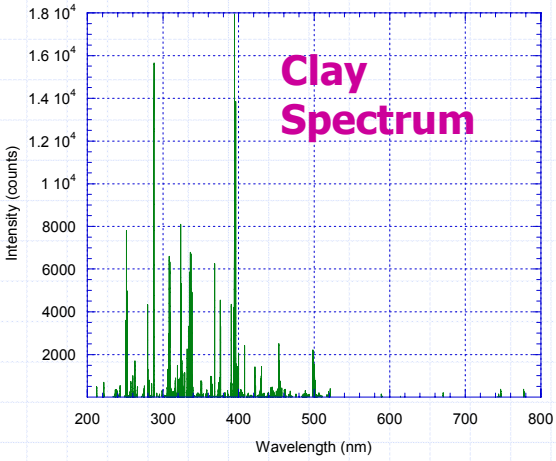
Laboratory Equipment

- Big Sky Laser CFR-400 Nd:YAG, solid state
- Q-switched at up to 20 Hz
- Simultaneous output at 1064nm (70 mJ), 532nm (182 mJ), and 266nm (42 mJ)
- Industrial Design
- Low Maintenance



Laboratory Equipment

- Advantages of Echelle Spectrometer
  - Complete elemental analysis with each laser pulse
  - Increased accuracy
  - Greatly reduced analysis time
  - Industrial Design
  - Low Maintenance

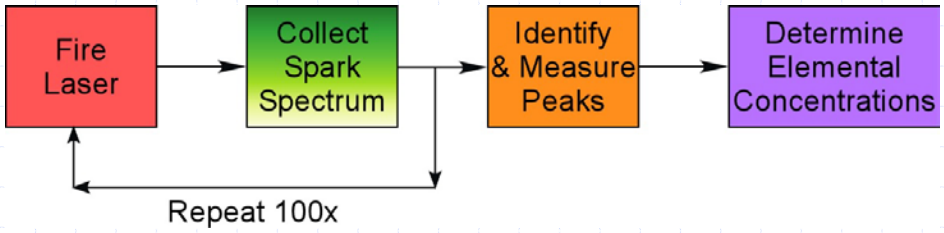


Apparatus and Method

- Silica, clay, colemanite, ulexite, and limestone are included in PPG's batch

- Proprietary material handling method developed for delivering material to laser pulses

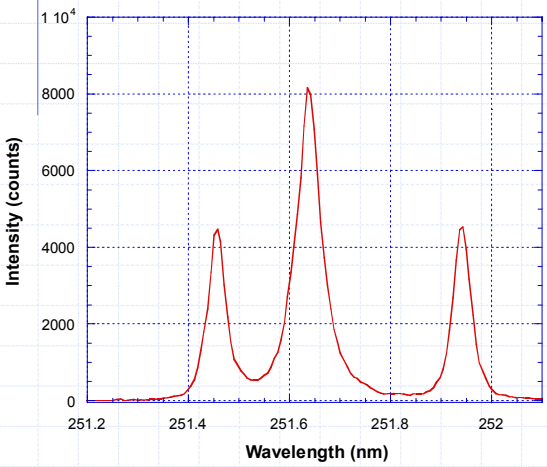
From Spectra to Concentrations

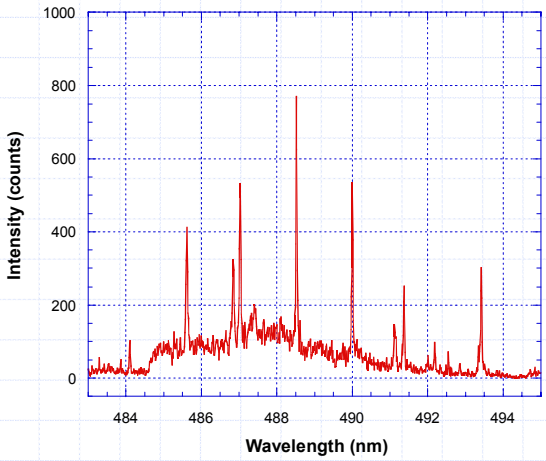


- What is in the sample?
  - Wavelengths identify the elements present
- How much is there?
  - Intensity correlates to concentration

Automatic Spectra Processing

- Innovative software developed to analyze spectral peaks automatically





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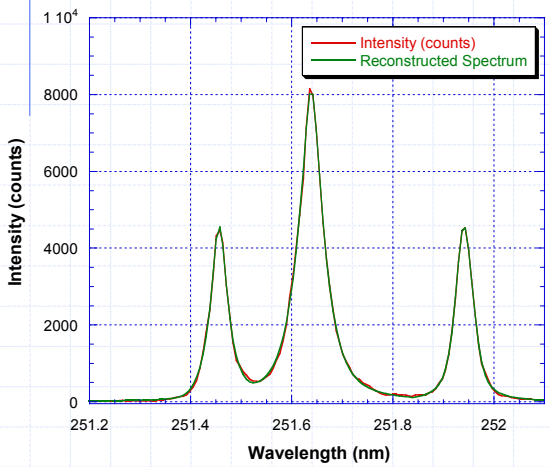
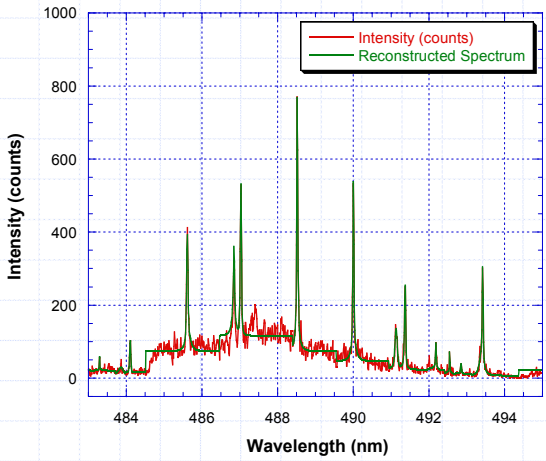
Automatic Spectra Processing

- Software accurately fits spectral peaks despite challenges





Calibrationless Software

- ERCo has Proprietary Software Using First Principles that Translates LIBS Spectra into Concentration Measurements
- Method is automatic – no user assistance necessary
- Method Applies to both Molten and Solid Data
- Method is Independent of Experimental Parameters that Can Fluctuate such as Laser Power
- No Calibration Data Required

Results

- All results reported as % error since concentrations are proprietary PPG data
- Major component error reported as relative error %

  % Relative Error=|Actual-Measured|/Actual x 100%

- Minor component error reported as absolute error %

  % Absolute Error=|Actual%-Measured%|

Clay Results (% error)

El.	A	B	C	D	E	Avg.
Si	0.21	2.64	2.64	2.16	2.37	**2.00**
Al	0.10	1.38	0.65	1.42	1.93	**1.10**
Ti	0.13	0.04	0.04	0.37	0.23	**0.16**
Fe	0.08	0.01	0.09	0.09	0.06	**0.07**
Na	0.03	0.03	0.03	0.03	0.03	**0.03**

Major Minor

Silica Results (% error)

El.	A	B	C	D	E	Avg.
Si	0.10	0.20	0.23	0.18	0.18	**0.18**
Al	0.05	0.02	0.04	0.01	0.01	**0.03**
Ti	0.01	0.01	0.01	0.00	0.00	**0.03**
Fe	0.01	0.02	0.02	0.00	0.00	**0.01**

Major Minor

Limestone Results (% error)

El.	A	B	C	D	E	Avg
C	1.28	0.62	1.54	1.59	0.09	**1.02**
Ca	0.26	0.09	0.57	0.41	0.18	**0.30**
Mg	0.00	0.00	0.01	0.01	0.00	**0.00**
Al	0.01	0.01	0.00	0.01	0.01	**0.01**
Si	0.08	0.07	0.10	0.10	0.13	**0.10**
Fe	0.00	0.00	0.01	0.04	0.02	**0.01**

Major Minor

Experimental Results Summary

- Calibrationless LIBS Successful
- Measurement Accuracies within Program Goals (<5%)
- High Degree of Repeatability in Calibrationless LIBS Results

Future Interest

- Measure Concentrations of Molten Glass in Tank in Real-Time, In-Situ

Molten Glass Data

Element	Result	% Outside Range
Si	Good	0.81
Na	Good	
Ca	Good	
Mg	Out	5.2
Ba	Out	2.8
Fe	Good	
Sr	Good	
Mn	Good	

Actual Concentrations Proprietary

Glass Analyzed Before And After Melting

Industrial Installation

- Molten Aluminum LIBS Probe Installation at Commonwealth Aluminum Newport Rolling Mill

LIBS Sensor for Molten Aluminum

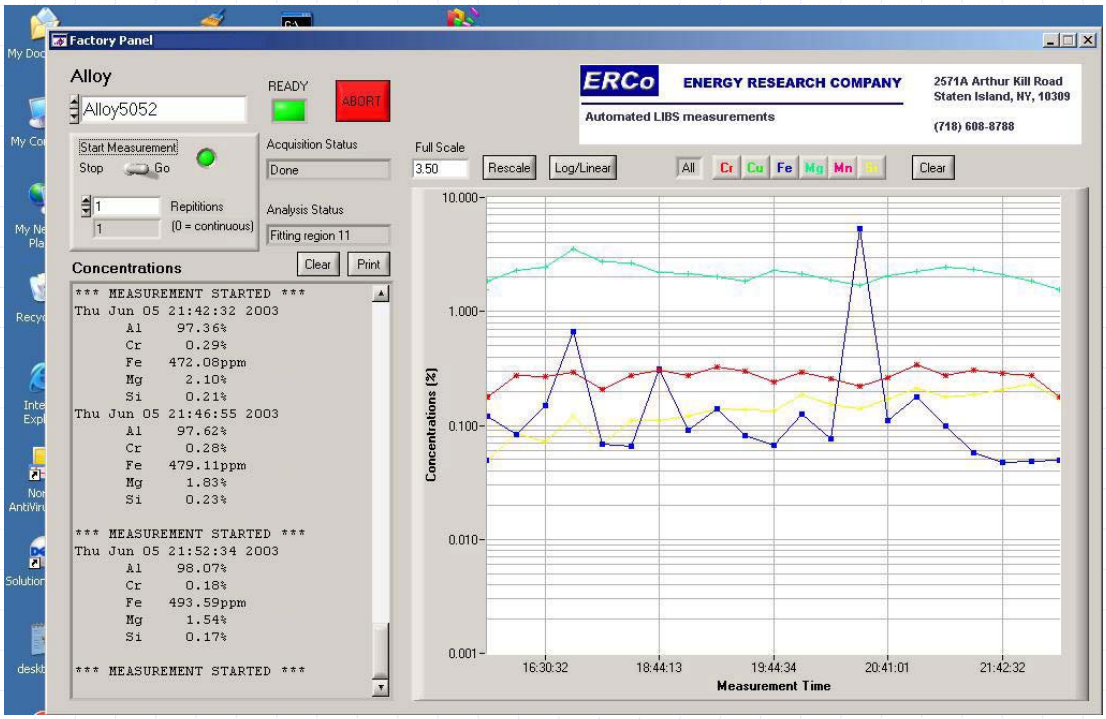
Commercial Installation

- Industrial Cabinet

- Sealed, Air Conditioned, EMI Shielded

Commercial Installation

- Laser Class Recertification
  - Class 4 Laser
  - Developed system of interlocks
  - Achieved Class 1 Laser Safety Rating (same as compact disc player)



Molten Aluminum Concentrations

Aluminum Alloy 3105

Element	ERCo Average	Independent Laboratory	Error
Aluminum	**98.70**	**98.89**	**0.19%**
Magnesium	**0.59**	**0.57**	**3.51%**
Manganese	**0.50**	**0.52**	**3.85%**

Discussion and Conclusions

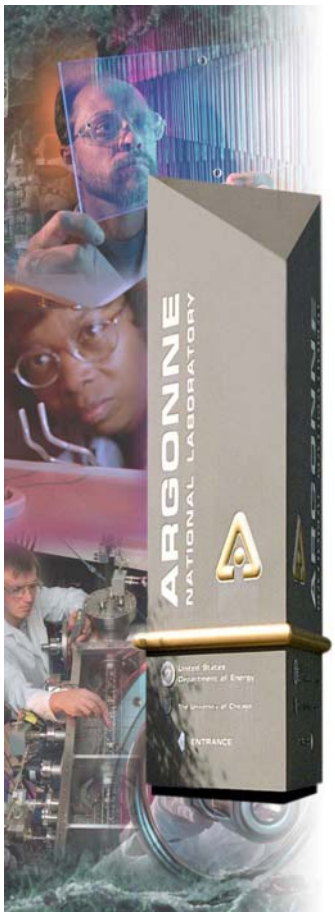
- LIBS is a promising technology for rapid glass batch analysis
- Oxide concentrations in PPG batch materials measured using ERCo's calibrationless method
- Molten glass preliminary concentration measurements successful

Milestones

- Year One
  - Develop capability to measure elemental composition of glass batch
  - Develop the capability to distinguish among different cullet colors
  - Develop the capability to identify contaminants
- Years Two and Three
  - Procure and construct a new LIBS system
  - Complete development of software systems
  - Collect LIBS spectra in adverse ambient conditions
  - Obtain feedback from industrial partners on operation and use of system

4

Final Project Evaluation Results and Presentations



Development of a Process for the In-House Recovery and Recycling of Glass from Glass-Manufacturing Waste

Prepared for

DOE GLASS PROJECT REVIEW
September 8-9, 2003

National Renewable Energy Laboratory- Golden Colorado

Argonne National Laboratory

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Sponsored by

U.S. Department of Energy

DOE Headquarters Contact-
Mike Soboroff

Project Team

- **Argonne National Laboratory**
  Sam Jody, Joe Pomykala Jr. & Ed Daniels
- **Saint-Gobain Vetrotex America**
  John Wells
- **CertainTeed Corporation**
  Terry Berg

Presentation Outline

- **Overview**
- **Technical Progress**
- **Summary & Conclusions**
- **Schedule & Milestones**
- **Financial Report**
- **Recommended Future Plans**

Problem/Need

- **Waste is presently landfilled and cost of disposal is rising.**
- **Earlier attempts to recycle the waste resulted in more frequent breakage of the filaments.**
- **The industry needs an energy-efficient and cost-effective process to recycle their waste.**

Objective

- **Develop a technology to enable the Glass Industry to recycle its glass-fiber waste**

Approach

- **Identify the cause for increased filament breakage - Identify species in the waste glass not present in the virgin glass:**
  - Qualitative analysis (SEM)
  - Quantitative analysis (EDS, ICP, Total Carbon)
- **Develop a process to remove contaminants from the waste material.**
- **Conduct economic evaluation of the process.**
- **Demonstrate the process in the field.**

Accomplishments

I. **Identification of Impurities in Glass-Fiber Waste:**

- **Samples of Waste glass fibers and virgin glass were analyzed using :**
  - Scanning Electron Microscope (SEM)
  - Electron Dispersion Spectroscopy (EDS), and
  - Inductive Coupling Plasma (ICP)
  - Total Carbon Analysis

Accomplishments (cont'd)

- **No noble metal contamination was detected in the waste fibers down to detection limits of 5 ppb**
- **Metallic particles, including noble metals, were found at ppt levels in samples of the liquid dripping of the waste glass fibers**
- **Except for the polymeric-coating layer, same elements were present in the waste glass fibers and in the virgin glass and at the same concentrations.**

Accomplishments (cont'd)

- **We also analyzed two samples of the fused residue left at the bottom of an industrial glass furnace used for recycling coated glass fiber waste. The results showed elevated levels of several elements—**

Carbon Wt % in samples

Virgin Glass	Waste Fibers	Residue Samples
(< 100 ppm)	~ 2,500 ppm	160 ppm 180 ppm

Weight % of Elements in Residue

Element	Virgin Glass	Waste Fibers	Residue Samples	
Zr	0.01	0.02	0.03	1.76
Sr	0.01	0.01	0.11	0.10
Cr	0.007	0.006	0.0157	0.0796
Cu	UD	UD	0.0020	0.0161
Mg	0.19	0.18	0.34	0.32
Fe	0.2	0.2	0.23	0.29

Accomplishments (cont'd)

Conclusions Based on Analysis

- **Washing of the excess liquid on the waste fibers before it solidifies helps to reduce contamination of the fibers**
- **The carbonaceous coating coating layer has to be removed before the fibers are melted. Not all of the carbon is burned off some is encapsulated in the glass.**
- **Noble metals may be present in the waste fibers at very low concentrations (ppt levels) but it is difficult to detect because it is not evenly distributed.**

Accomplishments

II. Development of a Process to Remove the Polymeric Coating and Binders:

- **We tested and evaluated 2 methods :**
  - Thermal processing
  - Chemical processing
- **Both methods were successful in removing the polymeric layer.**
- **The thermal method is more efficient and more economical.**
- **The thermal method produces no liquid waste or sludge.**

Accomplishments – Thermal Method

- **Treatment should be conducted at temperatures below the melting point of the glass fibers.**
  - 1250 ºF for glass-fiber waste
  - 1050 ºF for fiberglass waste
- **Melting of the glass results in the encapsulation of solid carbonaceous particles .**

Treatment at Temps Above Melting Resulted in Trapping Carbon Particles and Air Bubbles

Accomplishments – Thermal Method (cont'd)

- **Reduced the total carbon content of the treated glass-fibers from several thousand ppm to less than 100 ppm – typical of what is in virgin glass.**
- **Removed over 99.5% of the binder materials off of the fiberglass scrap.**
- **The required residence time is ~ 10 minutes.**
- **Packing density affects the required treatment time**

Accomplishments – Thermal Method (cont'd)

- **Fluffing of glass fibers before treatment reduces required residence time but it complicates the handling of the treated fibers down stream**
- **Samples of glass fibers are being evaluated by Vetrotex**
- **We produced samples of fiberglass for CertainTeed to evaluate**

Accomplishments – Thermal Method (cont'd)

- **A paper describing the process was presented and published**
  - "A Process to Recycle Glass Fibers from Glass-Manufacturing Waste" presented at and published in the proceedings of the 2003 TMS Conference-EPD Congress, San Diego, CA, March 3-6, 2003, pp. 337-346.
- **We developed a process to produce fiberglass panels with one or more sides blackened for refrigeration applications**

Accomplishments – Thermal Method (cont'd)

- **Identified a problem**
  - Shredding and conveying of the glass fiber waste could introduce new contaminants.

Accomplishments – Thermal Method (cont'd)

III. Economic Analysis of the Thermal Process

- **We developed process conceptual designs.**
- **We conducted economic analysis on the conceptual designs using operating data developed in the lab.**
- **The thermal method can be integrated with existing operations.**
- **Expected payback is ~ than 2 years.**

Accomplishments – Thermal Method (cont'd)

IV. Environmental Analysis of the Thermal Process

- **In a reduced oxygen environment (some air leakage)**
  - < 0.009 wt% of the glass fiber waste &
  - ~ 0.001 wt% of the fiberglass waste evolved as VOCs.

- **The collected VOCs should be readily oxidized when enough oxygen is present.**

Accomplishments – Thermal Method (cont'd)

- **Major VOCs Emitted in an O_2-Deficient Environment:**

Compound	**% of Total Emissions**	**% of Total Emissions**
	From Glass Fibers	From Fiberglass
Acetone	77	65
Isopropyl Alcohol	08	
Benzene	06	
Acrylonitrile	04	21
Vinyl Chloride		06
Dimethyldifluorosilane		04
Others	05	04

Conclusions

- **We developed a process for removing the polymeric-coating layer off of the glass-fiber waste and the binder material off of the fiberglass waste.**
- **The process can be integrated with existing glass-manufacturing operations.**
- **The process has a potential payback of less than two years.**

Tasks to be Completed

- **Complete evaluation and characterization of recycled products.**
- **Develop implementation/commercialization plan & submit final report.**

Recommended Future Plans

- **Demonstrate the process at an industrial site.**

FY 2001 Milestones

Milestone	Scheduled Comp. Date	Status
Identify “impurity” causing filament breakage	07/01	Done
Complete thermal treatment set-up and start experiments	07/01	Done
Send thermally-treated samples to the industrial partners	08/01	Done
Complete set-up for chemical treatment and start experiments	09/01	Done

2002 Milestones

Milestone	Scheduled Comp. Date	Status
Complete technical & economic evaluation of the thermal-treatment method	3/02	Done
Complete technical & economic evaluation of the chemical-treatment method	5/02	Done
Produce treated glass for testing by industrial partners	08/02	Done

2003 Milestones

Milestone	Scheduled Comp. Date	Status
Complete evaluation and characterization of recycled products	10/02	In Progress
Develop implementation/ commercialization plan & submit final report	2/03	In Progress

Budget

Phase/Budget Period			Approved Spending Plan			Actual Spent to 6/30/02		
			DOE	Cost Share	Total	DOE	Cost Share	Total
	From	To						
Year 1	7/01	9/01	200	200	400	58,966	4,374	63,340
Year 2	10/01	9/02	200	200	400	324,900	38,097	362,997
Year 3	10/03	2/03	100	100	200	69,861*	5,790*	75,651*

*Costs shown as of 6/30/03.

Development of Models and On-Line Diagnostic Monitors of the High-Temperature Corrosion of Refractories in Oxy/Fuel Glass Furnaces

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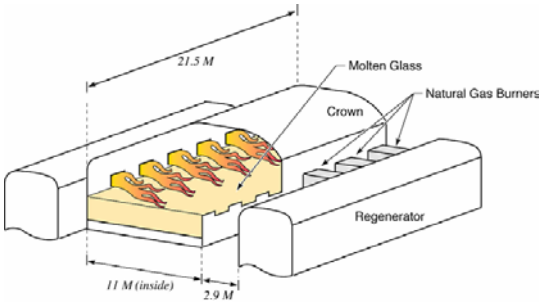
George Pecoraro
Principal Investigator (retired)
PPG Industries, Inc., Pittsburgh, PA

A project conducted with support from the
U.S. DOE/Office of Industrial Technologies
and
American Air Liquide, BOC Gases, PPG Industries, Inc., Gallo Glass, RHI Refractories, Monofrax Inc., Pennsylvania State University, and University of Missouri-Rolla

The need to understand corrosion processes in oxy/fuel furnaces has several major drivers

- **Melting furnaces represent major capital investments for glass manufacturers**
  - **Example: $10 M to rebuild a float-glass furnace (<u>$20 – 40 M for a float-glass furnace if costs of lost production are included</u>)**
- **Highly competitive industry, so reducing manufacturing costs and increasing productivity are important objectives**
- **Federal air-quality regulations are tightening, esp. with regard to NOx**



This project has three major objectives

- Identify factors controlling corrosion of refractories
- Develop models to predict corrosion rates based on these factors
- Develop *in-situ* optical techniques to monitor gas-phase alkali concentrations:
  - Process optimization
  - On-line monitoring

All three of these objectives have been met during this 5-year project

Sandia, glass manufacturers, gas suppliers, refractory manufacturers and universities worked together

- **PPG Industries, Inc. (Project PI; furnace gas analysis; *direct funding support*) – George Pecoraro**
- **American Air Liquide (CFD modeling; *direct funding support*) – Ovidiu Marin**
- **BOC Gases (*direct funding support*) – Greg Prusia**
- **Gallo Glass Co. (corrosion data; furnace access) – John Neufeld**
- **NARCO/Harbison-Walker Refractories (refractory samples; post-mortem analysis) – Dilip Patel**
- **Monofrax Corp. (refractory samples; corrosion tests; post-mortem analysis) – Amul Gupta**
- **University of Missouri, Rolla Dept. of Ceramics (corrosion tests; post-mortem analysis; pilot-scale diagnostic tests) – Mariano Velez**

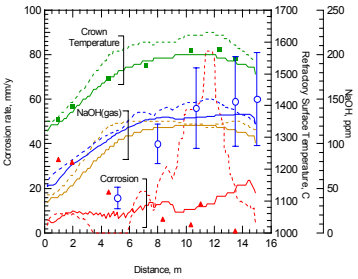
- **Thermodynamic data were obtained through a subcontract:**
- **Prof. Karl Spear, Pennsylvania State University Dept. of Materials Science and Engineering**

Project tasks

- Task 1: Experimental characterization of the corrosion process
  - — Simulate corrosion process in controlled laboratory environment
  - — Measure furnace concentrations using conventional methods
  - — Characterize samples of corroded furnace brick
- Task 2: Corrosion modeling
  - — Compile thermodynamic database for predicting corrosion chemistry
  - — Construct models describing corrosion phenomena
  - — Evaluate competition between transport and chemistry
  - — Verify model predictions
- Task 3: On-line monitors for gas-phase alkali detection
  - — Laboratory development/evaluation
  - — *In-situ* furnace testing
  - — Commercialization

Major accomplishments have been achieved in FY03

- Used thermodynamic analysis to assess the effects of calcium on silica corrosion
- Used Air Liquide's *Athena* code to predict corrosion in a container-glass furnace
- Three field tests completed:
  - PPG, Fresno oxy/fuel float-glass facility
  - PPG, Meadville

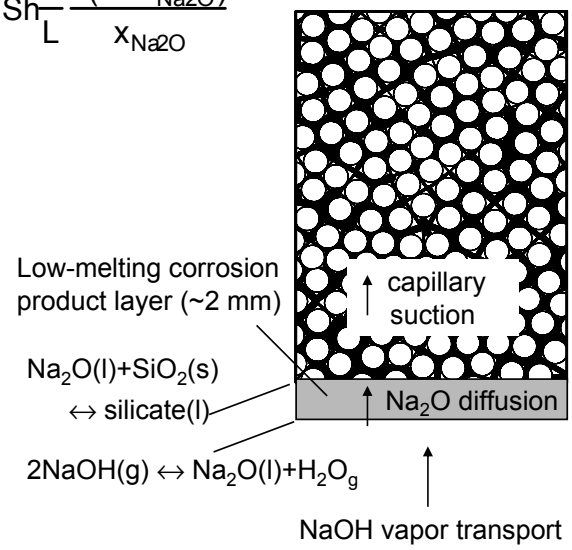


At Least Five Separate Processes May Be Occurring During Corrosion Of Porous Silica Refractories

$$\frac{dl}{dt} \approx \frac{\rho_{gas}}{\rho_{liq}}\left(X_{NaOH,\infty} - X_{NaOH,0}\right) Sh \frac{D}{L} \frac{2(1-x_{Na2O})}{x_{Na2O}}$$

Possible rate-limiting mechanisms:

- ***Gas Phase Transport:*** **NaOH(g) is transported from melt surface to crown surface and reacts there. Primary corrosion mechanism**
- ***Liquid-Phase Diffusion:*** **Na_2O diffuses through melt layer and reacts with silica to form liquid glass**
- ***NaOH transport through pores:*** **reaction occurs in-depth via gas-phase diffusion**
- ***Kinetic limitations:*** **recession is limited by chemical reaction**
- ***Capillary Suction:*** **removes liquid-phase reactants from the crown surface by withdrawal to the interior**



Task 2. Corrosion modeling FY03 activities

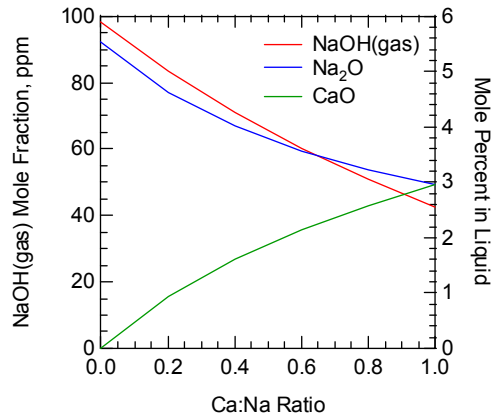
- **Thermodynamics of corrosion**
  - **Effect of CaO addition to silica examined**
- **Subroutines for modeling corrosion:**
  - **Prototypes incorporated by American Air Liquide into *Athena* furnace code to model Gallo Tank 1 furnace corrosion**
  - **Process to transfer code to Argonne National Laboratory for incorporation in their furnace model initiated**
- **Documentation of corrosion model**
  - **Manuscript accepted as a review article in *Glass Science and Technology***

Adding CaO to silica increases the driving forces for corrosion

- Equilibrium calculations for typical oxy-fuel mixture
- p(NaOH,gas) decreases with CaO addition
- Fraction Na_2O in corrosion product decreases

➔ Both factors increase corrosion rate

- Results are consistent with field observations by Brown et al. (Corning Inc.)



$$\frac{dl}{dt} \approx \frac{\rho_{gas}}{\rho_{liq}} \left(X_{NaOH,\infty} - X_{NaOH,0} \right) Sh \frac{D}{L} \frac{(1 - x_{Na\,2O})}{2 x_{Na2O}}$$

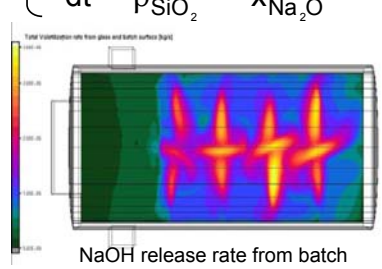
$CH_4/O_2/Na_2O$ = 1.0/2.05/0.1
1765 K. Gas/liquid/SiO_2(solid) equilibrium

Air liquide *Athena* CFD model allows crown recession rates to be computed using Sandia surface corrosion model

- **CFD calculations could provide 2-D maps of:**
  - **Crown temperature**
  - **NaOH(gas) concentration**
  - **Gas velocity**
- **$P_{NaOH}(T) < P(T)_{NaOH,\,equil}$ at crown surface: <u>No corrosion</u>**
  - **surface flux of NaOH, *F*, and local recession rate, *dL/dt*, set to zero**
- **$P_{NaOH}(T) > P(T)_{NaOH,\,equil}$ at crown surface: <u>Corrosion</u>**

$$\begin{cases} P_{NaOH} < P_{NaOH,eq}(T_{crown}) \\ F = 0 \quad \text{and} \quad \dfrac{dL}{dt} = 0 \end{cases}$$

$$\begin{cases} P_{NaOH} = P_{NaOH,eq}(T_{crown}) \\ \dfrac{dL}{dt} = \dfrac{F}{\rho_{SiO_2}} \dfrac{2(1 - x_{Na_2O})}{x_{Na_2O}} \end{cases}$$



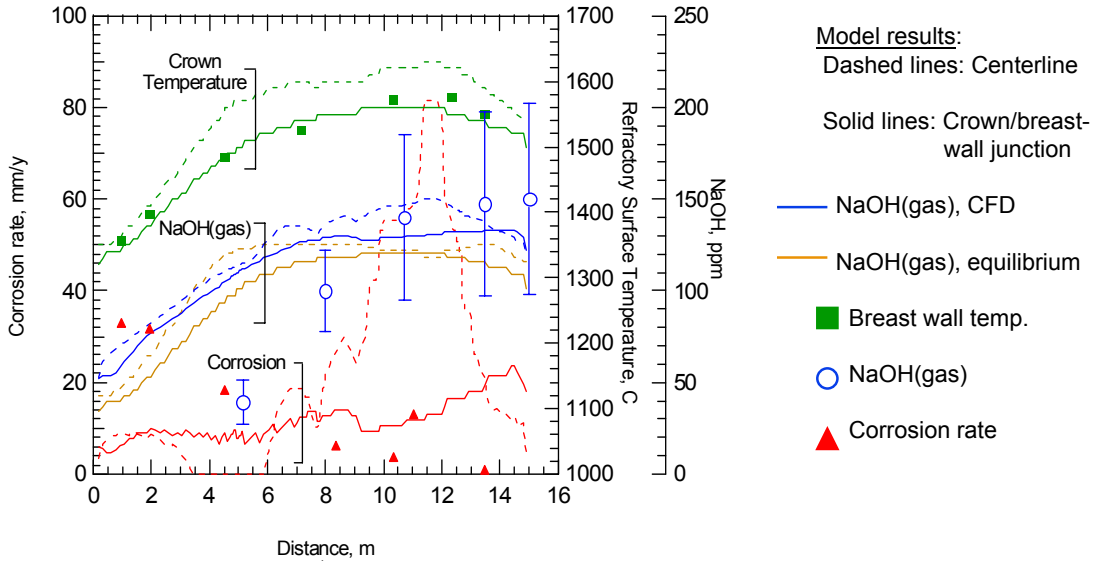
NaOH release rate from batch predicted by *Athena*

Corrosion data from an oxy-fuel container-glass furnace provided an opportunity to test the corrosion model

- **Gallo Tank #1 post mortem**
  - **operated oxy/fuel for 7 years**
  - **Furnace rebuild in 1998**
  - **Gallo provided:**
    - **Furnace operating conditions**
    - **Furnace dimensions**
    - **Photographs and video**
    - **Harbison-Walker post-mortem analysis of Gen-Sil brick**
    - **Corrosion rates**

Interior of Gallo Tank 1

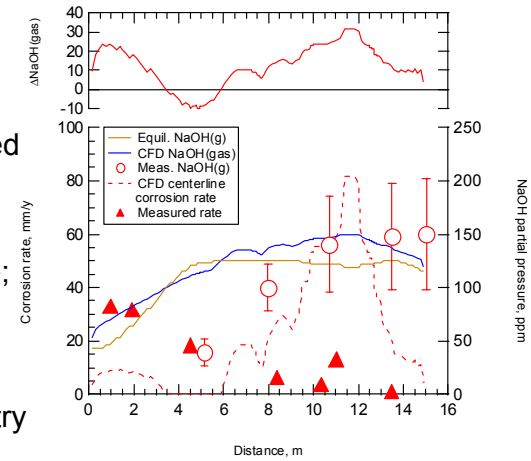
Predicted temperatures, NaOH concentrations are reasonable, while corrosion rates are in partial agreement with experiment



Use of the model in conjunction with measurements is probably the most effective approach to furnace optimization

$$\frac{dl}{dt} \approx \frac{\rho_{gas}}{\rho_{liq}} \left(X_{NaOH,\infty} - X_{NaOH,0} \right) Sh \frac{D}{L} \frac{(1 - x_{Na\,2O})}{2x_{Na\,2O}}$$

- Crown temperatures
  - Rarely measured, but can be calculated by furnace models
  - Accuracy of predicted values is limited by the heat-transfer model
- NaOH(gas) concentration:
  - Very few experimental data available; large uncertainties
  - NaOH volatilization models need further testing to be fully validated
  - Small uncertainties in thermochemistry also exist



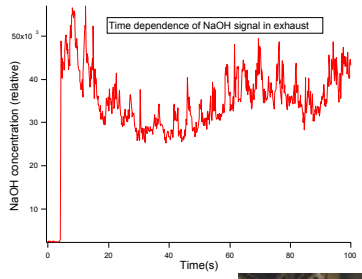
Centerline measurements vs. Model

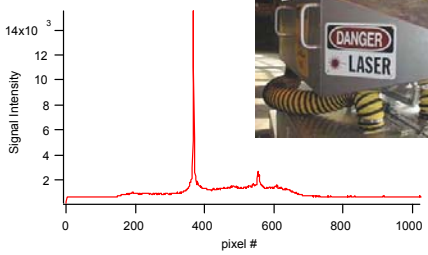
Conclusions

- Two potential rate-limiting steps are found to be unlikely:
  - Diffusion through product layer
  - In-depth corrosion (only important when $X_{NaOH(gas)} < X_{NaOH,eq}(T_{surface})$
- Gas-phase transport is likely rate-limiting mechanism, but requires either:
  - Actual NaOH(gas) concentrations less than generally accepted, or
  - Predicted *equilibrium* NaOH pressures that are <u>slightly</u> low
- Predicted corrosion rates are very sensitive to:
  - Gas-phase NaOH concentration
  - Solubility of Na_2O in SiO_2 at equilibrium
  - Crown temperature
  - ➔Clearly, additional measurements of both NaOH and temperature would be helpful in validating model predictions
- Within the limitations of model accuracy, CFD computational tools useful for designing furnaces to minimize corrosion should be feasible:
  - Useful for predicting trends as a function of conditions or design
  - High accuracy in absolute recession rates will be difficult to achieve

FY03 activities Task 3. Completed two field tests in representative full-scale glass facilities

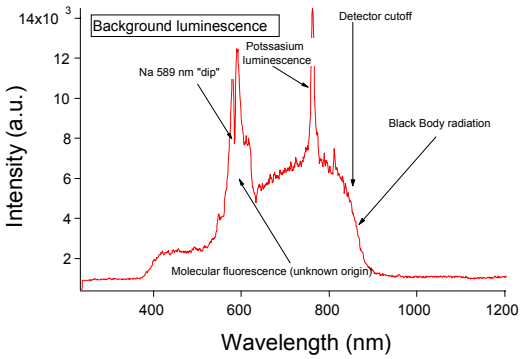
- September 2002 - Field tests at PPG Float plant in Fresno, CA -
  - LIFF instrumentation tests
  - Atmospheric sampling methodology transfer from PPG
- December 2002 - Field tests at PPG in Fresno, CA
  - Successful LIFF measurements
- March 2003 - Field tests at PPG in Fresno, CA
  - Successful atmospheric sampling
- July 2003 - Field tests at PPG in Meadville, PA
  - Successful LIFF measurements





December 2002 - Field tests at PPG in Fresno, CA

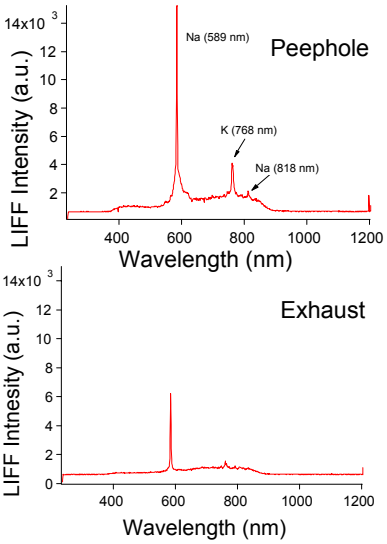
- Successful LIFF experiments
  - Strong NaOH signals detected
  - No interference from background radiation
- New cooling system worked well
  - All electronic equipment performed adequately (T > 120 °F near the furnace)
- Measured LIFF signal due to NaOH at 5 locations
  - Mid-tank peephole
  - Exhaust
  - Uptank peephole
  - Feeder
  - Downtank peephole
- Atmospheric sampling not completed due to gas-extraction sampling pump failure



Luminescence background looking directly into furnace through a peephole (5 second exposure)

December 2002 –LIFF signals through peephole & exhaust

- NaOH signal varied throughout the tank and exhaust ports
- Lowest signal at feeder due to minimum volatilization
- Signal in exhaust is about 1/2 the intensity in the tank
- KOH vs. NaOH varies as well
  - KOH/NaOH is higher in the tank than in the exhaust



LIFF signal - 1 second exposure time

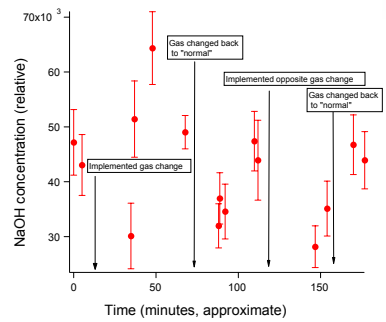
March 2003- Field tests at PPG in Fresno, CA

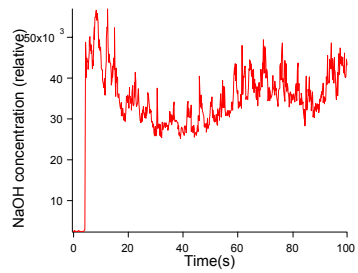
Extractive sampling and subsequent Na concentration analysis by PPG using Plasma Emission Analysis

- Measured atmospheric water vapor and total Na concentration using sampling probe and condensate collection
- Results agree well w/ measurements made in 2000 by PPG personnel
- More ash collected at the upper end of the tank
- Na concentrations relatively constant until the refiner, where they drop dramatically (as expected).
- Na distribution appears fairly uniform within tank.
- Sampling turnaround about 60-90 minutes.

July 2003 – field tests demonstrate utility of real-time diagnostics for process optimization

- PPG float-glass facility in Meadville, PA
- Monitor NaOH in exhaust only
- Made measurement while burner operating conditions were varied (top figure)
- Observed time dependence of NaOH signal (bottom figure)
- Improvements to LIFF instrumentation yielded much-improved NaOH sensitivity (6 X increase)





Results of this work are being transferred to industry

- Corrosion model converted to a subroutine for incorporation in large-scale furnace codes
  - Model already given to Air Liquide
  - Software will be transferred to Argonne National Laboratory for use in their furnace code
    - Follow-on funds will be requested from OIT to facilitate this transfer
- Thermodynamic data available on a web site
- Detailed modeling discussion published as a review article in *Glass Science and Technology*
- Publication of LIFF diagnostic results in progress

Potential follow-on work

- New concepts for reducing corrosion in crown refractories
  - OIT proposal submitted to FY03 solicitation
- Modeling framework (especially thermodynamics) could be applied to issue of melt-line corrosion
- Expanded use of the computational models of corrosion by incorporation in other codes, extension to other refractories, and application to a wider range of furnace types

Acknowledgements

- **Sandia National Laboratories**
  - **Dr. Robert Nilson (Transport Modeling)**
  - **Dr. Steven Rice (Laser Diagnostics)**
  - **Dr. Peter Walsh (Technical Discussions; furnace data)**
  - **Dr. Nancy Yang (Electron Microscopy)**
- **NARCO/Harbison-Walker Refractories**
  - **Ed Wolfe (Refractory Post Mortem Aalysis)**
- **Monofrax Inc.**
  - **Dr. Amul Gupta (Corrosion Testing)**
- **Gallo Glass Inc.: John Neufeld (Furnace Data); John Moore**
- **Pennsylvania State University: Prof. Karl Spear (Thermodynamic Calculations)**
- **American Air Liquide (CFD Calculations)**
  - **Dr. Ovidiu Marin**
  - **Dr. Ben Bugeat**
  - **Dr. Usman Ghani**

5

New Project Presentations

Development/Demonstration of an Advanced Oxy-fuel Fired Front-end System

In collaboration with

SYLVANIA THOMSON BOC ECLIPSE

DE-FC36-03GO13091

2003 DOE Glass IOF Project Review, Golden, Colorado, Sept. 9, 2003

Presentation Outline

- Background
- Project Goals
- Technical Approach
- Planned Work
- Expected Results
- Commercialization Plan
- Potential Value to Glass Industry

SYLVANIA THOMSON BOC ECLIPSE

Background – Vision & Reality

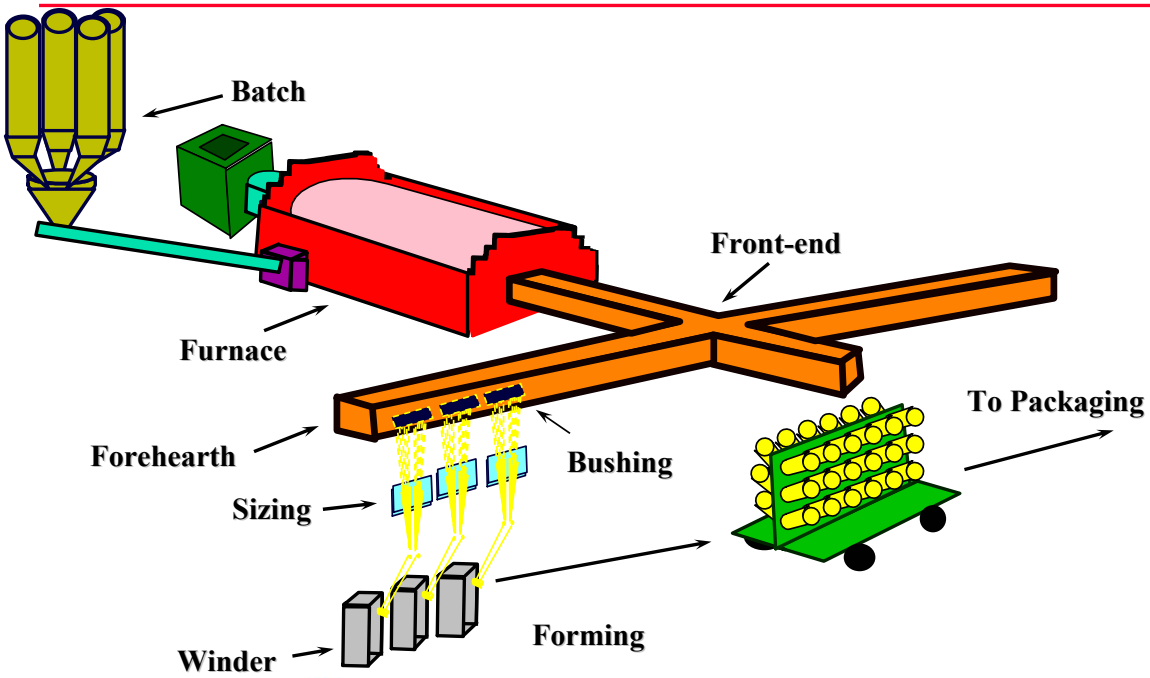
- Roadmap Calls for 50% Energy Reduction towards Theoretical Minimum and Six Sigma Glass Quality
- No Major Innovations in the Past 50 Years in Front-end Technology
- Oxyfuel Furnace Technology Redistributed Energy Usage
  - Oxyfuel Furnace 47% — Front-end System 53%
- Current Technology: Energy InEfficiency = 25%
  Massive Piping & Control Systems
- Premixed System Always a Safety Concern

Project Goals - The E^3 Advantage

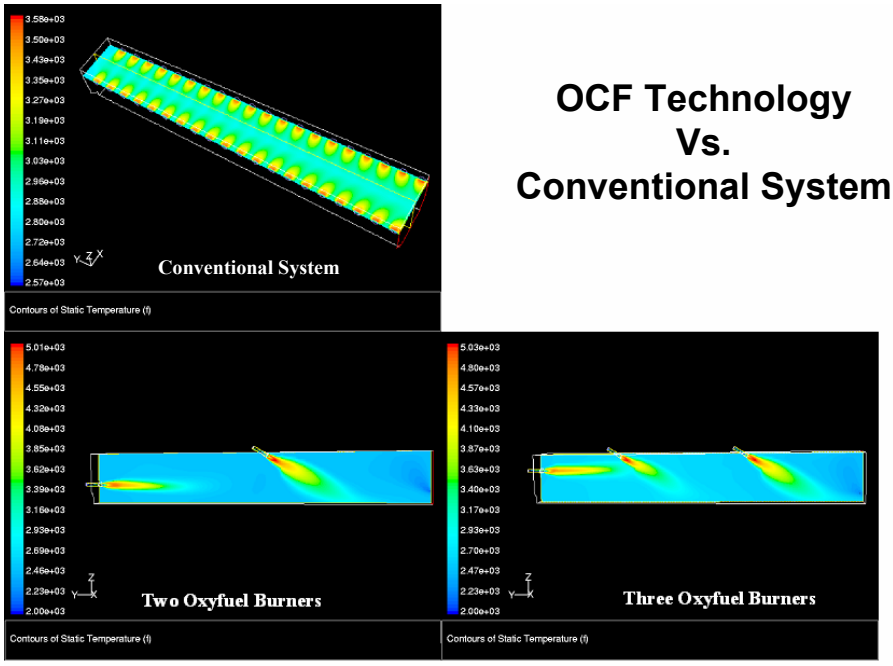
Develop Oxygen Combustion Front-end (OCF) Technology specifically for front-end systems that delivers high energy efficiency, improved glass quality, and robust environmental performance.

- Energy – 150% improvement in energy efficiency.
- Efficiency – Significant productivity benefit due to high glass thermal quality.
- Environment – Reduction in "Greenhouse" gas emissions (90% for NO_x and 70% for CO_2)

Technical Approach – Direct Melt Process

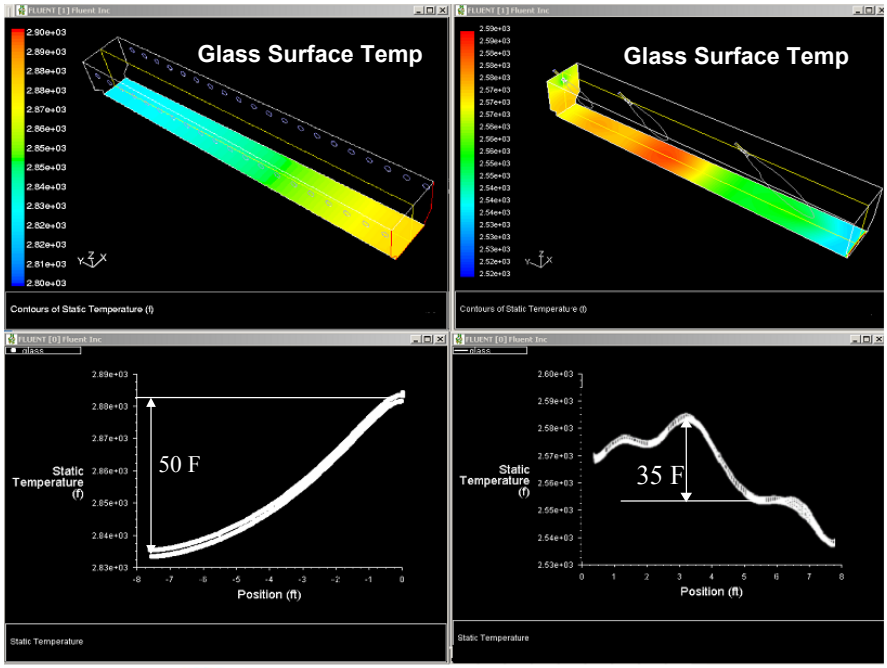


Technical Approach – OCF Technology

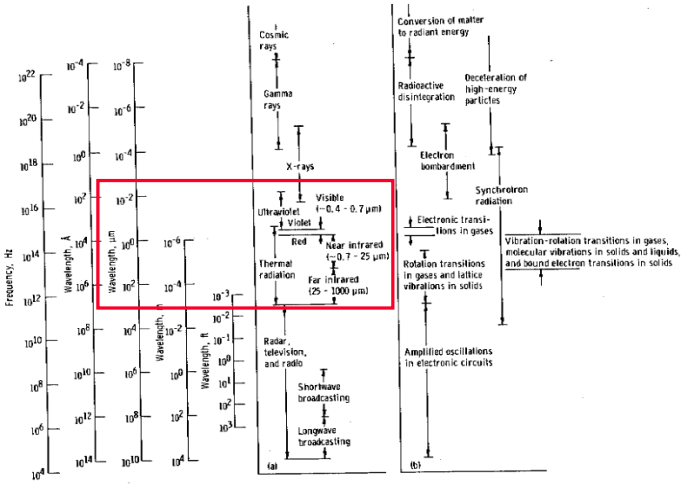


OCF Technology
Vs.
Conventional System

Technical Approach – Temperatures

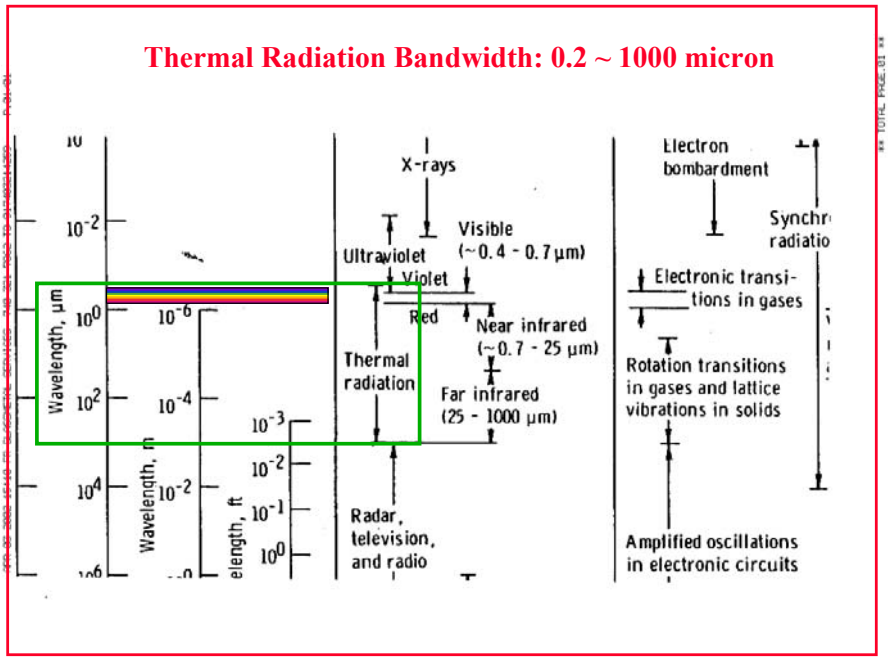


Technical Approach – Thermal Radiation



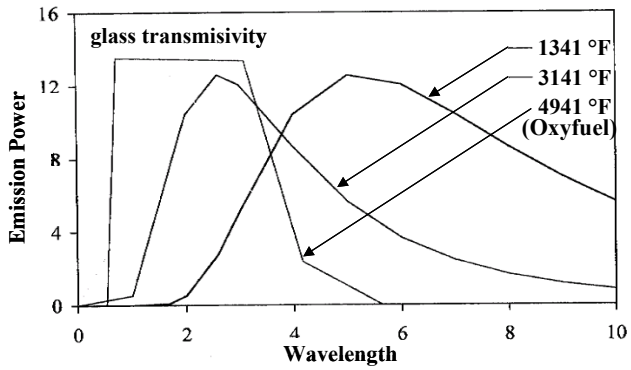
Spectrum of Electromagnetic Radiation

Technical Approach – Thermal Radiation



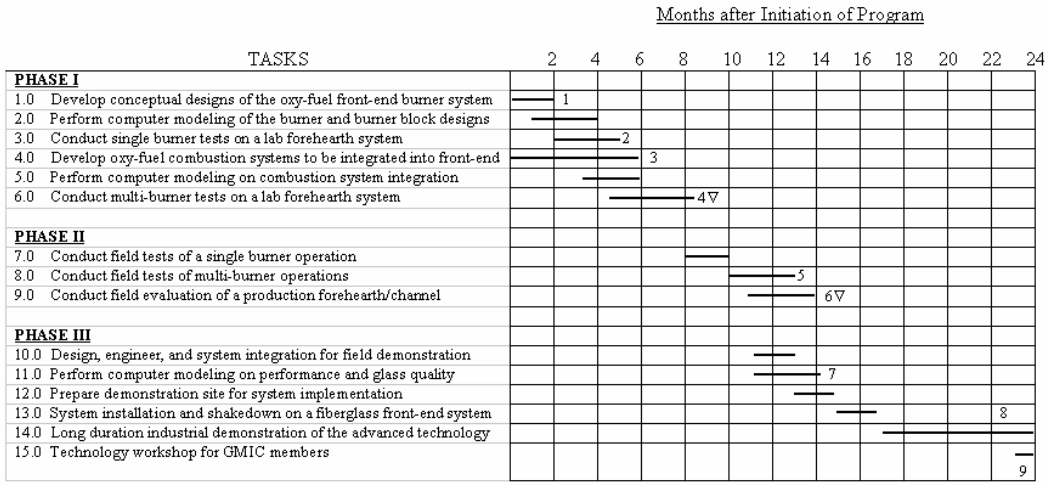
Technical Approach – Thermal Radiation

Spectral Radiation Emission Power



Radiation from combustion can penetrate glass melt.

Planned Work – Milestones & decisions



KEY MILESTONES

1 Conceptual designs specifically for front-end systems completed
2 Single burner operability completed
3 Complete system designs for front-end integration
4 Acquire field data on system controllability and durability
5 Evaluation of multiple burner systems completed
6 Complete field evaluation on production operation
7 Modeling of system performance and glass quality completed
8 Long duration demonstration operation underway
9 Provide feedback to the industry on the future of the technology
∇ Go/No Go decision points

Planned Work – At a glance

Strategy: Phased Approach

- **Phase I: Development & Lab Tests (Yr 1) (OC, CTI, BOC)**
- **Phase II: Field Tests of Components and Subsystems (Yrs 1&2) (OC, OS, TI, CTI, BOC)**
- **Phase III: Technology Demonstration on Production System (Yr 2) (OC, OS, TI, CTI, BOC)**

Expected Results

- Achieve Significant Energy Benefit
- Demonstrate Robust Environmental Performance
- Showcase System Simplicity & Capital Efficiency
- Initiate Investigation in Productivity Improvement

ALL ON A LARGE-SCALE PRODUCTION SYSTEM!

Commercialization

- Technology Proliferation: Consortium will ensure that the OCF Technology will benefit the industry
- Technology Transfer: GMIC Workshop
- Commercialization Strategy:
  - Additional testing in other sectors
  - A detailed commercialization plan will be developed

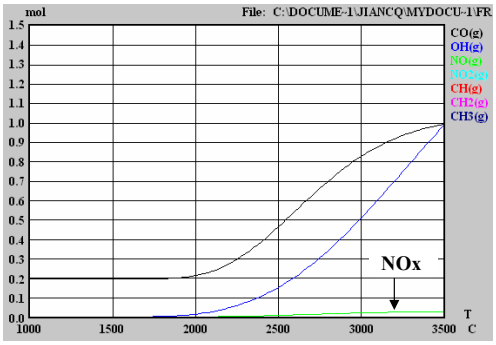
Potential Value to Glass Industry

Annual Market Growth: 2.0%
% Energy Savings Natural Gas: 70.0%

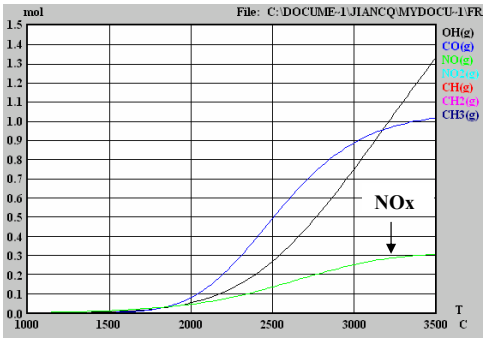
Sector: Fiber	2005	2010	2015	2020
Total Market (Million tons)	3.42	3.78	4.17	4.61
Market Penetration	4.4%	78.9%	99.7%	100%
ENERGY SAVINGS				
Energy Savings (trillion Btu)	0.5	10.2	14.2	15.7
POLLUTANT REDUCTIONS				
Carbon (MMCE/yr)	0.007	0.147	0.205	0.227
Carbon Monoxide (tons)	14.9	295.4	412.1	456.3
Nitrogen Oxides (tons)	54.5	1080	1506	1668

Potential Value to Glass Industry

- **Carbon Dioxide Reduction: 0.8 MMton/yr**
- **Nitrogen Oxides Reduction: 1,500 ton/yr**



Oxyfuel



Air/gas

Concluding Remarks

- Exciting Project Undertaken by an Industry Consortium
- Significant Energy, Environmental, and Efficiency Benefits
- Excellent Alignment with Glass Industry Vision and Technology Roadmap
- Enhancement of U.S. glass industry competitiveness

The Team welcomes all suggestions, comments, and opportunities!

Energy-Efficient Glass Melting - The Next Generation Melter

by
David Rue
Gas Technology Institute

Glass Industry Consortium

2003 Project-Industry Review
Sept. 9, 2003

Glass Melting - Overview

- Melting varies in scale, residence time, glass composition, temperature, refractory composition, heating method, etc. but the same general approach is used for all industrial glass production
- Glass melting is a demanding industrial process
- Glass furnaces have improved with better refractory, better design, oxy-gas firing, etc. but the basic process has not changed in 100 years
- Any new glass melting process must –
  - do everything current melters do
  - lower the cost of making glass
  - Save energy and lower emissions
  - Be highly reliable

Requirements for NGMS Melting Step

- Melt all glass compositions
- Scalable from 25 to 500+ tons/day
- Rapid melting (high heat transfer)
- Low capital cost (small size, minimal refractory)
- Long furnace life
- High thermal efficiency
- Homogeneous product (needed for rapid fining)
- Low emissions (CO, NO_x, particulates)
- Stable operation over wide range of pull rates
- Low volatilization of alkalis, borates, etc.
- Reliable, low-cost batch handling and charging
- Foam management
- Redox control
- Physically compatible with rapid fining step of NGMS

Submerged Combustion Melting Principle

- Air-fuel or oxygen-fuel mixture is injected directly into a pool of hot melt
  - intense combustion
  - direct contact heat transfer - combustion products bubble through the melt
    - reduced NO_x formation
    - reduced CO and unburned hydrocarbon emissions
  - High rate of heat transfer and rapid mass transfer
    - High thermal efficiency
    - Reduced melter size

Submerged Combustion Melting Features

- Melting and mixing in a single stage
  - Provides simplicity and lower capital cost
  - Rapid glass melter that homogenizes the glass and does NOT need a mixing stage before the rapid fining stage
- Melter is simple, robust, and reliable
- Compatible with other stages of a segmented glass melting system
  - Charging
  - Rapid fining
  - heat recovery

Submerged Combustion Melting History

- Over 40 U.S. and international patents have been issued in the last 50 years related to SCM for glass
  - Most patents are not practical
  - Many of the patents are related or refinements
- Related patents have been obtained by Selas, PPG, IGT, Union Carbide, Owens Corning, St. Gobain, Ausmelt, and others
- SCM processes have mostly been limited to concepts but several have been built and operated
  - Selas Corp. pilot-scale container glass SCM
  - GI-Ukraine and GTI pilot-scale test SCM and commercial melters for mineral wool and cement aggregate

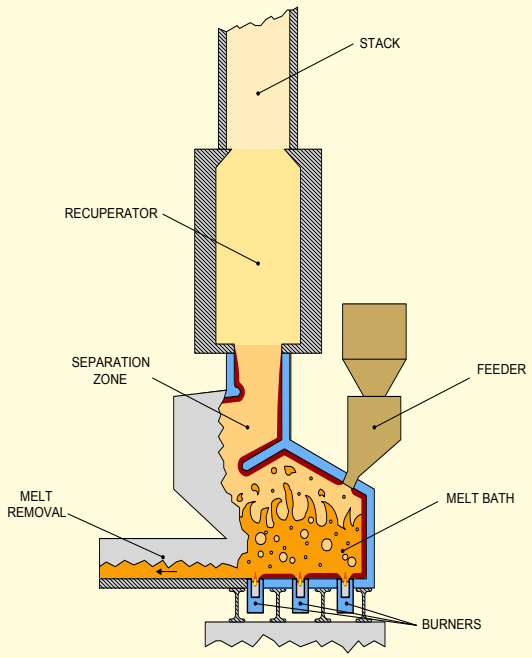
Limitations of Early SCM Approaches

- Air-gas fired melters
  - Too many burners were needed
  - Heat transfer to melt was not optimized
  - Too many bubbles, including N_2 bubbles, added to the melt
- Refractory walls
  - Active melt abraded the wall
  - Melter was too large and costly
  - Hot repair work was still required
- Shallow bath
  - Required too many burners
  - Difficult to control foaming
  - Surface area of melt was too large

GTI and GI SCM History

- Gas Institute (Ukraine) developed SCM for mixed nuclear waste vitrification and industrial melting
- GTI holds patents and background IP in melting, submerged firing, and heat recovery
- Commercial, air-fired units have been operating for more than 10 years
  - two 3-ton/h rockwool SCM units in Kiev, Ukraine
  - three 3-ton/h rockwool SCM units in Byarosa, Belarus
  - One SCM cement aggregate unit in Noril'sk Russia
- GTI has licensed the SCM technology for applications outside the former Soviet Union
- 500-lb/h SCM unit fabricated and operated at GTI
  - Multiple melts compositions including black glass
  - First use of oxy-gas burners

GTI and GI-Ukraine SCM Technology



- Developed by Gas Institute-Ukranian National Academy of Sciences and Gas Technology Institute
- Natural gas-fired process to generate high-temperature melts
- Externally cooled walls used instead of refractory
- 5 Commercial 75 ton/day mineral wool units in Ukraine and Belarus
- 6 ton/day pilot plant installed at GTI – air-gas and oxy-gas second generation burners

SCM Advantages - Operational

- Ease and speed of start-up and shut-down
  - cold start to full operation in under 4 hours
  - shut-down with empty or full melt chamber
  - No hot repairs required
- Rapid switching of product composition while maintaining a homogeneous product melt
- Oxy-gas firing provides high thermal efficiency, rapid heat transfer, and simple combustion system
- Reliable, proven melting technology
  - Can be idled if necessary
  - Deep bed enables control of foaming and volatilization
- Accepts wide batch size range, multiple feed streams, any charging below the melt surface
- Compatible with rapid fining and heat recovery
- Excellent redox and color control

SCM Advantages - Economic

- Compact melter with very little refractory
  - Melt area is approximately 15% of tank melter area
  - >80% reduction in refractory
- Low capital cost – >75% capital cost reduction
- Lower fuel requirements
  - 10% decrease from lower wall losses
  - Lower peak temperature also decreases fuel use
  - Energy can be recovered several ways from externally cooled walls
- Easy start-up and shut-down allows operation in small markets
- High H_2O content makes fining and forming easier
- Lower cost fuels such as syngas can be used
- Reduced feed preparation costs since SCM can handle a wide range of feed sizes, either mixed or uniform
- Alternative raw materials such as Na-Li can be utilized

SCM Advantages - Environmental

- NO_x emissions 50% below oxy-gas melters as a result of lower fuel use and decreased peak flame temperatures
- Alkali attack virtually eliminated since walls are protected with frozen glass
- Essentially ANY glass can be melted at ANY temperature because walls are externally cooled
- Volatiles can be captured by batch and returned to the melter
- Reduced CO_2 emissions with fuel savings
- Culltet and scrap glass can be returned to the melter
- Very little waste refractory requiring disposal

SCM Saves Energy

Melter		Tank	SCM	SCM
Wall Heat Rec., %		0	0	20
Res. Time, h	Melter	--	4.5	4.5
	Fining	--	3.25	3.25
	Total	30	7.75	7.75
Pull Rate, ton/ft2.day	Melter	--	0.63	0.63
	Fining	--	0.47	0.47
	Total	4.2	1.1	1.1
Surface Area,	Melter	--	15	15
% of tank melter	Fining	--	11	11
	Total	100	--	--
Wall Loss,	Melter	--	0.48	0.39
MMBtu/ton	Fining	--	0.07	0.07
	Total	0.73	0.55	0.46
Total Energy, MMBtu/ton		3.64	3.46	3.37
Energy Savings, %		0	5	7.5

Assuming SCM wall losses of 3 times tank wall losses in Btu/ft^2.h

MELT CHAMBER – Byarosa Belarus

SCM MELT CHAMBER

Pilot-Scale SCM at GTI

Pilot-Scale SCM Operation-

Cement Kiln Dust Mixture

SCM Burners

First generation

air-gas only

operating in Kiev and Belarus melters

Second generation

oxy-gas and air-gas

operated on GTI pilot-scale melter

Energy Efficient Glass Melting - The Next Generation Melter

- Project objective is to demonstrate the melting and homogenization stage of a low capital cost, energy efficient Next Generation Glass Melting System
- The high intensity glass melter will be based on the submerged combustion melting technology
- Work will include
  - design and operation of a 500 to 1000 lb/h melter
  - CFD modeling of the process
  - Evaluation of oxygen production using Praxair Oxygen Transport Membranes (OTM)
  - Product glass analysis
  - Planning for next phase of NGMS development

Project Sponsors

- U.S. Department of Energy – OIT
- Gas Industry
  - GTI Sustaining Membership Program (SMP)
  - Gas Research Institute FERC funds
- New York State Energy Research and Development Authority (NYSERDA)
- Six glass companies each providing –
  - cash
  - 1 man-year of effort

Project Participants

- GTI
- Glass company consortium (6 glass companies)
- Fluent, Inc.
- A.C. Leadbetter and Son, Inc.
- Praxair, Inc.
- Combustion Tec / Eclipse
- Consultants
  - Leonard S. Pioro - SCM developer
  - Vladimir Olabin – Gas Institute, Ukraine
  - John Brown – glass technology and GMIC contact
- GMIC - monitoring

Glass Company Consortium

Member have over 50% of domestic glass sales value

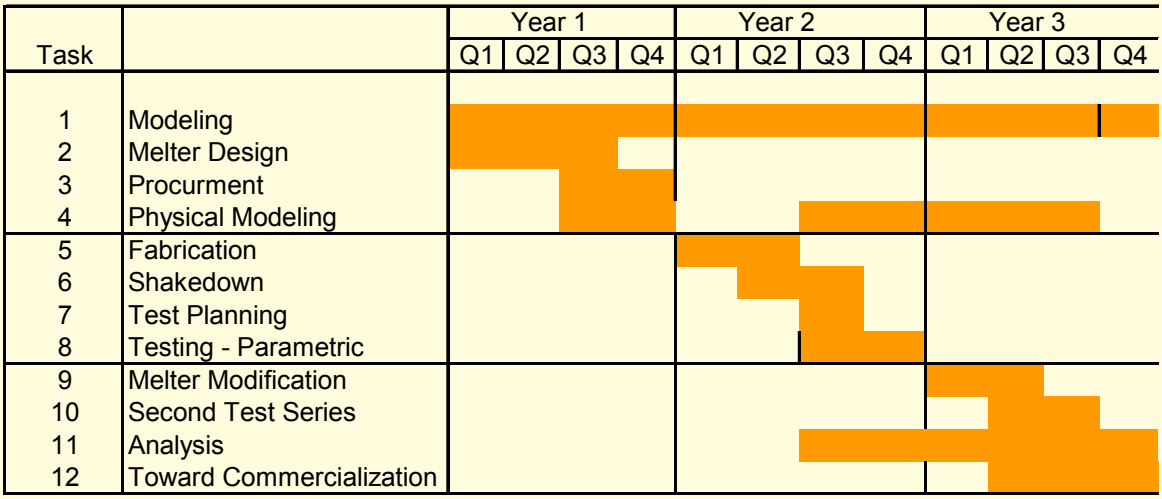
- CertainTeed Corp.
- Corning Incorporated
- Johns Manville
- Owens Corning
- PPG Industries, Inc.
- Schott Glass Technologies, Inc.

Work Scope – Focus on Melting

36-month project

Year 1	Preparation for Melting	•CFD Modeling •Design •Procurement •Physical Modeling (OTM)
Year 2	Melter Assembly and Initial Testing	•Fabrication and Shake-Down •Test Planning •Testing and Analysis
Year 3	Testing and Moving Toward Commercialization	•Melter Modifications •Testing and Analysis •Toward Commercialization

Project Schedule



Year 1 – CFD Modeling

- CFD model to be developed by Fluent, Inc.
- Model of melter 3-phase flow
  - Mixing – charging and discharge locations, melter shape and depth
  - Heat transfer – in the melter, to exhaust, to walls
  - Combustion – burner placement, emissions
  - Residence time – glass homogeneity, bubbles, seed count, foaming, devitrification
  - Thickness and impact of frozen glass on externally-cooled walls
- Initial model to be available to project team companies to assist in pilot melter design

Year 1 - Design

- Design of pilot-scale melter by GTI
- after consultation with Dr. Pioro to learn background experience
- With review and recommendations of glass company consortium
- Detailed pilot melter design by A.C. Leadbetter and Son
- Design of 500-1000 lb/h melter to include
  - Batch charging system with prepared forumulas
  - Melter with water-cooled walls
  - Combustion system
  - Melter with as much flexibility in charging, burner patterns, and melt discharge as possible
  - Melt discharge and glass collection system
  - Exhaust gas cleaning and monitoring systems
  - Instrumentation and controls

Year 1 – Design Support

- Consultation with glass company consortium on needed capabilities of pilot melter
- Detailed review of early SCM design and testing of multiple melt formulas by Pioro at Gas Institute of Ukraine
- Laboratory tests may be useful to check various questions
  - Metal contamination of glass
  - Devitrification
  - Burner placement patterns
- Final design will be reviewed by full project team befor procurement and assembly begins

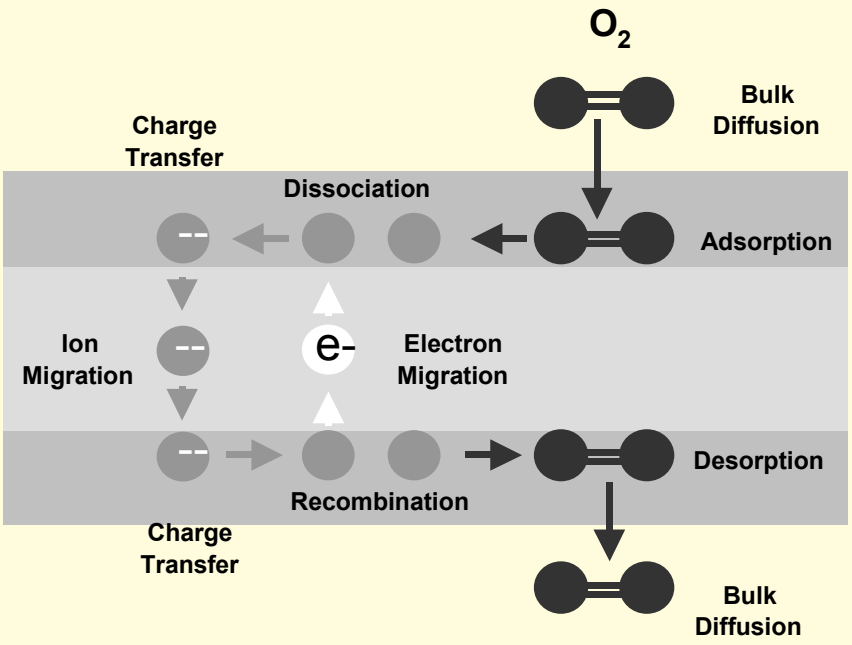
Year 1 - Procurement

- To be assembled at GTI
- Procurement through GTI with Leadbetter specification and review
- Leadbetter engineers have seen working SCM units in Ukraine and Belarus
- Design will be as simple as possible to provide the needed data and operating experience
- Standard equipment will be used for all systems except the melter itself and the burners
- The melter will be designed to operated for reasonable periods of time in continuous mode but will not be designed for continuous operation

Year 1 – Physical Modeling (OTM)

- Praxair (project partner) is developing oxygen transport membrane (OTM) technology to use energy in hot exhaust gas to separate oxygen from air
- OTM holds potential to lower oxygen cost for oxy-gas glass melters
- Praxair will begin in Year 1 with initial OTM process design tailoring OTM to the SCM design

Praxair Mixed Conductor Transport Mechanism for OTM



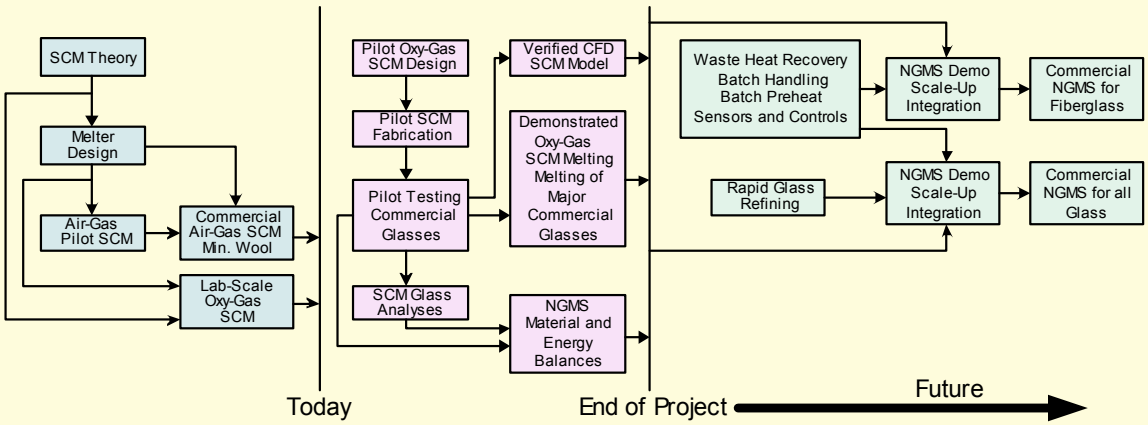
Project Status

- All paperwork is submitted to DOE and NYSERDA
- Gas industry support (FERC and SMP) is approved
- DOE project started in September (last week)
- Organizing GTI project team including consultants
- Glass company consortium met at GTI in July
  - Discussed goals and support from each company
  - Agreed on general language of consortium agreement
  - Agreement to be signed soon (thanks for Fred Quan's work)
- Melter siting is arranged at new GTI facility
- Plans to meet with Prof. Pioro in September
- Engineering company and Fluent ready to begin when design approach is set for the pilot melter

Project Budget

Budget, $K	Year 1	Year 2	Year 3	Total
DOE - OIT	1311	1335	1186	3832
Gas Industry - FERC	700	0	0	700
Gas Industry - SMP	0	150	150	300
NYSERDA	67	67	67	201
Glass Co. Consortium	100	100	100	300
Total - Cash	**2178**	**1652**	**1503**	**5333**
Fluent - In-Kind	28	28	28	84
Glass Co. - In-Kind	167	167	167	501
Praxair - In-Kind	7	7	7	21
Total Budget	**2380**	**1854**	**1705**	**5939**

NGMS Development Path



Plasmelt Glass Technologies, LLC
High Intensity Plasma Glass Melter

- Agenda (*What, How, Why, When, Who*)
  - Project Overview (What)
  - Theory of Operation (How)
  - Plasma Melting Value to the Glass Industry (Why)
  - Project Plan (When)
  - Project Team (Who)
  - Summary

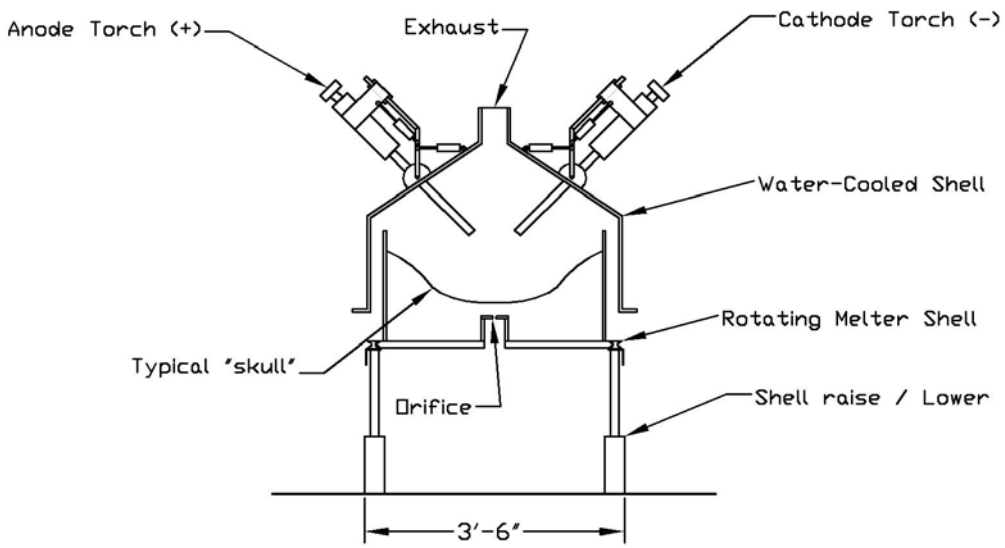
Project Overview

- History
  - JM developed technology in 90's
  - Developed scrap processing and batch melting
  - Tested and proved system works at:
    - Low throughput rates / low efficiency
    - High throughput rates / high efficiency / low torch life
  - Tested with scrap material
  - Program canceled because of time to complete / risk / business focus / questionable efficiencies

Project Overview

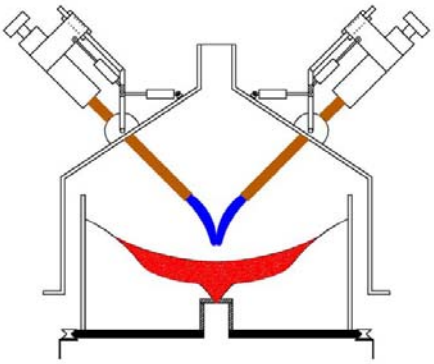
- Build a transferred-arc plasma melter
- Establish baseline operation at 500 lbs/hour
- Determine market requirements
- Produce marbles & fibers / test quality at partners site
- Commercialize process

Project Overview



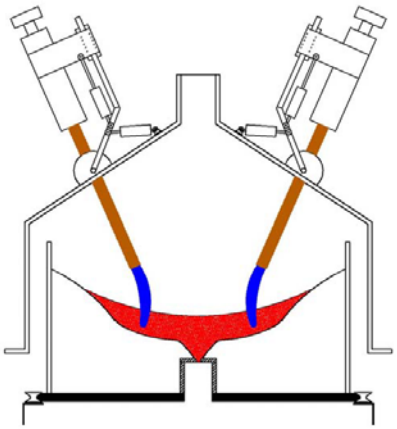
Theory of Operation

- Operating Condition #1
  - ~500 Amps, 200 Volts
  - Radiant HT + Conductive
  - 15 to 25% efficient
  - 200 lbs/hr
  - Stable operation / Long torch life



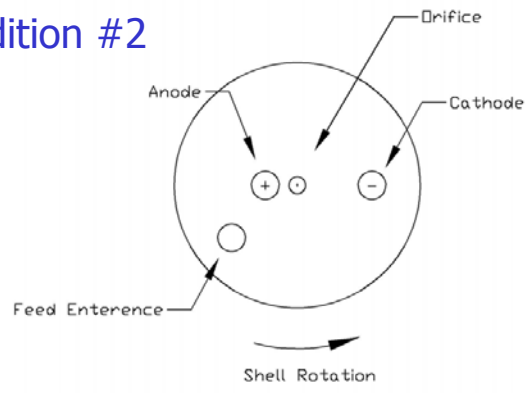
Theory of Operation

- Operating Condition #2
  - ~1,000 Amps, 400 Volts
  - Radiant + Conductive + *Resistive* HT
  - 30 to 50% efficient
  - 1,200 lbs/hr
  - Unstable operation / Short torch life



Theory of Operation

- How to get to Operating Condition #2
  - Feed position
  - Material feed rate
  - Optimize HT
  - Torch design
  - Amperage control
  - System control
  - Exit glass temperature and mass flow controls



Theory of Operation

- Video of Condition 1

Theory of Operation

- Video of Condition 2

Plasma Melting – Value to Glass Industry

(Sample Data from DOE Energy Estimator)

Energy Source	Total Energy (10^6 Btu/Ton)	1997 Production (Tons)	Net Industry Use (10^{12} Btu)
Pressed and Blown			
Regenerative	5.5	645,887	3.6
Direct Melters	12.0	844,622	10.1
Oxy-Fuel	3.6	869,464	3.1
Electric	10.3	124,209	1.3
Insulation Fiber Glass			
Electric Melters	7.5	1,436,400	10.8
Recuperative Melters	7.0	402,192	2.8
Oxy-Fuel	5.6	76,608	0.4

Plasma Melting – Value to Glass Industry

(Sample Data from DOE Energy Estimator - Continued)

Energy Source	Total Energy (10^6 Btu/Ton)	1997 Production (Tons)	Net Industry Use (10^{12} Btu)
Textile Fiber			
Recuperative Melters	10.5	1,079,808	11.3
Oxy-Fuel Fired	5.6	44,992	0.3
Grand Total—Annual Potential Target Market		3,608,982	43.7

- Project plasma energy consumption:
  - Our model: 4.1 (10^6 Btu/Ton Glass)

Plasma Melting – Value to Glass Industry

- Energy Efficiency
- Production Flexibility
  - 20 min startups / stops
  - Can melt many different materials
  - Fast process response time
- Modular / Scalable
  - Can add additional melting capacity in modular blocks
  - Provide means of matching production requirements with market demand
- Ability to Quickly Start / Stop Process
  - Better power rates
  - Improved labor utilization

Plasma Melting – Value to Glass Industry

- Scrap Processing
  - Standard technology with ability to process several types of material
  - Ability to use same melter for batch melting and scrap processing
  - Industry-proven technology for processing scrap material
  - Landfill cost was very expensive
  - Potential long-term issues with landfill of big concern
- Low-capital system
  - Small
  - Modular
  - No refractory
- Capability to process new materials
  - Unique high temperature materials
- Small exhaust stream

Plasmelt's Market Focus

- Broadly commercialize a generic melter in both glass and non-glass applications
  - Glass (Pressed & Blown and Fiberglass) are Initial Targets
    - Specialty Fiberglass
    - Insulation Fiberglass
    - TV Tubes and LCD's
    - Lighting
    - Labware
  - Non-glass materials with lower quality-critical needs
    - High Temperature Refractories
    - High Temperature Reinforcing Materials (e.g. Low CTE Materials)
    - Scrap & Waste Recovery

.....to be validated / updated by the Plasmelt Marketing Study

Project Plan

- Project Plan – Year 1

Project Start	7/29/03
Facility Selection	8/21/03
Utilities / Facility Modifications	10/28/03
System Design	12/11/03
Construction	1/22/04
Initial testing	2/27/04
Full-scale testing	4/30/04
Market Development	2/13/04
Glass Cullet Testing	6/11/04

Project Plan

- Project Plan – Year 2
  - Marble production / fiberizing and quality testing at cost-share partners site
  - Continued equipment / process development to meet market requirements
  - Prototype installation in production facility

Project Accomplishments to Date

- Facility selected / leased
- PRD Published
- Staff identified / retained
- Torch design started 15% complete
- Ancillary equipment design started
- HF Start unit designed / components purchased
- Energy model completed

Known Obstacles

- Technical Obstacles:
  - Anode torch life
  - Glass Quality (mixing, refining, volatilization)
- Market Obstacle
  - No installed base in the glass industry
  - Process economics
    - Capital, abatement, power source, etc.

Project Team

- Plasmelt Team
  - Ron Gonterman-Glass Technology & Glass Research Management
  - Michael Weinstein-Mechanical Engineering & Plasma Technology
  - Jim Hayward-Glass Melting, Furnace Operations, and Design
  - Oleg Prokhorenko-Glass Properties & Computer Modeling
  - Bob Kirkland-Plasma Technology Benchmarking
  - Gabe Tincher-Technoeconomic Analysis & Marketing
  - David Bennert-Environmental Systems Engineering & DOE Project Work
- Cost Share Partners
  - **Johns Manville**
  - **Advanced Glassfiber Yarns**

Summary

- Plan
  - Year 1:
    - Design, construct, operate 500 #/hr high-quality glass melter in Boulder, Colorado Lab
  - Year 2:
    - Install, operate marble making facilities and produce fibers for glass quality assessments
    - Install industrial process at first prototype location
  - Year 3:
    - Commercialize and scaleup at cost share partners fiberglass facilities & in other US glass industry segments
    - Continue to operate the Boulder Lab melter to support materials-melting trials for potential commercial clients identified by the Plasmelt Marketing Study
    - Broadly license and support the technology

Summary

- Technical Merit:
  - Potential 25 to 40% energy savings
  - Need – New technology / new markets
  - Contribution of knowledge – Little existing
- Technical Progress:
  - Progress – On track
  - Expectations for successful solution – Our system is building on proven technology. We are using best resources with an entrepreneurial drive to make this a successful project.

Summary

- Market Potential:
  - Broadness of application – serves several segments of glass industry
  - Adaptation potential – Low-cost solution to several commercial requirements / opportunities
- Programmatic Merit:
  - Benefits – Lower cost of production on several fronts
  - Resources - Best in industry
  - Commercialization plan – Focused on profit

Appendix A

Sample Evaluation Forms and Scoring Standards

PROJECT:
Project Title Here
(Principal Investigator, Organization)

Reviewer:_____

I. Technical Merit **Rating** **1** **2** **3** **4** **5**

A. Technical Need (Does the project address an important technical need of the glass industry?)

Comments: _____

_____

B. Contribution of Knowledge (Will this project contribute new information or technology to the knowledge base of the glass industry?)

Comments: _____

_____

II. Technical Progress **Rating** **1** **2** **3** **4** **5**

A. Adequacy of Progress (Is the research being performed competently and proceeding at a reasonable pace? Are project objectives being addressed as planned?)

Comments: _____

_____

B. Expectations for Successful Completion (How appropriate is the planned technical approach and schedule for completion? What is the likelihood that the project will meet its technical objectives as scheduled?)

Comments: _____

_____

III. Market Potential **Rating** **1** **2** **3** **4** **5**

A. Broadness of Application (If successful, will results be applied in the entire industry, or narrowly applied to a particular segment? Will results be applicable to other industries?)

Comments: _____

_____

B. Adoption Potential (If successful, will the technology/information achieve widespread adoption? Will adoption be achieved in the near-term, or not until the long-term?)

Comments: _____

_____

Please turn to reverse side ---------->

IV. Programmatic Merit **Rating** **1** **2** **3** **4** **5**

A. Energy, Economic, and Environmental Benefits (If successful, will the research results provide tangible energy, economic, and environmental benefits to the glass industry?)

Comments: _____

_____

B. Project Resources and Commercialization Plan (Does this project have adequate resources to accomplish its objectives? Has the project team developed a reasonable commercialization plan?)

Comments: _____

_____

C. Project Value (In your opinion, is the cost of the project in line with the anticipated value of the results?)

Comments: _____

_____

VI. Other Comments

Please comment on the project's strengths and weaknesses:

_____

_____

_____

Please comment on whether there are potential barriers to successful completion and, if so, has the project team addressed these barriers:

_____

_____

_____

Please provide additional comments or suggested changes that could be made to improve this project:

_____

_____

_____

_____

_____

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_____

GLASS PROJECT REVIEW SCORING STANDARDS
CONTINUING PROJECT EVALUATIONS

Reviewers should use the following numerical scale in rating the projects:

Technical Merit

5 **Outstanding**: The project's technical merits are exceptional and directly relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project represents a critical, significant advancement over current technical capabilities.

4 **Very Good**: The project's technical merits are very good and directly relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project will substantially supplement existing knowledge and/or offer an entirely new technology to the U.S. glass industry.

3 **Satisfactory**: The project's technical merits are sound and relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project will supplement existing knowledge and/or offer a modification on existing technology.

2 **Marginal**: The project's technical merits are marginal and somewhat relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project will produce a new application of existing technology but will not supplement existing knowledge or offer new technology.

1 **Unsatisfactory**: The project has few technical merits and is a repetition of existing work.

Technical Progress

5 **Outstanding**: The research is being performed expertly and is proceeding at an impressive rate. The overall project schedule is appropriate. Project objectives are being met at or ahead of schedule, and the project team is almost assured of meeting the remainder of its technical objectives on or ahead of schedule. The project team includes direct involvement in planning, guidance, and conducting the research from multiple industrial partners.

4 **Very Good**: The research is being performed expertly and is proceeding at a reasonable rate. The overall project schedule is appropriate. Project objectives are being met on schedule, and the project team is highly likely to meet the remainder of its technical objectives on schedule. The project team includes direct involvement in planning, guidance, and conducting the research from at least one industrial partner.

3 **Satisfactory**: The research is being performed competently and is proceeding at a reasonable rate. The overall project schedule is appropriate. Project objectives are being met on or slightly (less than 60 days) behind schedule, and the project team is likely to meet most of its remaining technical objectives on schedule. The project team includes direct involvement in planning and guidance, but no direct R&D involvement, from at least one industrial partner.

2 **Marginal**: The research is being performed competently in most aspects, but there are areas where improvement is needed. The overall project schedule is unnecessarily lengthy. Progress is slow; the project team is behind schedule in meeting most objectives. The project team is likely to meet some of its remaining technical objectives but not meet others. The project team has had moderate communication with industry on planning and guidance, but limited direct industry involvement.

1 **Unsatisfactory**: The research is not being performed competently, and significant improvement is needed. The overall project schedule is unnecessarily lengthy. Progress is slow; the project team is far behind schedule in meeting its objectives, and the team is unlikely to meet its remaining technical objectives. The team has demonstrated little interaction or involvement with industry.

Market Potential

5 **Outstanding**: The technology or knowledge being developed by this project is broadly applicable across multiple segments of the U.S. glass industry. The project team has developed a detailed, realistic written commercialization plan, and, if successful, the potential for application of the project results is highly likely.

4 **Very Good**: The technology or knowledge being developed by this project is broadly applicable across more than one segments of the U.S. glass industry. The project team has completely and accurately considered commercialization, and a cursory written plan is in place. If successfully concluded, continued development and application is highly likely.

3 **Satisfactory**: The technology or knowledge being developed by this project is broadly applicable across more than one segment of the U.S. glass industry. The project team has considered and recorded preliminary commercialization plans. If successfully concluded, continued development and application is likely.

2 **Marginal**: The technology or knowledge being developed by this project is applicable across a single segment of the U.S. glass industry. The project team has considered a commercialization plan on a cursory basis, but no written plan exists. If successfully concluded, continued development and application is unlikely.

1 **Unsatisfactory**: The technology or knowledge being developed by this project is applicable to only a single company in the glass industry. The project team has not considered a commercialization plan. If successfully concluded, continued development and application is highly unlikely.

Programmatic Merit

5 **Outstanding**: The project, if successfully developed and implemented, will offer significant energy savings, environmental benefits, and economic benefits in multiple segments of the U.S. glass industry. The project has outstanding technical, financial, and human resources assigned to it.

4 **Very Good**: The project, if successfully developed and implemented, will offer significant energy savings, environmental benefits, and economic benefits in more than one segment of the U.S. glass industry. The project has strong technical, financial, and human resources assigned to it.

3 **Satisfactory**: The project, if successfully developed and implemented, will offer significant energy savings, environmental benefits, and economic benefits in at least one segment of the U.S. glass industry. The project has appropriate technical, financial, and human resources assigned to it.

2 **Marginal**: The project, if successfully developed and implemented, will offer moderate energy savings, environmental benefits, and economic benefits at least one segment of the U.S. glass industry. The project has inadequate technical, financial, or human resources assigned to it.

1 **Unsatisfactory**: The project, if successfully developed and implemented, will offer minor energy savings, environmental benefits, and economic benefits to only participating firms. The project has inadequate technical, financial, and human resources assigned to it.

PROJECT:
Project Title Here
(Principal Investigator, Organization)

Reviewer:_____

I. Technical Success **Rating** **1** **2** **3** **4** **5**

A. Technical Objectives (Has the project met its technical objectives?)

Comments: _____

_____

B. Contribution of Knowledge (Has this project contributed new information or technology to the knowledge base of the glass industry?)

Comments: _____

_____

II. Commercial Readiness **Rating** **1** **2** **3** **4** **5**

A. Ready for Commercial Use (Is the technology/information ready for commercial use, or is further development needed?)

Comments: _____

_____

B. End-User Commitment (Are potential end-users committed to implementing the technology/information?)

Comments: _____

_____

III. Market Potential **Rating** **1** **2** **3** **4** **5**

A. Broadness of Application (Will results be applied in the entire industry, or narrowly applied to a particular segment? Will results be applicable to other industries?)

Comments: _____

_____

B. Adoption Potential (Will the technology/information achieve widespread adoption? Will adoption be achieved in the near-term, or not until the long-term?)

Comments: _____

_____

Please turn to reverse side ---------->

IV. Programmatic Merit **Rating** **1** **2** **3** **4** **5**

A. Energy, Economic, and Environmental Benefits (Will the research results provide tangible energy, economic, and environmental benefits to the glass industry?)

Comments: _____

_____

B. Project Resources and Commercialization Plan (Were project resources sufficient to accomplish its objectives? Has the project team developed a reasonable commercialization plan?)

Comments: _____

_____

C. Project Value (In your opinion, was the cost of the project in line with the anticipated value of the results?)

Comments: _____

_____

VI. Other Comments

Please comment on the project's strengths and weaknesses:

_____

_____

_____

Please comment on whether there are potential barriers to successful development and implementation and, if so, has the project team addressed these barriers:

_____

_____

_____

Please provide additional comments to guide the development and implementation of this technology/information:

_____

_____

_____

_____

_____

_____

_____

GLASS PROJECT REVIEW SCORING STANDARDS
FINAL PROJECT EVALUATIONS

Reviewers should use the following numerical scale in rating the projects:

Technical Success

5 **Outstanding**: The project's technical results were exceptional and directly relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project represents a critical, significant advancement over current technical capabilities.

4 **Very Good**: The project's technical results were very good and directly relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project substantially supplements existing knowledge and/or offers an entirely new technology to the U.S. glass industry.

3 **Satisfactory**: The project's technical results were sound and relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project supplements existing knowledge and/or offers a modification on existing technology.

2 **Marginal**: The project's technical results were marginal and somewhat relevant to the technology needs of the U.S. glass industry. The technology or knowledge resulting from this project produced a new application of existing technology but does not supplement existing knowledge or offer new technology.

1 **Unsatisfactory**: The project had few successful technical results and was a repetition of existing technology.

Commercial Readiness

5 **Outstanding**: The results from this project are more than sufficient to make an informed decision on commercial application. The project team included direct involvement in planning, guidance, and conducting the research from multiple industrial partners that intend to implement the technology as soon as possible.

4 **Very Good**: The results from this project are sufficient to make an informed decision on commercial application. The project team included direct involvement in planning, guidance, and conducting the research from at least one industrial partner that intends to implement the technology as soon as possible.

3 **Satisfactory**: The results from this project are sufficient to make an informed decision on commercial application. The project team included direct involvement in planning and guidance from at least one industrial partner that is evaluating implementation of the technology.

2 **Marginal**: The results from this project are insufficient to make an informed decision on commercial application. The project team included direct involvement in planning and guidance from at least one industrial partner that may decide to implement the technology at a later date. It is likely additional development will be required before end-users will commit to using the technology.

1 **Unsatisfactory**: The results from this project are insufficient to make an informed decision on commercial application. The project team included direct involvement in planning and guidance from at least one industrial partner that may decide to implement the technology at a later date. It is highly likely additional development will be required before end-users will commit to using the technology.

Market Potential

5 **Outstanding**: The technology or knowledge developed by this project is broadly applicable across multiple segments of the U.S. glass industry. The project team has developed a detailed, realistic written commercialization plan, and the potential for application of the project results is highly likely.

4 **Very Good**: The technology or knowledge developed by this project is broadly applicable across more than one segments of the U.S. glass industry. The project team has completely and accurately considered commercialization, and a cursory written plan is in place. Continued development and application is highly likely.

3 **Satisfactory**: The technology or knowledge developed by this project is broadly applicable across more than one segment of the U.S. glass industry. The project team has considered and recorded preliminary commercialization plans. Continued development and application is likely.

2 **Marginal**: The technology or knowledge developed by this project is applicable across a single segment of the U.S. glass industry. The project team has considered a commercialization plan on a cursory basis, but no written plan exists. Continued development and application is unlikely.

1 **Unsatisfactory**: The technology or knowledge developed by this project is applicable to only a single company in the glass industry. The project team has not considered a commercialization plan. Continued development and application is highly unlikely.

Programmatic Merit

5 **Outstanding**: The project, if successfully implemented, will offer significant energy savings, environmental benefits, and economic benefits in multiple segments of the U.S. glass industry. The project had outstanding technical, financial, and human resources assigned to it.

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Appendix B

Other Presentations

Status of GPLUS Efforts - FY 2003

Peter Angelini
Oak Ridge National Laboratory

September 9, 2003

Topics

Background

FY 2003 activities

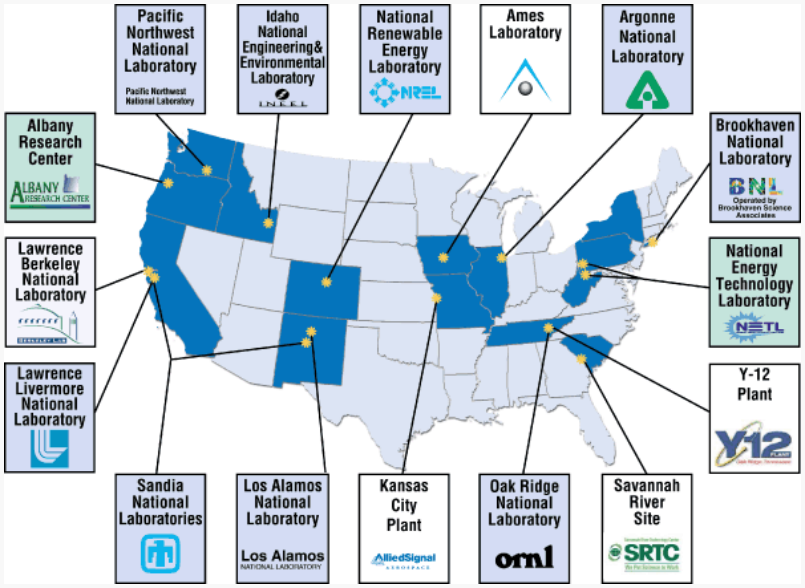
Summary

Purpose

GPLUS - (Glass - Project Laboratory User Services) project

- Provides GMIC members access to unique capabilities of DOE National Laboratories
- Industry defined projects
  - $25K per project (one per member)
  - funding to participating national laboratory/ies
- Projects - involve one or more core members, and associate members
- Project descriptions submittal by GMIC core and associate members

DOE National Laboratory Participants



GPLUS activity started in FY 2000

FY 00

Three projects were started

FY 01

Seven projects initiated;

FY 02

Fourteen projects initiated

FY 03

Eight Projects initiated

Projects Have Addressed Various Areas of Glass Processing

Properties
- High Temp
  - Viscosity, Thermal Conductivity

Modeling
- Thermodynamic
- Furnace modeling
- Fracture strength

Sensing
- Laser Breakdown Spectroscopy
  - Flue gas, batch
- Thermocouple degr.

Melting
- Furnace components
  - Refractory Metal degr.
- Batch and Cullet
- Encapsulants

Process/Glass Behavior
- Surface
  - Blisters, optical defects
  - Coatings
- Bulk
  - Combustion atm on glass oxidation
  - Foaming

mm Wave Diagnostics for Glass Fiber Drawing

Participants: Cleveland State Univ., Johns Manville; PNNL

Issue: Bushing temperature and glass level are critical in fiber glass processing; mm waves are not obstructed by glass fibers.

Objective: Set up of a mm wave system at Cleveland State and Determine feasibility of using mm waves for measuring the bushing T; glass liquid level; and glass viscosity.

Benefits: Temperature of Bushing is a key parameter affecting breakage which controls production efficiency.

Foaming of E-glass

Participants: PPG; PNNL

Issue: Foaming of E-glass is severe during processing especially in oxy-fuel fired furnaces.

Objective: study the effect of furnace atmosphere and water content on E-glass foaming and recommend solutions.

Benefits: Ability to control or reduce foaming would enable melter energy reductions as foam acts as thermal insulator in the glass melt.

TV Glass Surface Problems

Participants: Techneglas; ORNL

Issue: Various types of surface contaminations can cause loss of tube/glass in later manufacturing steps (seals and inner surface issues).

Objective: Improve understand of the composition of the contaminant on glass surface and identify mechanism that leads to the contamination.

Benefits: Reducing glass defects increases yield and overall energy efficiency.

Strength Data and Design Method for Tempered Automotive Glazing which is Subject to Stress Corrosion Cracking

Participants: Visteon; PNNL

Issue: Stress concentrations near holes in glass can cause cracking.

Objective: Develop a design procedure, including recommendations for limits on design stresses, for tempered automotive glazing subject to strength reductions caused by hole penetrations.

Benefits: Generalized data can lead to recommendations for increasing production efficiency and enable new glazing designs.

Application of Furnace Model to Longhorn Glass Corp. Oxy-Fuel Furnace for the Production of Amber Glass

Participants: Metal Container Corp.; ANL

Issue: Oxy fuel fired furnaces can lead to refractories issues and energy inefficiencies if not optimized.

Objective: Investigate the gaseous species and the transport of gases released during batch/melting both in the furnace and in the exhaust.

Benefits: Modeling may lead to indication of possible location of corrosion in the crown of the furnace; more efficient firing of the furnace; and decreased costs.

High Temperature Thermocouple Study

Participants: Schott Glass Technologies; INEEL

Issue: Precious metal thermocouples used throughout the glass making process can drift over time resulting in incorrect temperature measurements.

Objective: Increase the understanding of how and why thermocouples degrade in use.

Benefits: Improved understanding of the impact of furnace and other process conditions on the stability of thermocouples will lead to improved glass yields and efficient control of the furnace and other processes.

Improvement of Oxy Fuel Burner Design/Operations

Participants: Owens Corning; SNL

Issue: Oxy Fuel firing enables increased energy efficiencies in the production of glass. In order to maximize the benefits of oxy fuel technology improvements in burner designs, serviceability, performance, and flexibility are needed

Objective: Determine key parameters leading to improved oxy fuel burner design and operations

Benefits: Increased acceptance and use of oxy fuel process can lead to improved energy, production efficiencies and environmental aspects

Laser Induced Laser Breakdown Spectroscopy (LIBS) as a Glass Melt Monitor

Partners: Corning; SNL

Issue: Harsh environment of molten glass makes it difficult to probe the chemistry of the glass components as the melt progresses to completion.

Objective: To determine the feasibility of focusing a LIBS plasma above the glass melt and collect emission from the elements that are in the glass phase directly above.

Benefits: A method of monitoring the glass composition during the glass making process can result in improved efficiencies.

Contact Information

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Coordinating Laboratory Contact
Tel., (865) 574-4565
E-mail: angelinip@ornl.gov

CGR NSF Industry-University Center for Glass Research

Melt Properties Measurements at the Center for Glass Research

(A DOE-CGR Cost-Shared Project)

Thomas P. Seward III

September 9, 2003

CGR

Outline

- Project participants
- Objectives of this study
- Glasses and properties investigated
- Methodology and example results
- Statistical modeling status
- Evaluation, dissemination and commercialization of results

DOE-CGR Project at Alfred University

- Grant # DE-FG07-96EE41262
- Title
  - » Modeling of Glassmaking Processes for Improved Efficiency
- Sub-title
  - » High Temperature Glass Melt Property Database for Modeling

DOE-CGR Project at Alfred University

- Multi-year, multi-investigator project
- Two phases
  - » Property measurements and database generation
  - » Evaluation by industry process modelers
- Principal Investigators
  - » T.P. Seward, W.C. LaCourse, A.G. Clare, J.E. Shelby, A.K. Varshneya, D.Oksoy, D.A. Earl
- Researchers
  - » T. Vascott and D.M. Korwin
- Sub-contracts
  - » CELS (Corning), Thermex Company (St. Petersburg, Russia), Pacific Northwest National Laboratory and Inregrex Testing Services

Project Objective

- To develop a comprehensive and reliable data base for glass forming melts that will allow full use of numerical simulation models by a broad cross-section of the glass industry for the purpose of achieving energy savings, improving product quality, increasing productivity, and meeting present and future environmental regulations.

- In response to melt properties measurements needs established at the DOE-CGR jointly sponsored 1996 "Modeling Workshop"

Properties Required for Furnace Modeling

GLASS FLOW	Viscosity		ν
	Density	ρ	
	Volume expansion coefficient		β
	Surface tension		$\gamma_{(melt-atmosphere)}$
ENERGY TRANSFER	Effective thermal conductivity	$k_{eff} - (16n^2\sigma T^3)/3\ \alpha_r$ **	
	Absorption coefficient		α_λ, α_r
	Heat capacity		C_p
	Surface tension		$\gamma_{(melt-atmosphere)}$
GAS EXCHANGE WITH BUBBLES			
	Concentration of species "i" in glass	c_i	
	Solubility		$S_i = c_{sat,i}/Pi$
	Diffusivity of species "i"	D_i	
	Equilibrium constants for gas producing reactions	K_i	
ELECTRICAL	Resistivity		ρ_{elec}
BATCH MATERIALS	Enthalpy (to melt)		ΔH_{batch}
	Thermal conductivity		k_{batch}
	Emissivity		ε_{batch}
REFRACTORIES	Thermal conductivity		$k_{refractory}$
	Emissivity		$\varepsilon_{refractory}$

* Adapted in part from a presentation by William W. Johnson, Corning Inc., at "Modeling in the Glass Industry" Workshop. CGR members added surface tension and refractory-related properties to the table after the Workshop.

** n = refractive index, σ = Stephan's constant, T = absolute temperature (K)

DOE Project Process

- Select target composition areas for study
- Statistically design experimental composition variations
- Melt and chemically analyze glasses
- Measure melt properties
- Statistically analyze data
- Evaluate results
- Disseminate information

Glass Families Studied

- Low-expansion borosilicate
- Container (soda-lime-silica)
- E-type textile fiberglass
- Float (soda-lime-silica)
- Color TV panel glass
- Wool-type insulation fiberglass

Families of Glasses (Commercial Base Glasses)

Component	Container	Float	E-Glass	TV Panel	Low α Borosilicate	Wool
SiO_2	74.05	73.1	55	61.29	81	62
Al_2O_3	1.26	0.10	15	1.96	2	4.0
Fe_2O_3	0.031	0.5	0.4	0.044		0.3
TiO_2	<0.01	0.02	0.5	0.42		
CaO	10.53	8.9	18	0.06		8.0
MgO	0.20	3.8	4.0			4.0
SrO	<0.01			9.15		
BaO	<0.01			9.32		
PbO				0.03		
Na_2O	13.49	13.7	0.5	7.46	4	16
K_2O	0.27	0.1		7.59		1.0
B_2O_3			7		13	5.0
Li_2O				0.002		
As_2O_3						
Sb_2O_3				0.27		
CeO_2				0.27		
MnO_2	<0.007					
Cr_2O_3						
SO_2	0.22					0.2
ZrO_2	<0.03			1.46		
ZnO				0.48		
F_2			0.2	0.002		

All Values in Weight %

Melting and Chemical Analysis

- Composition variations statistically designed about the six base glasses
- Melting program:
  - » Phase I - 15 melts per “family”
  - » Phase II - 9 additional melts per “family”
  - » Total - Approximately 140 different glasses
- Chemical analysis available for almost all glasses. (Some float and wool glass analyses missing.)

Composition Ranges of Experimental Glasses

	DOE Glass-Melt Properties Project			Glass Composition Ranges (wt. %)		
	Container	E	Float	Low-exp. B-Si	TV Panel	Wool
SiO_2	65-75	52-60	70-74	70-81	58-64	56-66
B_2O_3		0-9		10-15		3-9
Al_2O_3	1-3	12-16		2-7	1.3-3.5	0-6
MgO	0-3	0.5-4.5	3-4		0-1.5	1-5
CaO	7-12	16-24	7-9	0-2	0-3.5	5-11
SrO					1-10	
BaO				0-2	2-13	
Li_2O	0-1				0-0.5	
Na_2O	11-15	0-2	12-15	4-8	6-9	13-17
K_2O	0-2	0-0.5	0.05-0.8	0-3	6-9	0-2
Fe_2O_3	0-0.4	0-0.8	0.1-1.5			0-0.6
Cr_2O_3	0-0.3					
TiO_2	0-0.5	0-1			0.1-0.5	
CeO_2					0-0.7	
ZrO_2					0-3	
PbO					0-3	
ZnO					0-1.5	
As_2O_3					0-0.3	
Sb_2O_3					0.2-0.6	
SO_3	0-0.3					0-0.2
F		0-0.6			0-0.7	0-0.6

Properties Measured only on Commercial (Base) Glasses

- Gas Solubility - He, Ne, Ar, N_2, H_2O, CO_2, SO_2
- Gas Diffusivity - H_2O, SO_2
- Surface Tension, Density, Thermal Expansion
- Radiative Conductivity of Melts
- Non-Newtonian Flow Behavior of Melts
- Oxygen Partial Pressure of Melts

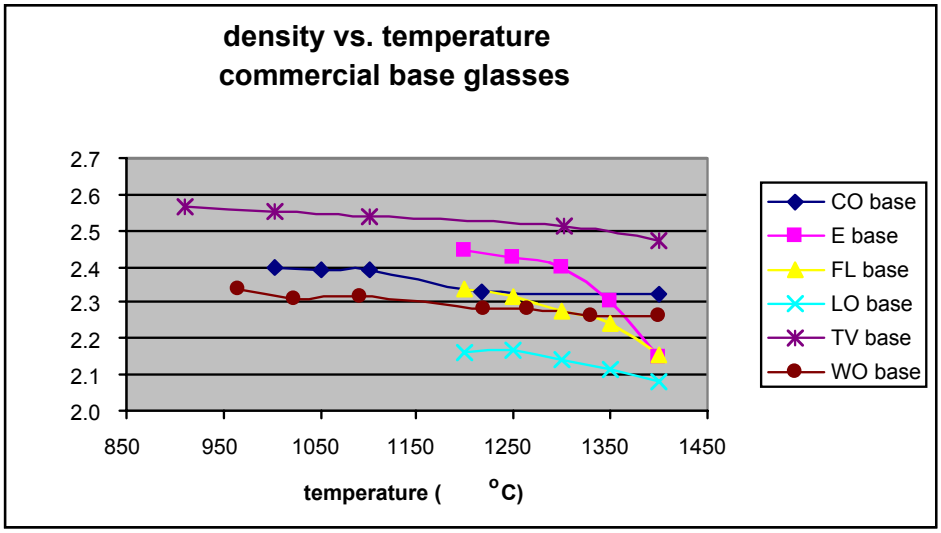
Gas Solubility and Diffusivity

- James Shelby and Oleg Prokhorenko, PIs
- Important for understanding and modeling the fining of glass - an important phase of glass melting
- Most of these studies have been reported elsewhere, particularly through the ICG TC14 Gases in Glass Technical Committee, and will not be discussed in this presentation.

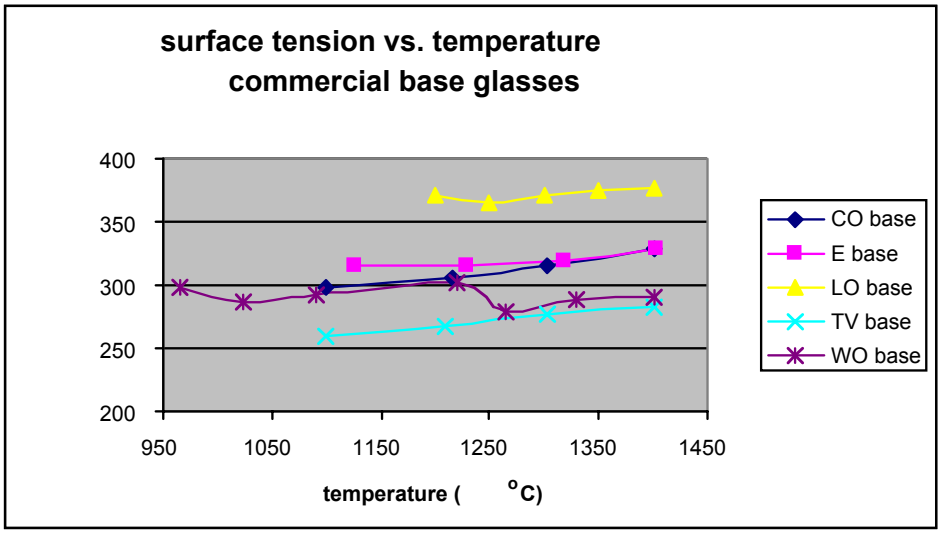
Density and Surface Tension

- Dr. Alexis Clare, PI
- Sessile and pendent drop techniques developed; algorithms written; atmosphere varied; volatility effects studied
- Data for the temperature dependence of density is important for calculating thermally driven convection in glass melting tanks (furnaces)
- Current round-robin testing; ICG TC18
- Some examples follow:

Melt Density



Melt Surface Tension



Non-Newtonian Viscosity

- Dr. Arun Varshneya, PI
- Installed parallel plate viscometer on hydraulic Instron™ testing machine
- Measured six base glasses at ~ 10^{10} Pa·s and seven different strain rates
- Deviations from Newtonian behavior characterized
- Important for understanding glass forming manufacturing operations, particularly pressing and fiber drawing
- Data being used by at least one CGR member company

Radiative Conductivity

- Work conducted at Thermex Company
  (St. Petersburg, Russia - Dr. Oleg Prokhorenko, PI)
- High temperature (600ºC-1450ºC) spectrophotometer and sample cells constructed; Measurement techniques developed
- Important for understanding heat transfer between glass furnace and melt, and during forming operations
- Examples follow:

Radiative Conductivity

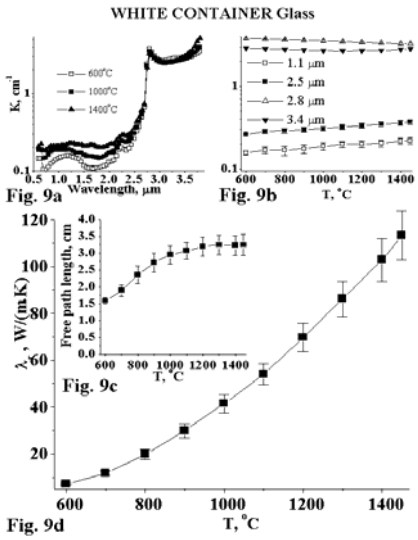


Fig. 9. Absorption spectra at temperatures 600, 1000 and 1400°C (a), and temperature dependences of absorption coefficients at 1.1, 2.2, 2.8 and 3.4 μm (b) measured for white container glass. Temperature dependences of free path length (c) and radiative conductivity (d) calculated for white container glass by using Rosseland formula.

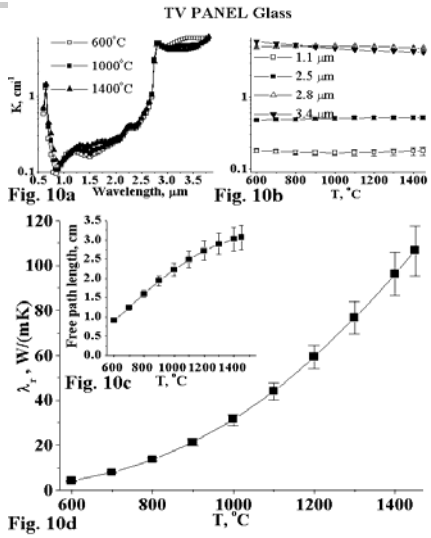


Fig. 10. Absorption spectra at temperatures 600, 1000 and 1400°C (a), and temperature dependences of absorption coefficients at 1.1, 2.2, 2.8 and 3.4 μm (b) measured for TV-panel glass. Temperature dependences of free path length (c) and radiative conductivity (d) calculated for TV-panel glass by using Rosseland formula.

Properties Measured on 140 Experimental Glasses

- Viscosity - 10^1-10^{13} poise
  - Rotating Spindle, Parallel Plate, Beam Bending
- Electrical Resistivity - 900-1450°C
- Physical Properties of Glass
  - Density, Refractive Index, Coefficient of Thermal Expansion
  - Dilatometric Softening Point, Glass Transition Temperature
  - Dissolved H_2O Concentration
  - Electrical Conductivity at 200°C and 300°C

Physical Properties of the Glasses

Note: The physical properties measurements of the solid glasses have considerably extended the database, but because they are not melt properties they will not be discussed in this presentation.

(These studies were conducted under the direction of James Shelby.)

Melt Viscosity of Commercial Glass Types

- Viscosity information (log viscosity / Pa·s = 0 to 12) is of vital interest for melting, forming and annealing in the glass industry, including the design of glass melting furnaces and forming equipment. In this work we determined the viscosity of more than 140 industrial glass composition variations (including float, container, low expansion borosilicate, TV panel, wool, and textile fiber glasses) using three different techniques. We analyzed the composition-viscosity relationships using several statistical techniques.

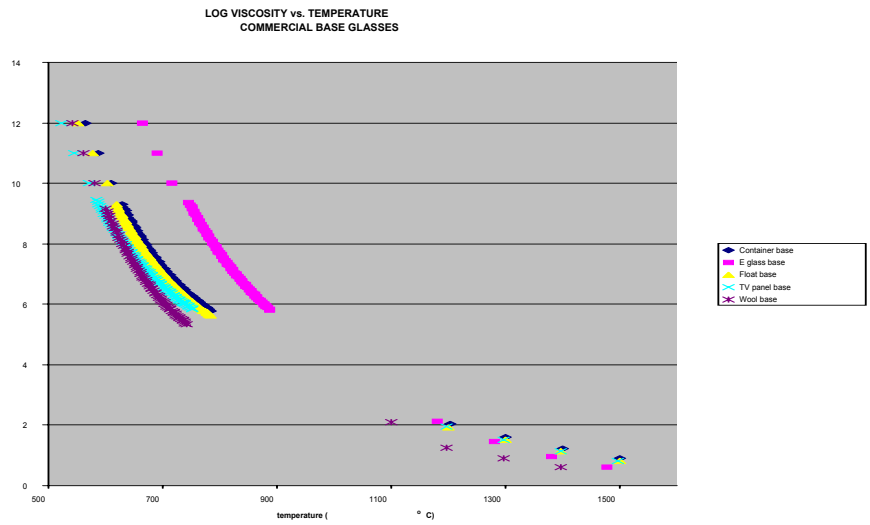
Viscosity Measurement

- Rotating Spindle (10^1 to 10^4 Poise)
  - » Measurements complete for all six commercial base glasses and all experimental composition variations
  - » Plagued by equipment failures during 2000-2001; became significantly behind schedule
  - » Schott Glass Technologies' GMIC DOE 2002 G-Plus DOE funding committed to measurements at PNNL; measurements completed there (Dr. Pavel Hrma, PI)

Viscosity Measurement continued

- Parallel Plate (10^5 to 10^{10} Poise)
  - » Dr. Arun Varshneya, PI
  - » Software rewritten
  - » Measurements restarted in January 2002 with postdoctoral researcher
  - » Measurements completed on all glasses in Fall 2002
- Beam Bending (10^{10} to 10^{13} Poise)
  - » Dr. James Shelby, PI
  - » Work conducted in 2001, funded by CGR
  - » Measurements completed on all glasses in Spring 2003

Combined Viscosity Data (Base Glasses)



Statistical Modeling of Viscosity

- Dolun Oksoy, PI
- Approach
  - » Fit each data set to a V-F-T equation (all the viscosity data for a single composition)
  - » Perform statistical analysis of all V-F-T coefficients as functions of composition for entire family of glass (using three different models)
  - » Predict the data points for each glass composition using the models
  - » Evaluate the models

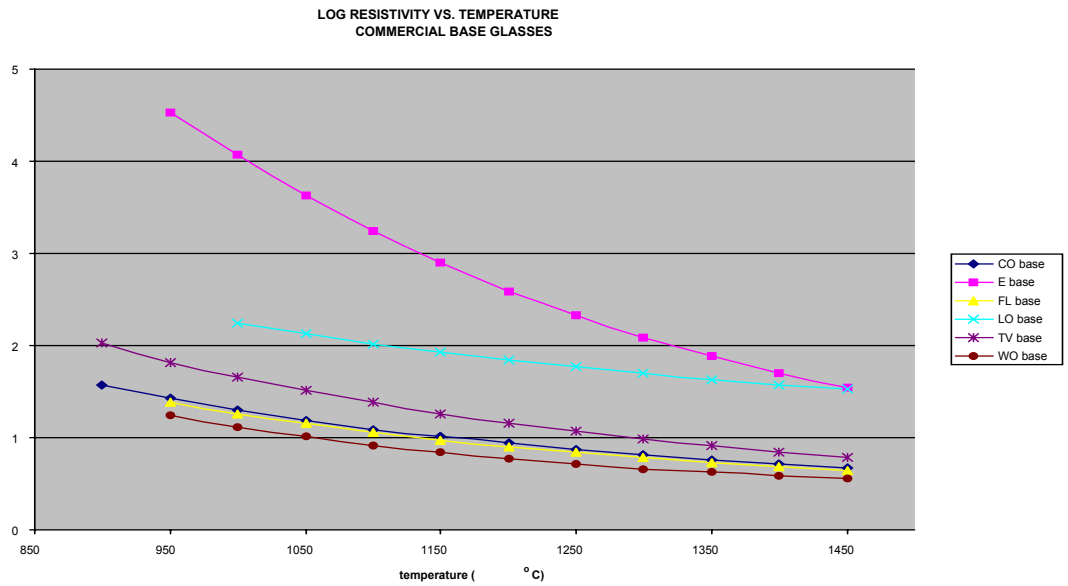
Melt Electrical Resistivity of Commercial Glass Types

- Electrical boosting of glass melters is commonplace and many specialty and optical glasses are melted completely by electricity. Increased fossil fuel prices and/or improved designs for electrically heated finers could extend this trend. Knowledge of melt electrical resistivity is essential for effective furnace modeling and design. We have measured electrical resistivity in the range of 950 to 1450°C for about 125 glass compositions of container, float, low-expansion borosilicate, TV panel, wool and textile fiberglass-types using a simple two-probe method. At least one furnace design company has requested our data for use in their design programs.

Electrical Resistivity

- Terese Vascott, Thomas Seward, and Arun Varshneya, PIs
- Two-probe system operating and calibrated
- Resistivity measured between 900˚C and 1450˚C for
  - » SRM 1414 NIST standard glass
  - » All six commercial base glasses
  - » All experimental glass compositions
- Measurements completed - February 2003

Electrical Resistivity (Base Glasses)



Statistical Modeling of Electrical Resistivity

- Dolun Oksoy and David Earl, PIs
- Approach
  - » Similar to that used for viscosity, except fit to an Arrhenius equation.

Companies Requesting to Evaluate Portions of Database

- Melt Properties Predictions
  - » PPG Industries
  - » Guardian Industries
  - » Osram Sylvania
  - » U.S. Borax
- Modeling and Properties Prediction
  - » Techneglas
  - » Corning Incorporated
  - » Owens Corning
  - » Visteon Glass

Guardian Industries

- "All of the glass property data for float glass and container glass has been used to verify our existing empirical numerical property prediction models. The data generally helped improve or confirm of models. We are outsourcing some thermo-mechanical FEA modelling at PNNL. Some of the data has been useful setting boundaries for material props for this modeling."(T. Longobardo)

U.S. Borax

- "Borax uses glass property models as a research tool to support our business activities associated with the glass and ceramic industries. The ability to relate glass composition to thermal expansion and viscosity is particularly important. The availability of data from these designed experiments for specific types of glass will enable us to greatly improve on the limited accuracy which was possible using existing models. The models will be used to reformulate glass with improved properties and lower cost. Development time and costs are substantially reduced." (R. Smith)

Techneglas Inc.

- "Obviously the glass property data is an integral part of the modeling effort. The validity of the model results depends among other things on the accuracy of the input parameters. We need the glass property data to make the modeling effort worthwhile." (James D. Williams)

Owens Corning

- "Today, engineers and scientists at Owens Corning continue to advance mathematical modeling with state-of-the-art technologies. The development of a comprehensive material database will greatly improve the effectiveness and robustness of mathematical modeling and allow the U.S. glass industry to maintain and expand its competitive edge." (C. Jian and P. McGinnis)

Owens Corning

- "The Melt Properties Database work is important and was enthusiastically supported by the CGR and GMIC member companies because it doesn't matter whose model you use, you still need reliable properties. I feel that this is a legitimate and good use of DOE money in the modeling area." (M.K. Choudhary)

Status

- Glasses of all designed compositions melted (approximately 140)
- Most glasses chemically analyzed
- Statistical analysis and predictive modeling in process
- Charts and graphs in final report to DOE
- Data files available to any CGR member company and to others on individual basis (Goal - evaluate the usefulness of the data)

Next Steps

- Complete the statistical modeling
- Obtain evaluations of data and predictive modeling from CGR member companies, former member companies and others
- Publish the results

Approximate Milestones

- September 2003 - Begin data transfer to member companies
- December 2003 - Complete statistical analysis of available data; share models with member companies
- Spring 2004 - Begin writing for publication

Information on the Web

- Glass composition ranges and examples of measurement results can be found on the CGR Web site at:
- http://cgr.alfred.edu/meltprops/meltprops.html
- Final report to the DOE can be found at: http://www.osti.gov/servlets/purl/809193-hMVo0M/native/

Modeling of Glass Making Processes for Improved Efficiency

High Temperature
Glass Melt Property Database
for Modeling

US DOE PROJECT DE-FG07-96EE41262

CGR NSF Industry-University Center for Glass Research

Principal Investigators

Thomas P. Seward III (1997-present)
William C. LaCourse (1996-1997)

Objectives of Study

Development of a comprehensive and reliable data base for glass forming melts that will allow full use of numerical simulation models by a broad cross-section of the glass industry for the purpose of achieving energy savings, improving product quality, increasing productivity, and meeting present and future environmental regulations.

Glass Compositions Studied

Container Glass E Glass Float Glass
Low-expansion Borosilicate Glass
TV Panel Glass Wool Glass

CGR NSF Industry-University Center for Glass Research

	DOE Glass-Melt Properties Project			Glass Composition Ranges (wt. %)		
	Container	E	Float	Low-exp. B-Si	TV Panel	Wool
SiO_2	65-75	52-60	70-74	70-81	58-64	56-66
B_2O_3		0-9		10-15		3-9
Al_2O_3	1-3	12-16		2-7	1.3-3.5	0-6
MgO	0-3	0.5-4.5	3-4		0-1.5	1-5
CaO	7-12	16-24	7-9	0-2	0-3.5	5-11
SrO					1-10	
BaO				0-2	2-13	
Li_2O	0-1				0-0.5	
Na_2O	11-15	0-2	12-15	4-8	6-9	13-17
K_2O	0-2	0-0.5	0.05-0.8	0-3	6-9	0-2
Fe_2O_3	0-0.4	0-0.8	0.1-1.5			0-0.6
Cr_2O_3	0-0.3					
TiO_2	0-0.5	0-1			0.1-0.5	
CeO_2					0-0.7	
ZrO_2					0-3	
PbO					0-3	
ZnO					0-1.5	
As_2O_3					0-0.3	
Sb_2O_3					0.2-0.6	
SO_3	0-0.3					0-0.2
F		0-0.6			0-0.7	0-0.6

Properties Measured on Base Glasses Only

- Gas Solubility - He, Ne, Ar, N_2, H_2O, CO_2, SO_2
- Gas Diffusivity - H_2O, SO_2
- Surface Tension, Density, Thermal Expansion
- Radiative Conductivity of Melts
- Non-Newtonian Flow Behavior of Melts
- Oxygen Partial Pressure of Melts

Properties Measured on All Experimental Glasses

- Viscosity - 10^1-10^{13} poise
  - –Rotating Spindle, Parallel Plate, Beam Bending
- Electrical Resistivity - 900-1450°C
- Physical Properties of Glass
  - –Density, Refractive Index, Coeff. of Thermal Exp.
  - –Dilatometric Softening Point, Glass Transition Temp.
  - –Dissolved H_2O Concentration
  - –Electrical Conductivity at 200°C and 300°C

VISCOSITY MEASUREMENTS

Rotating Spindle, Parallel Plate and Beam Bending Methods

Principal Investigators:
Drs. Arun K. Varshneya and James E. Shelby

Research Scientist:
Terese Vascott

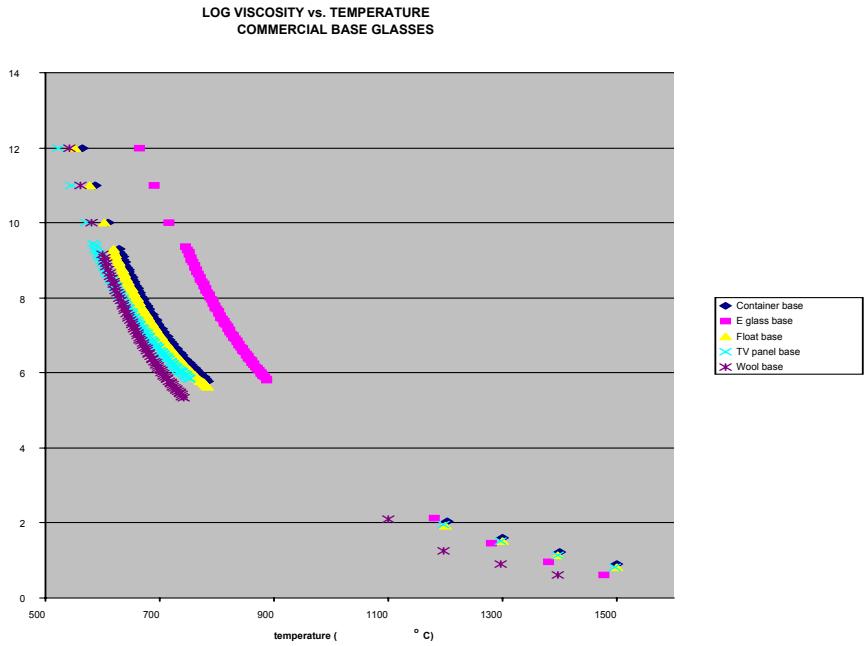
Post Doctoral Researchers:
Alexander Fluegel, Daniel L. Edson, Melissa G. Mesko and Holly Shulman

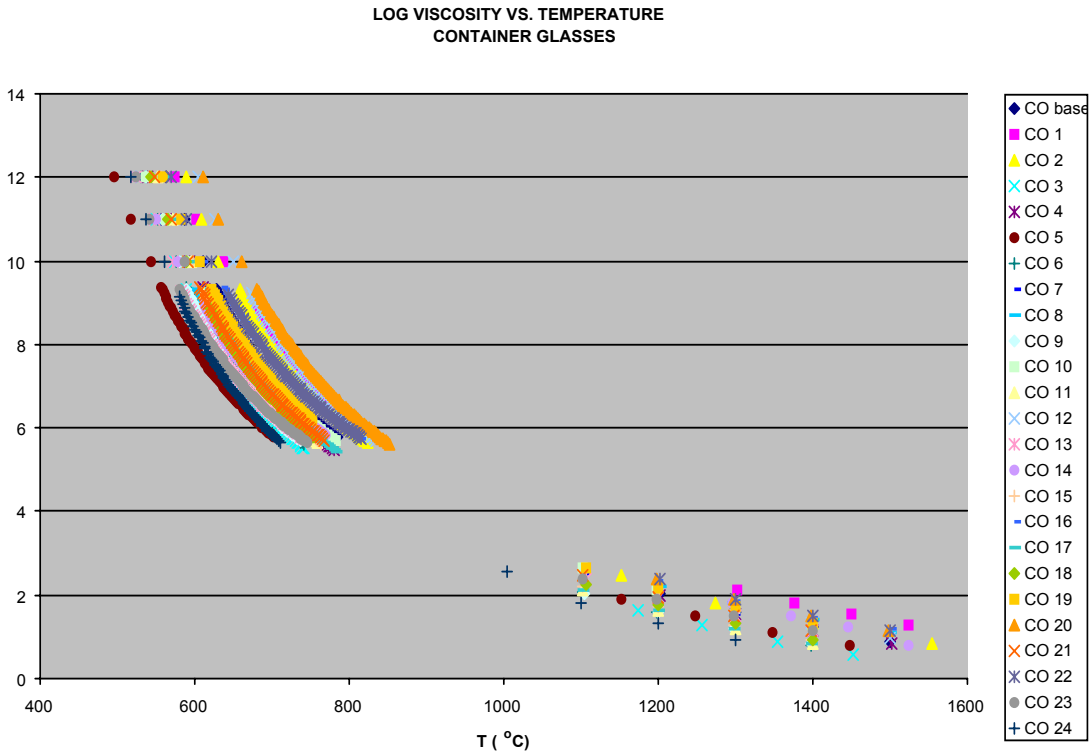
Subcontract:
PNNL, Dr. Pavel Hrma, PI

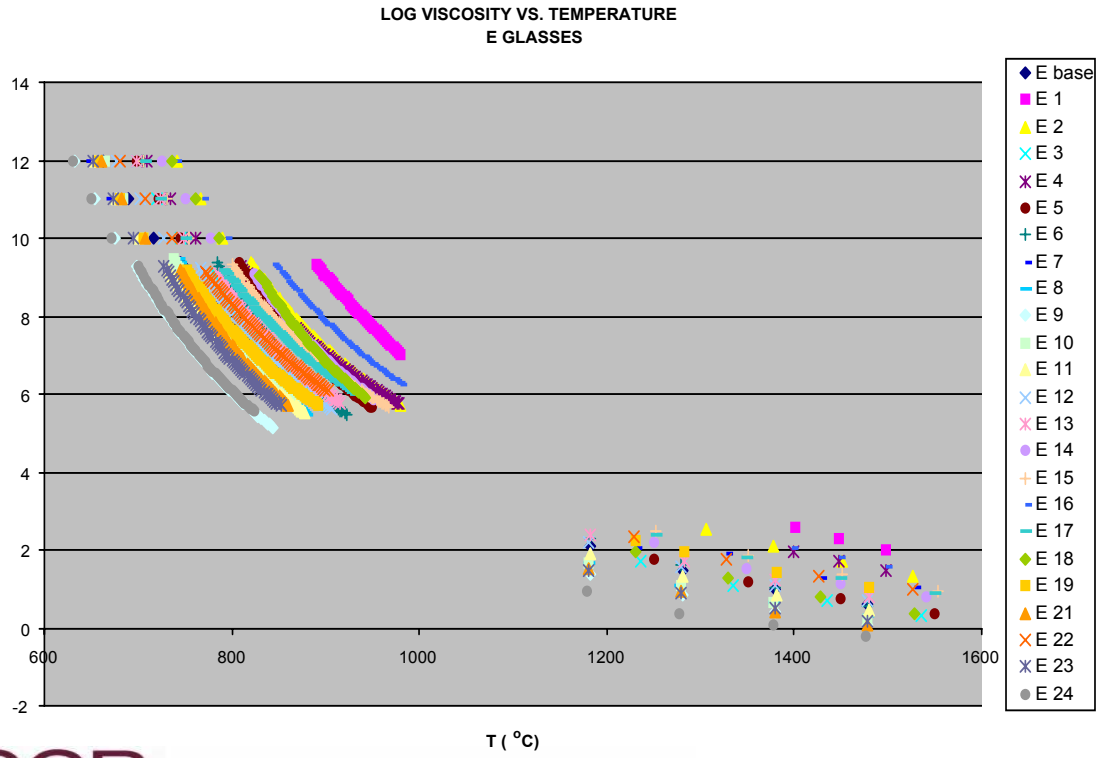
Melt Viscosity of Commercial Glass Types

- Viscosity information (log viscosity / Pa·s = 0 to 12) is of vital interest for melting, forming and annealing in the glass industry, including the design of glass melting furnaces and forming equipment. In this work we determined the viscosity of more than 140 industrial glass composition variations (including float, container, low expansion borosilicate, TV panel, wool, and textile fiber glasses) using three different techniques. We analyzed the composition-viscosity relationships using several statistical techniques.

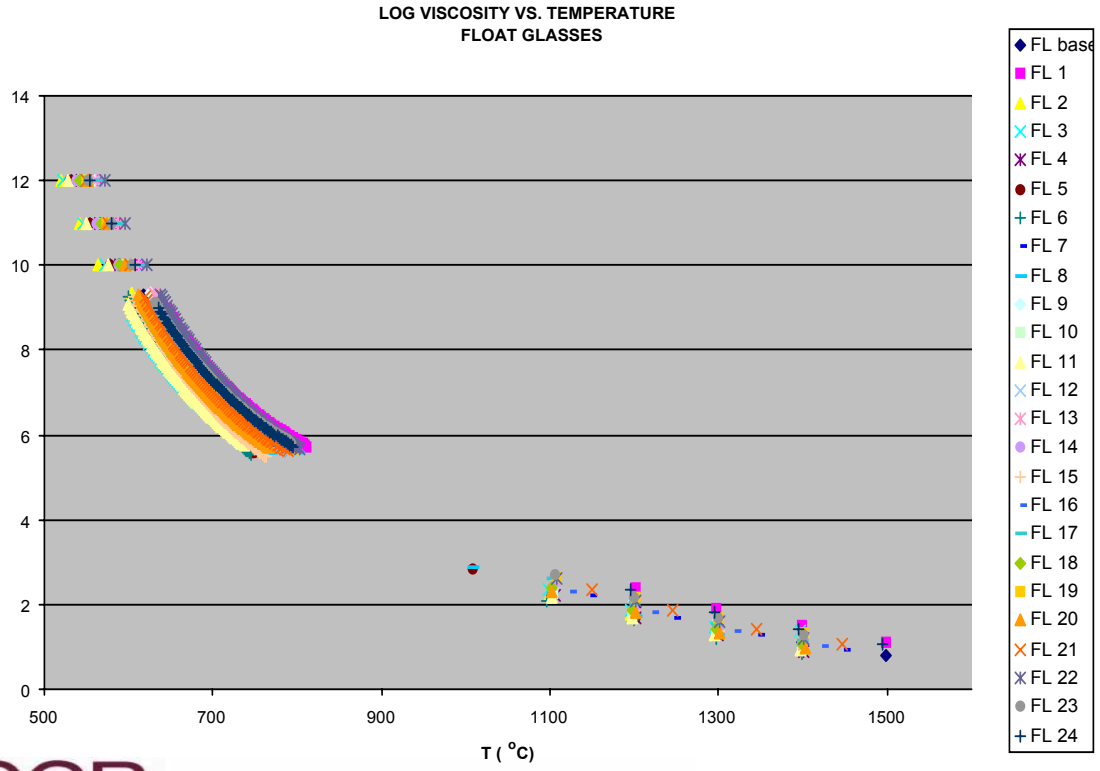
Viscosity vs. Temperature







CGR NSF Industry-University Center for Glass Research



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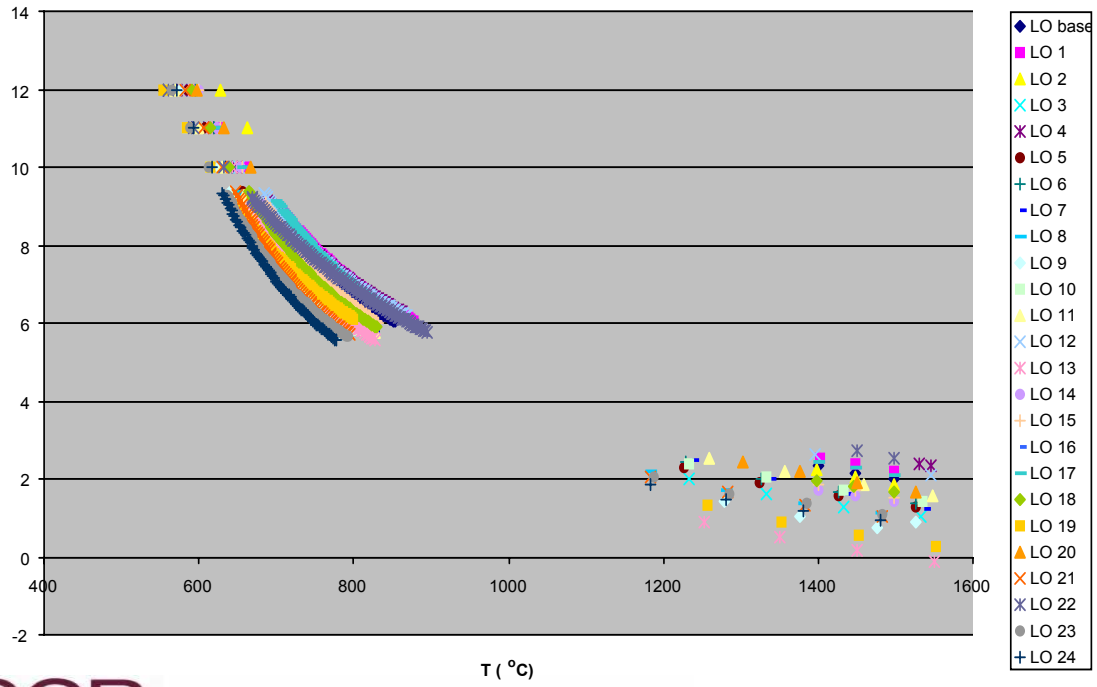
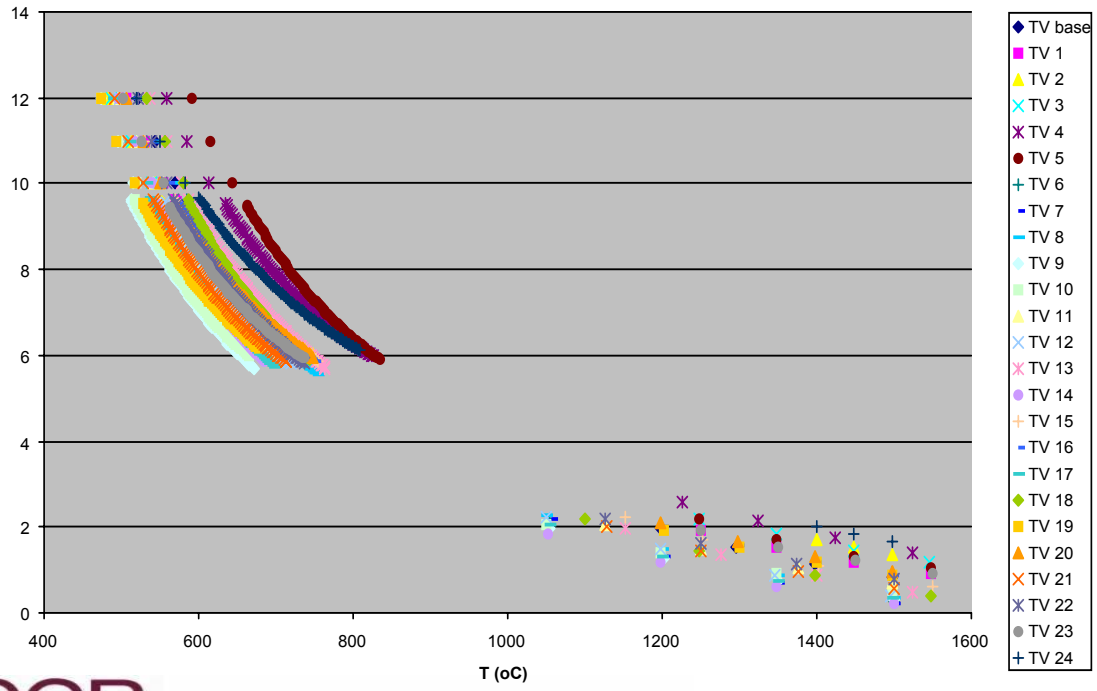
LOG VISCOSITY VS. TEMPERATURE
LOW-EXPANSION BOROSILICATE GLASSES

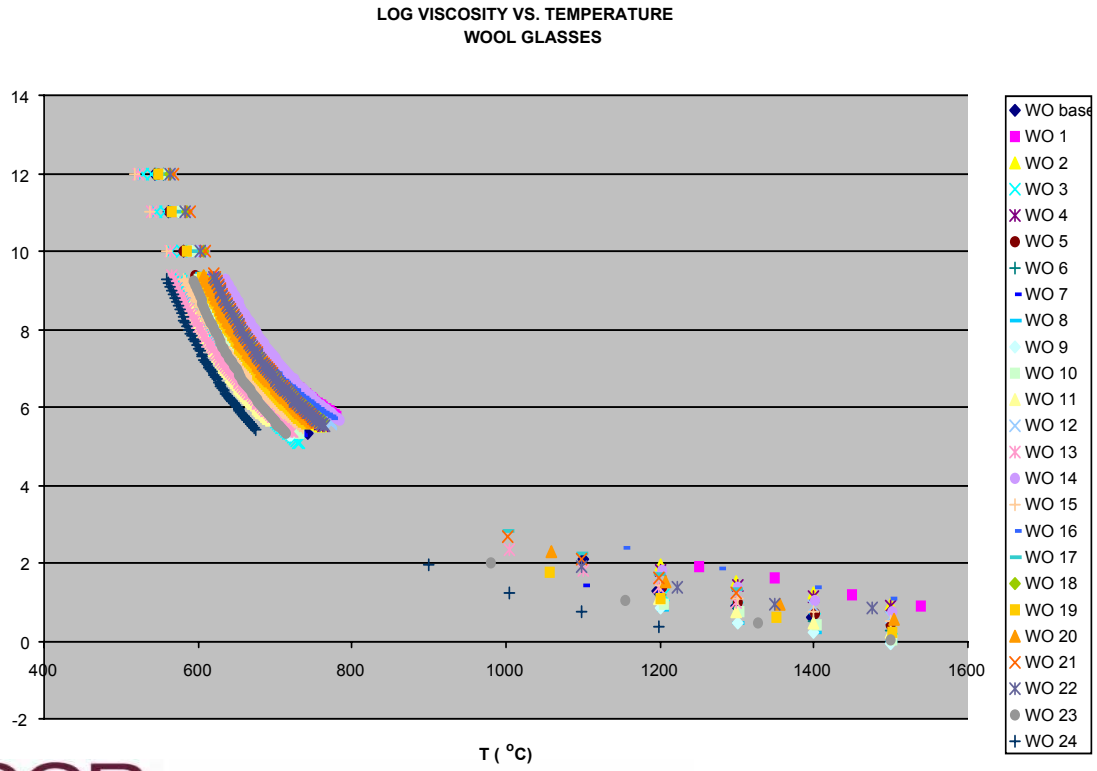


CGR NSF Industry-University Center for Glass Research

LOG VISCOSITY VS. TEMPERATURE
TV PANEL GLASS



CGR NSF Industry-University Center for Glass Research



Electrical Resistivity 1450°C-900°C

Two-point Probe Method

Principal Investigators:
Drs. Thomas P. Seward and Arun K. Varshneya

Research Scientists:
Terese Vascott and Douglas M. Korwin

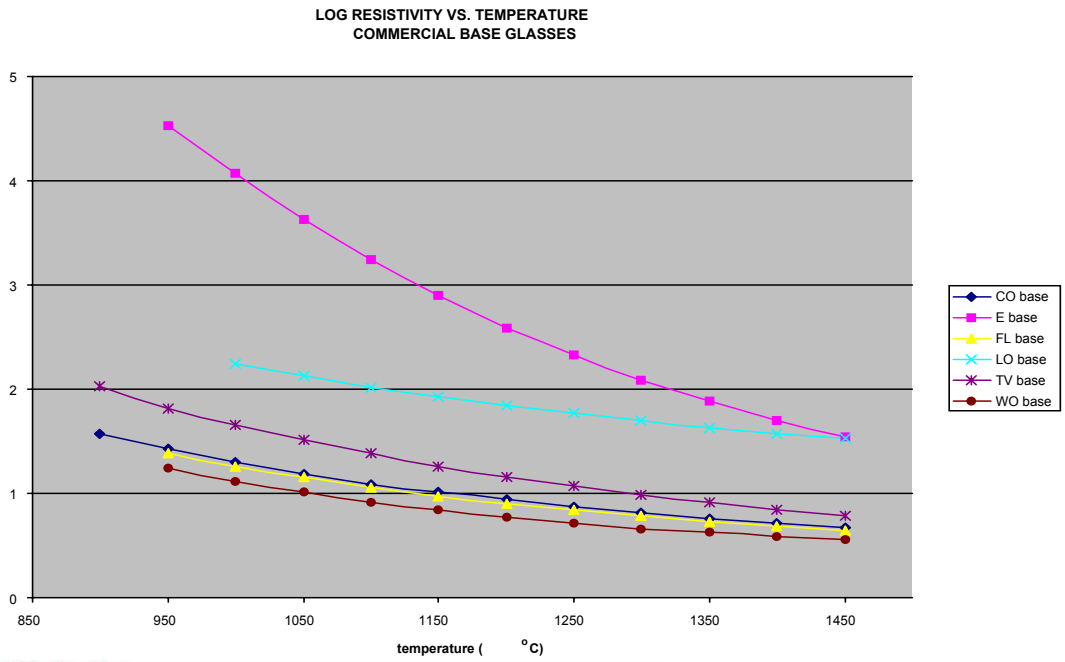
Post Doctoral Researcher:
Ramesh Karuppannan

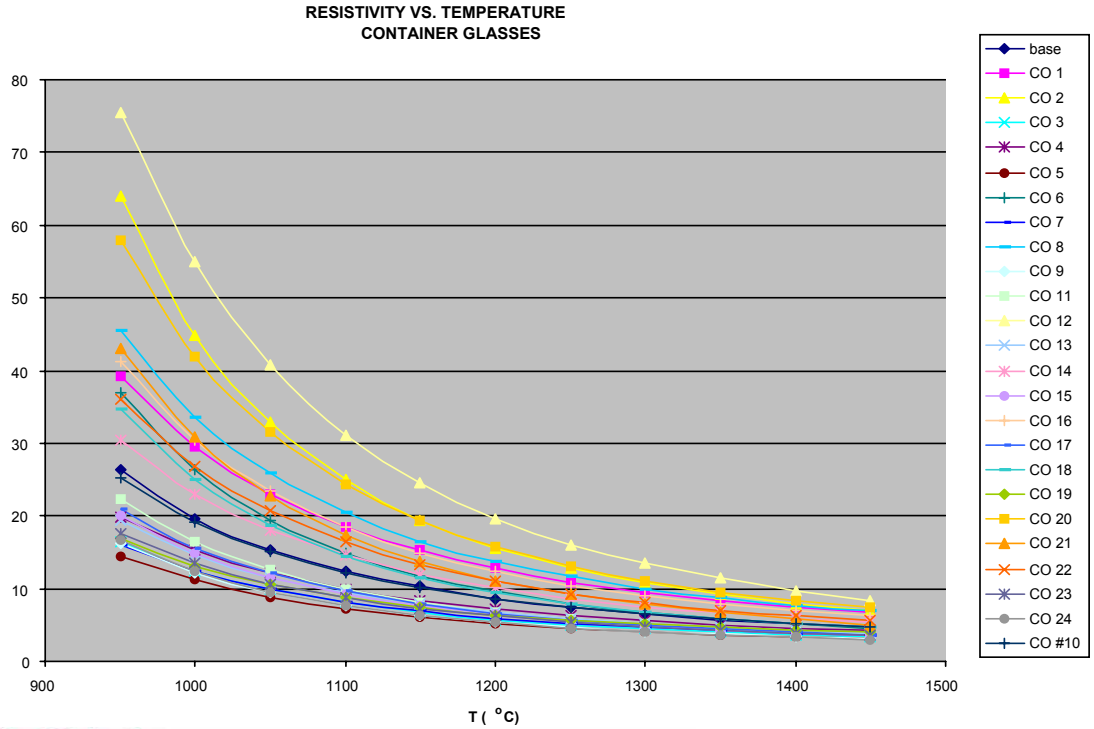
Undergraduate Research Assistants:
Heather K. Neil and Jeffrey M. Jones

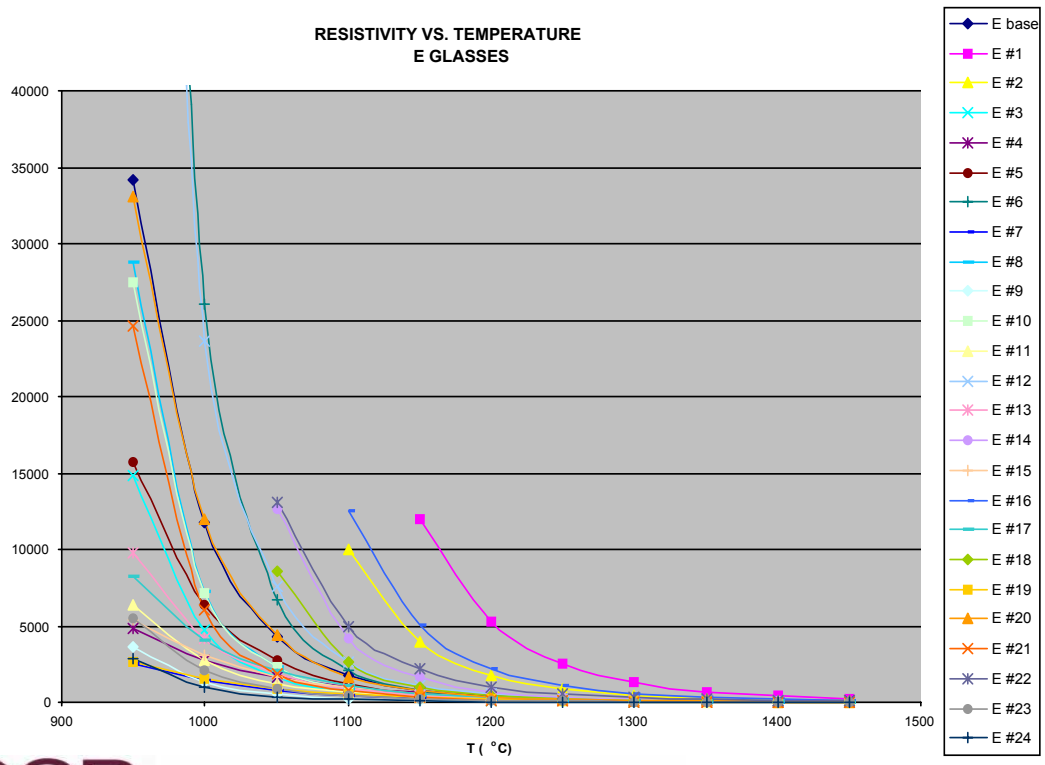
Melt Electrical Resistivity of Commercial Glass Types

- Electrical boosting of glass melters is commonplace and many specialty and optical glasses are melted completely by electricity. Increased fossil fuel prices and/or improved designs for electrically heated finers could extend this trend. Knowledge of melt electrical resistivity is essential for effective furnace modeling and design. We have measured electrical resistivity in the range of 950 to 1450°C for about 125 glass compositions of container, float, low-expansion borosilicate, TV panel, wool and textile fiberglass-types using a simple two-probe method. At least one furnace design company has requested our data for use in their design programs.

Resistivity vs. Temperature




RESISTIVITY VS. TEMPERATURE
CONTAINER GLASSES
80
70
60
50
40
30
20
10
0
900
1000
1100
1200
1300
1400
1500
T (°C)
base
CO 1
CO 2
CO 3
CO 4
CO 5
CO 6
CO 7
CO 8
CO 9
CO 11
CO 12
CO 13
CO 14
CO 15
CO 16
CO 17
CO 18
CO 19
CO 20
CO 21
CO 22
CO 23
CO 24
CO #10


RESISTIVITY VS. TEMPERATURE
E GLASSES
40000
35000
30000
25000
20000
15000
10000
5000
0
900
1000
1100
1200
1300
1400
1500
T (°C)
E base
E #1
E #2
E #3
E #4
E #5
E #6
E #7
E #8
E #9
E #10
E #11
E #12
E #13
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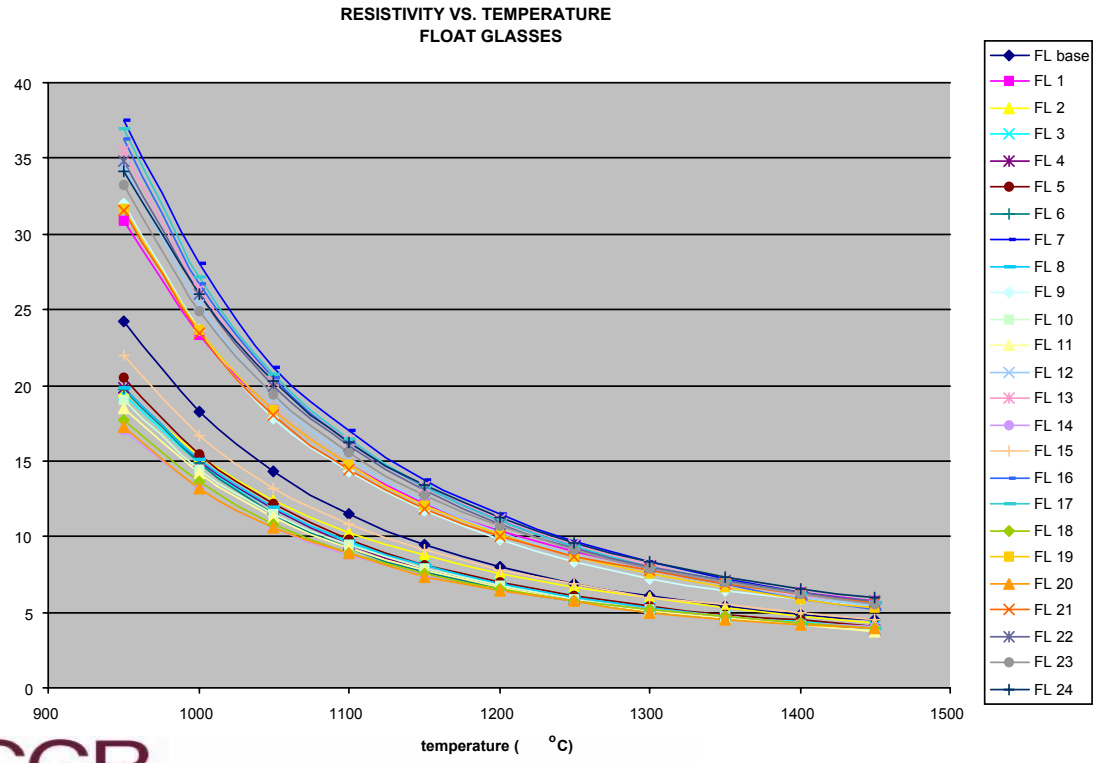
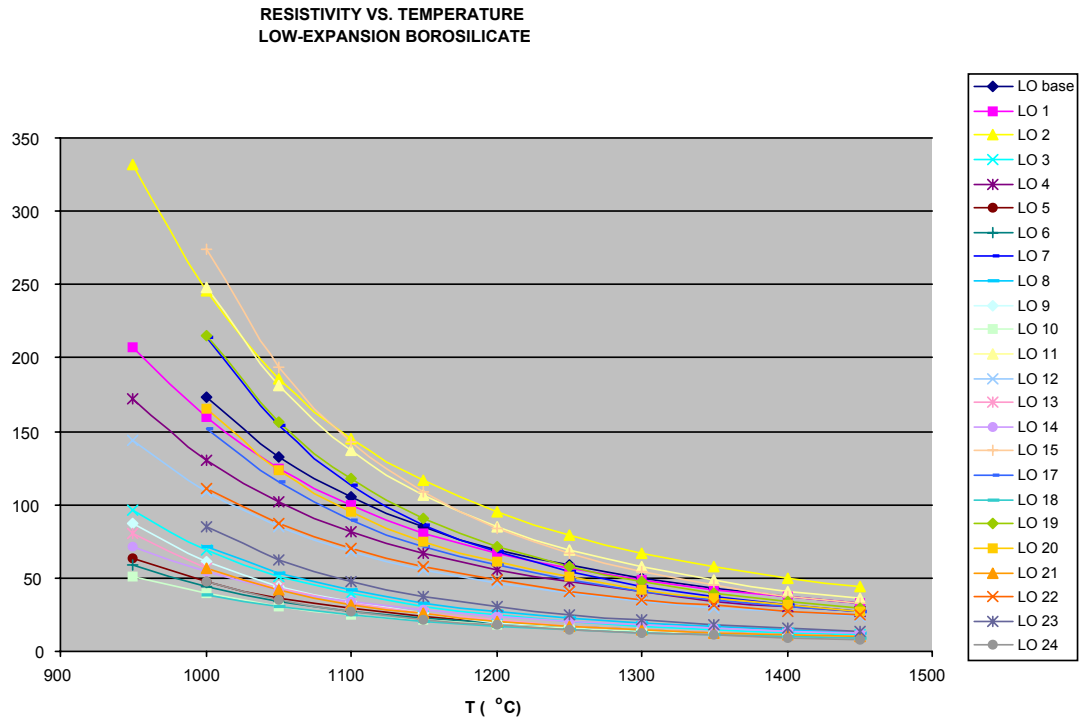


CGR NSF Industry-University Center for Glass Research



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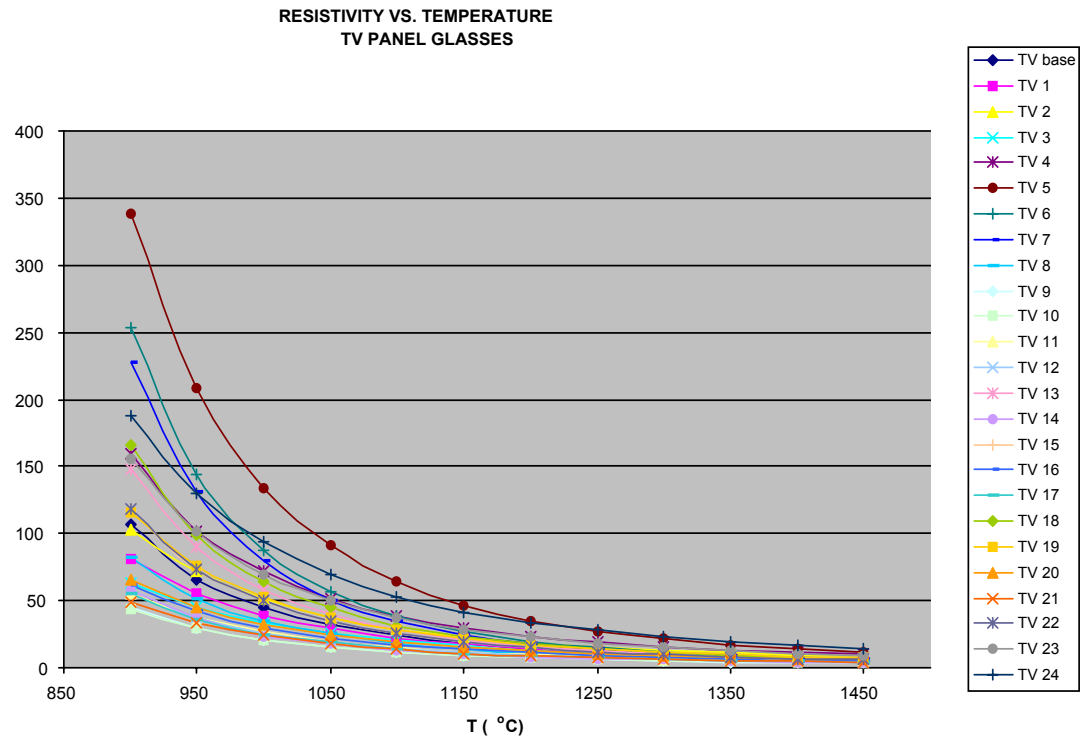

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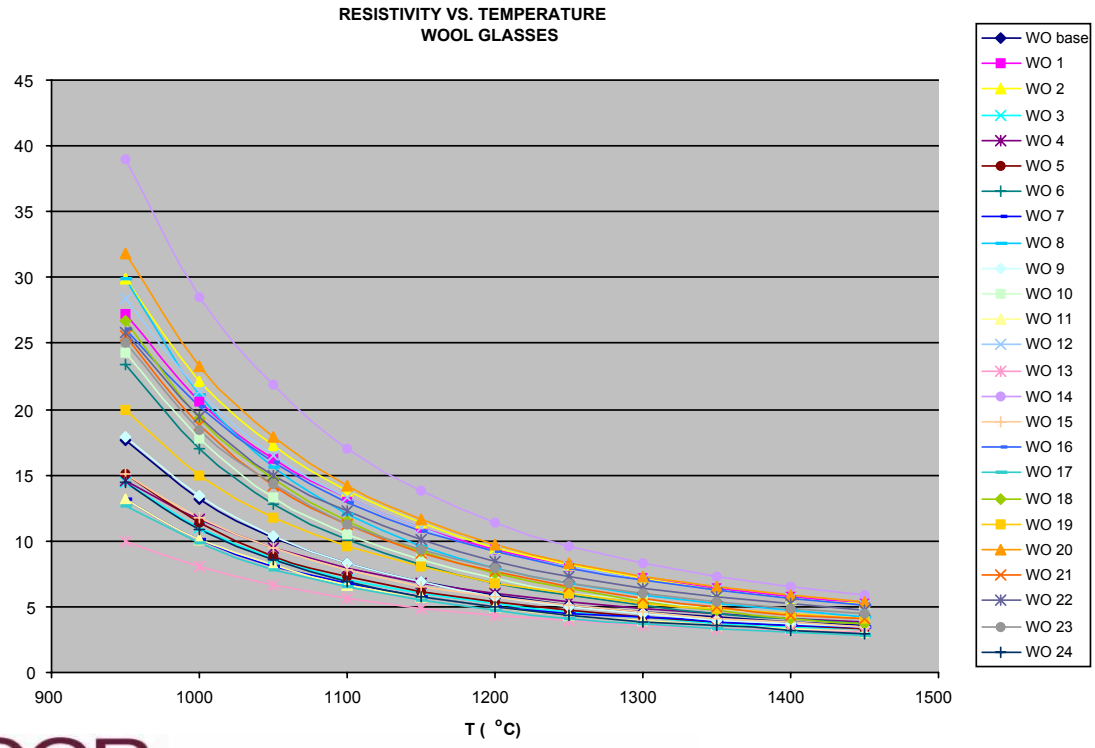


CGR NSF Industry-University Center for Glass Research

Companies Requesting to Evaluate Portions of Database

- Melt Properties Predictions
  - PPG Industries
  - Guardian Industries
  - Osram Sylvania
  - U.S. Borax
- Modeling and Properties Prediction
  - Techneglas
  - Corning Incorporated
  - Owens Corning
  - Visteon Glass

Sensors and Model Development for Improved Glass Processing Efficiency

MA Khaleel, CL Shepard, VN Korolev, KI Johnson, LJ Kirihara, and JT Munley — PNNL

DOE OIT Review

September 9, 2003

Battelle

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

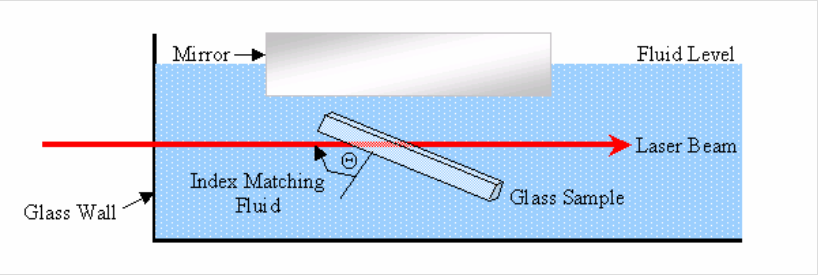
Motivation for the Work

- Reject rates in glass production significantly impact energy efficiency and production cost.
- Improved methods of monitoring stress and temperature in glass forming are needed for better process control.
- Processing standards call for limits on residual stress, but accurate methods for predicting stress and its relation to process parameters have not existed.
- A heat transfer code including the contribution of internal radiation in glass has not existed until now. This has limited the accuracy of thermal and thermal stress analysis methods.
- Advanced modeling tools combined with better diagnostics will improve glass production efficiency.

Measurement of Stress in Television and Automotive Glass

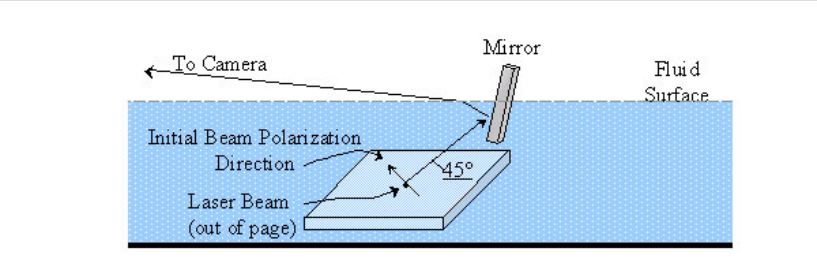
- Method for measuring in-plane stress throughout glass thickness has been developed — results shown
- Method is applicable to both TV and automotive glass products
- Method is applicable to a plant environment
- Research results have been publication in *The Journal of the American Ceramic Society*
- Patent is filed

Diagram of Experimental Arrangement

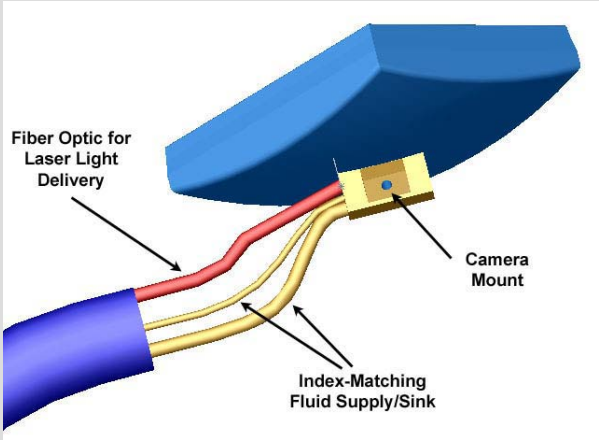


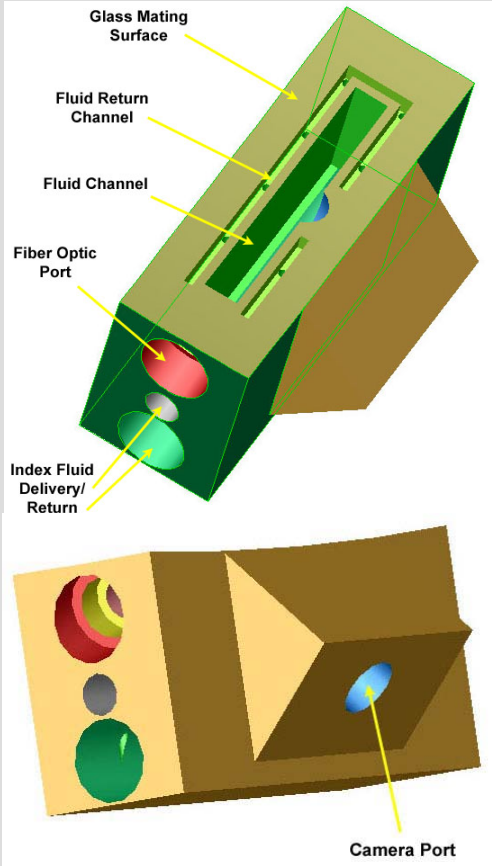
Side view

End view



Concept for Plant Stress Measurement Instrument





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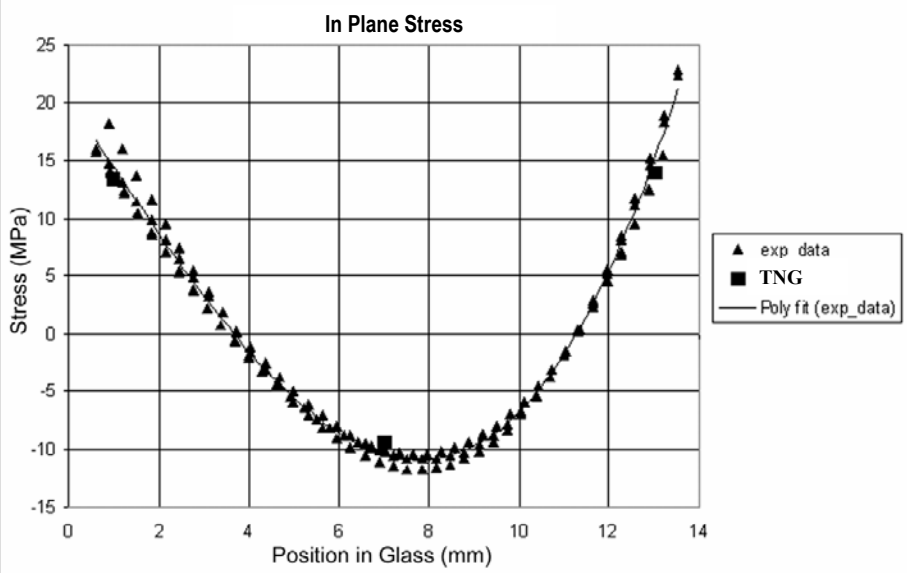
Plot of the In-plane Stress Through the Thickness of the TV Glass Sample



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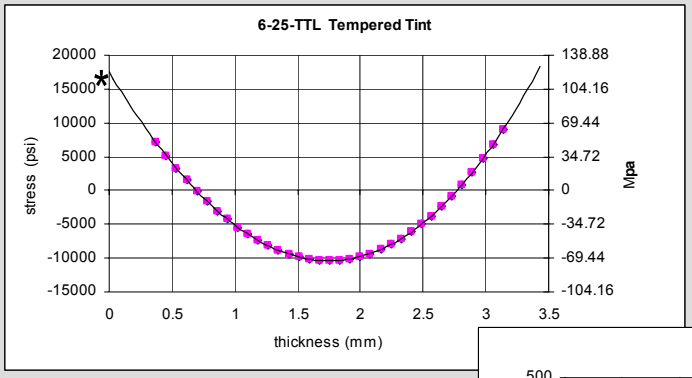
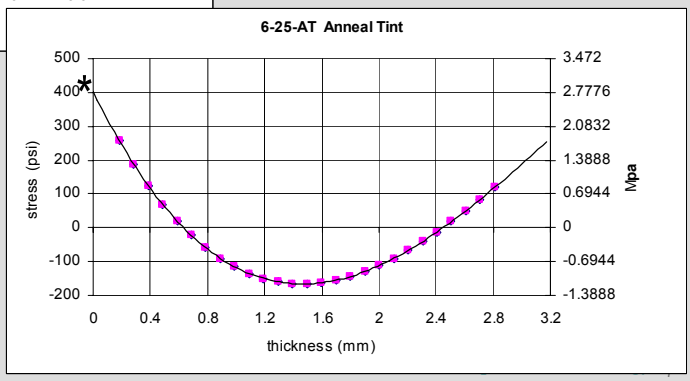
In-plane Stress Measurements Through the Glass Thickness of Low- and High-Stress Automotive Glass





* = GASP Measurements

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RAD3D Development and Validation

RAD3D is a finite element analysis tool for simulating glass heating (including internal radiation effects) in a production furnace envirionment.

<u>Technical Activities</u>

- Instrumentation of experimental furnace at PPG and collection of data
- Development of versatile modeling tool for furnace optimization and glass thermal analysis
- Model coupling to commercial codes
- Model validation with experimental furnace tests.

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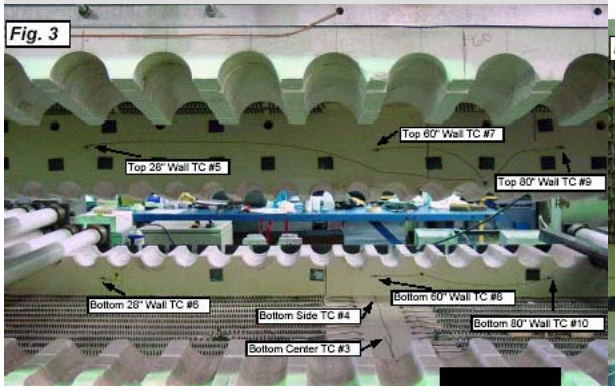
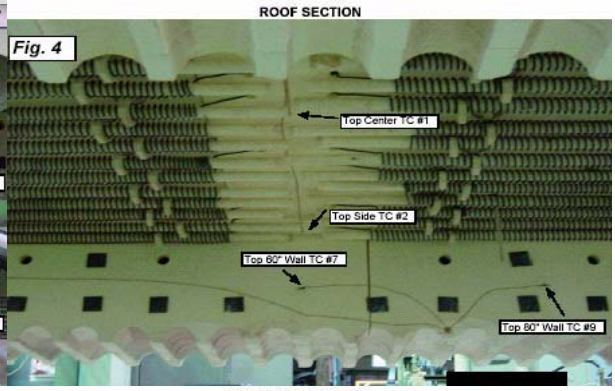
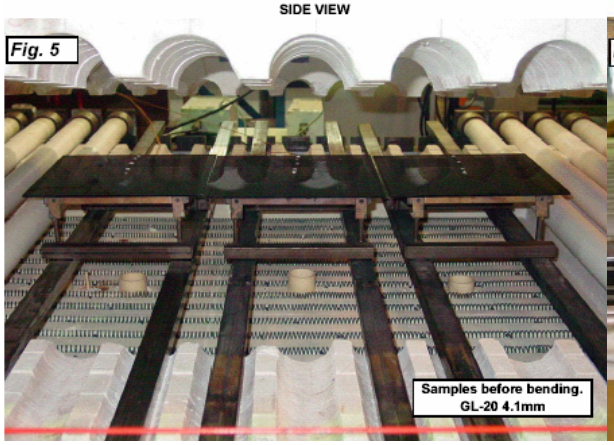
Experimental Furnace Layout



ROOF SECTION

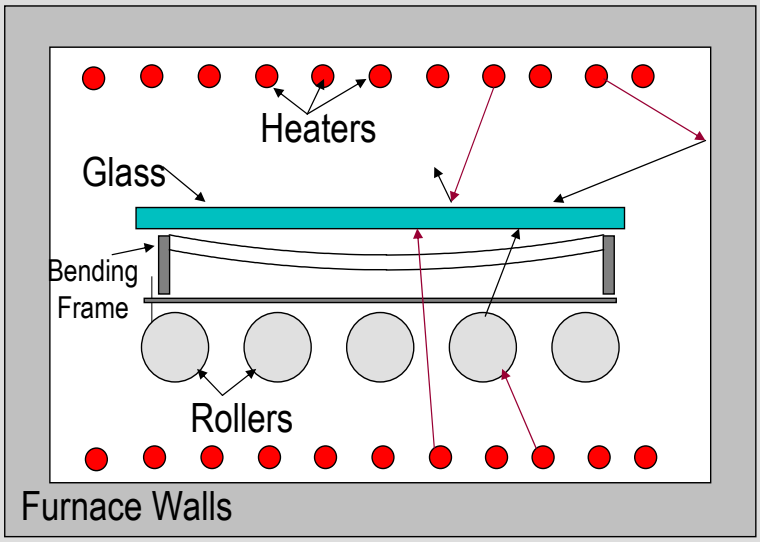


SIDE VIEW



VIEW FROM EXIT END

Description of the Furnace Heating Model



Heaters

- Uniformly distributed planar heat source

Walls

- Diffuse radiation to and from walls
- Heat conduction through layered walls with convection on the outside

Glass

- Specular reflection on the surface
- DOM for heat transfer in glass (1-D and 2-D through thickness and plane of glass respectively
- Conduction solved implicitly

Rollers

- Current – Non-rolling
- Future - moving temp field with fixed mesh for rollers

RAD3D Benchmarking: PPG Model of Radiant Heating in Glass

Model Size

15770 Nodes

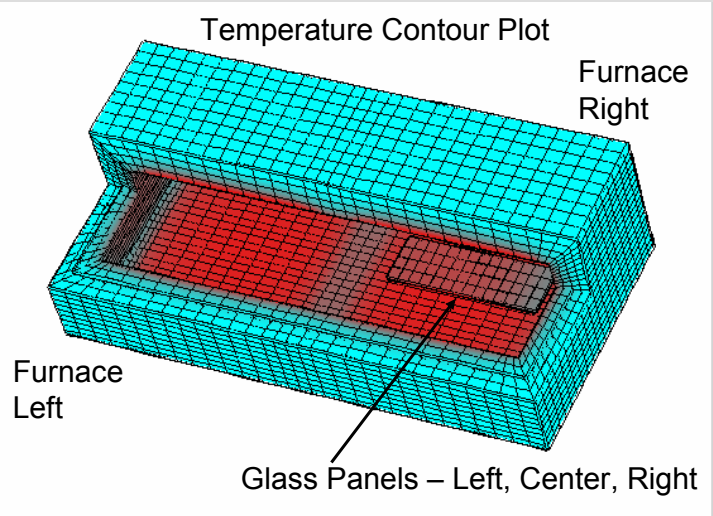
12512 Elements

10 Nodes through the glass thickness to capture internal radiation

10,000-second transient simulated

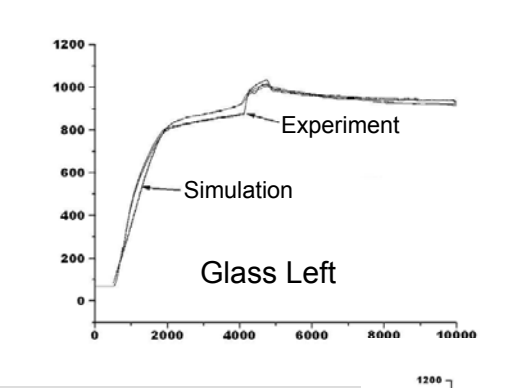
Solution Time: 5300-sec

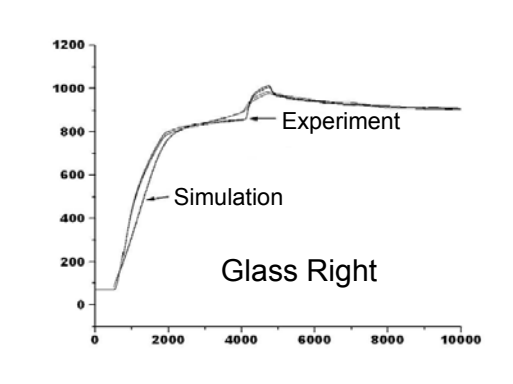
FASTER THAN REAL TIME!

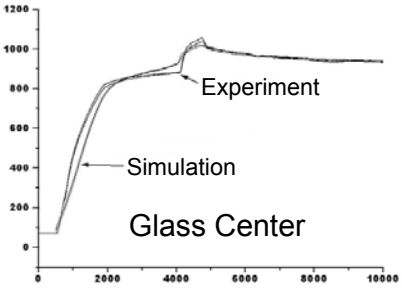


PNNL model of PPG single zone furnace.

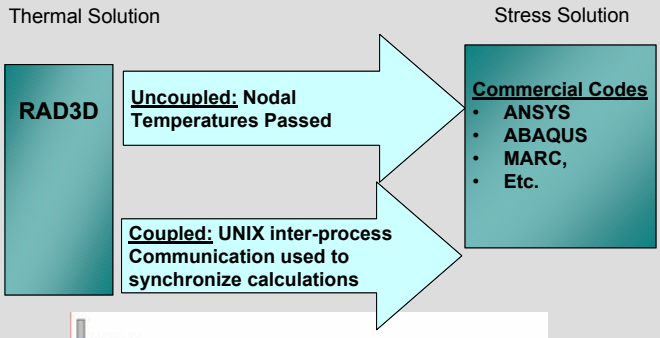
Comparison of Experimental and Model Glass Temperatures vs. Furnace Heating Time

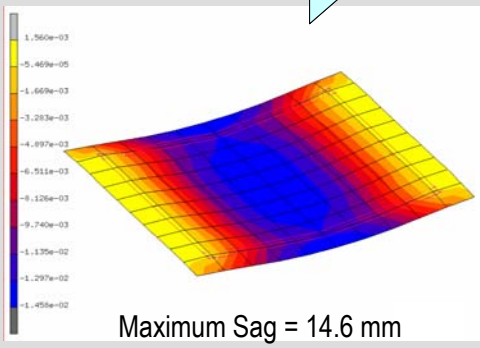






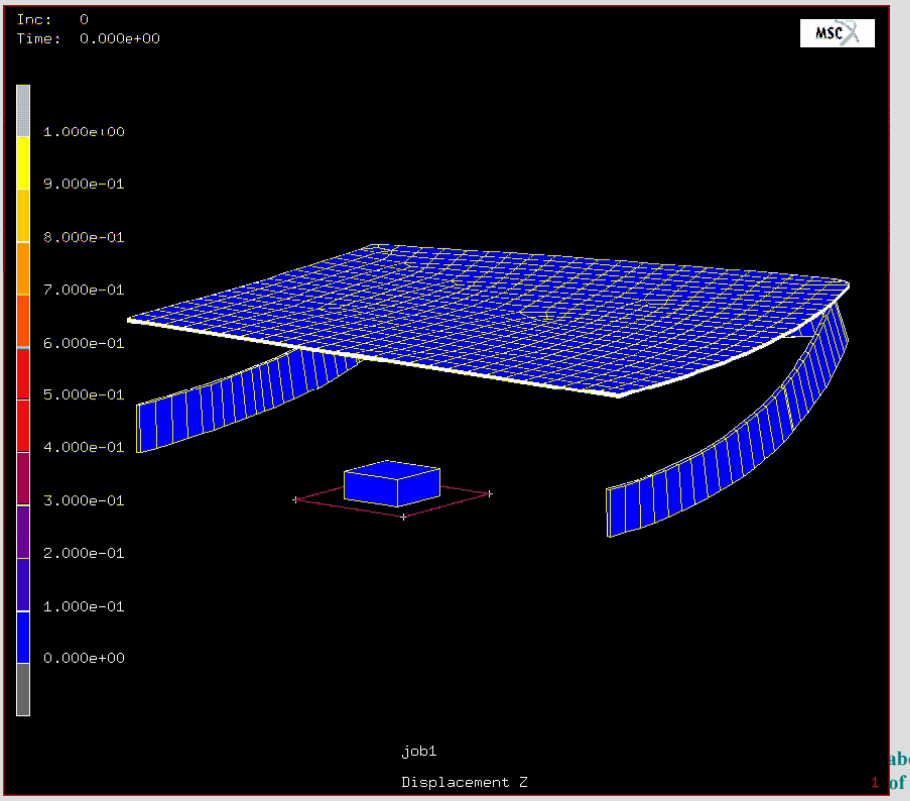
PNNL's *RAD3D* Code can Link with any Commercial Visco-Elastic Code



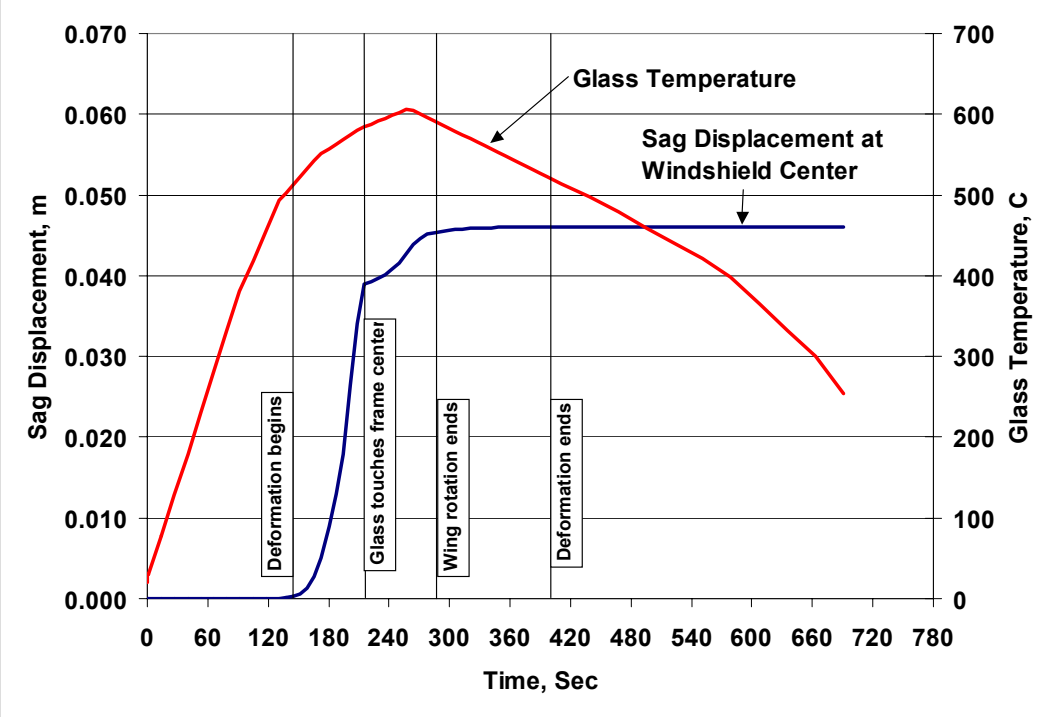


- *RAD3D* uses Unix Interprocess Communication (IPC) for coupling with commercial codes.
- C++ classes support shared memory operations and semaphors.
- *RAD3D* can run concurrently with any number of commercial codes using the synchronization logic in *RAD3D*.
- Socket-based communications are being developed to allow *RAD3D* to communicate through the internet.

Windshield Forming on an Articulated Bending Frame



Windshield Sag Depth v.s. Temperature



Summary

- A novel non-contact stress measurement method was developed that is capable of implementation in a production plant environment. A patent has been submitted. TAM Glass and at least 2 end user interested in producing prototypes.
- *RAD3D* - a first of a kind experimentally validated computer code for glass product forming and furnace development/ optimization.
- The computer code is versatile (runs on multiple hardware platforms and couples with multiple commercial codes) and computationally efficient (*fast-faster than real time*). MSC software is working with PNNL to include RAD3D into their commercial nonlinear software MARC.

COOPERATIVE EXTENSION
WASHINGTON STATE UNIVERSITY
ENERGY PROGRAM

Briefing on the OIT Clearinghouse

Sept 9, 2003

Gilbert McCoy
Energy Engineer

OIT Clearinghouse
WSU Energy Program

Office of Industrial Technologies

MISSION

Improve the energy intensity of U.S. industry through coordinated research and development, validation, and dissemination of energy efficiency technologies & practices.

Partner with industry and other stakeholders to:

- Increase energy savings
- Reduce environmental impacts
- Improve process yield/conserve resources
- Reduce reliance on foreign oil
- Increase use of renewable energy
- Improve competitiveness and quality of life

OIT Clearinghouse Current "Charter"

- Field questions and discuss OIT's portfolio of products/services 11 hours/day (both *programmatic* and *technical* assistance)
- Help promote integrated delivery of all OIT resources
- Continue to provide technical assistance for BestPractices areas

Technology Delivery

- Technical Assistance
- Plant-wide Assessments
- Industrial Assessment Centers
- Software Tools
- Training
- Information (Case Studies, Tip Sheets, etc.)

Software Tool Overview

- **Decision Tools CD**

  Contains:

  MotorMaster+

  AirMaster+

  Pumping System Assessment Tool

  Steam System Assessment Tool

  Process Heating Assessment Tool

MotorMaster+ 4.0

- Contains price and performance information for over 25,000 motors sold in North America
- Calculate energy savings for New Purchase, Repair versus Replace, or Replace Existing Motor scenarios
- In-plant Inventory Management and Maintenance Logging functions
- Energy Accounting and Savings Tracking capability
- Internal motor load and efficiency estimation capability

AirMaster+

- Models the supply side of your Compressed Air System.
- Can accommodate any number of rotary screw, reciprocating, or centrifugal compressors with independent control strategies and operating schedules
- Establishes an energy use “Baseline”
- Determine Energy Savings from eight energy efficiency actions.
- Considers interactive effects.

Pumping System Assessment Tool (PSAT)

- PSAT is a screening tool that allows users to prioritize energy and dollar savings opportunities
- Determine actual pump operating efficiency by comparing field electrical measurements with process flow and head requirements
- Obtain an indication of potential energy savings by comparing the actual system operation with that of a pump that is optimized for the application

Steam System Assessment Tool (SSAT)

- SSAT allows users to model their steam system and determine energy and dollar savings from a variety of efficiency improvements
- Savings can be determined from such measures as increased condensate return, reductions in steam leaks or vented steam, repair of failed steam traps, backpressure turbines, fuel switching, and changes in boiler blowdown or deaerator practices.

Process Heating Assessment Tool (PHAST)

- Survey all equipment in your plant that uses fuel, steam, or electricity for heating. PHAST indicates the estimated annual energy use and cost for each piece of equipment.
- Construct detailed heat balances for process heating equipment. Users can pinpoint sources of energy waste.
- Modify operating conditions and calculate potential energy savings.

Insulation Optimization with 3E Plus

- Tool developed by the North American Insulation Manufacturer's Association (NAIMA) and distributed by OIT.
- 3E Plus allows users to determine surface temperatures and heat losses and to optimize insulation thickness for steam, process heat, or chilled water lines.
- Contains a library with conductivity data for generic insulation materials.

Publications (Series)

- Energy Tips for Steam Systems, Motors and Drives, Pumps, Process Heat, Compressed Air, and (soon to come) Fan Systems
- Technical Briefs
- Sourcebooks (contains Fact Sheets on selected topics)
- Best Practices Project Case Studies, Plant-wide Assessments (Anchor Glass), and Showcase Demonstrations
- Research Project Fact Sheets

Publications (Packets or targeted)

- Selling Energy Efficiency to Management (packet)
- Energy Management for Motor-Driven Systems
- Motor Repair packet
- Pumping Efficiency packet
- Timely Tips to Reduce your Natural Gas Use
- Energy Matters quarterly (Special Editions)

Technical Assistance

- Call OIT Clearinghouse Hotline (800) 862-2086
- Log in request/case with an Intake Person
- Assigned to an engineer based upon technical needs
- Resident experts in Motors and Drives, Steam Systems, Refrigeration, Process Heating and Heat Recovery, Compressed Air Systems, Lighting Technologies, etc.
- Spend from 2 to 5 hours per case.

OIT Clearinghouse History

- Solicitation for "OIT Clearinghouse" awarded in 1999; operation now based on integrated delivery in support of *all* of OIT's goals
- Over **75,000** cases of programmatic and technical assistance for US Industry since 1994
- Since start of OIT Clearinghouse June 1999, we have handled **22,800** cases from over 13,000 OIT customers
- Case Management Database (CMD) Use keywords to identify Frequently Asked Questions (FAQ's)

Technical Assistance Topics

- Software tool technical support
- Data logging/information gathering
- Use of OIT software tools/Interpretation of results
- Efficiency measures appropriate to a process
- Life cycle costing
- Limited analysis and number crunching
- Check results
- Bounce ideas off of us
- Innovative and emerging technologies

Partners and Customers

- Energy end-users in all sectors
- Industry
- Manufacturers
- Inventors
- Consultants
- Purchasing officials
- Local, state and federal government agencies
- Federal power marketing administrations
- Utilities
- Researchers
- National labs
- Engineers
- Military
- Plant Operators
- Educators

Contact Information

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Website www.oit.doe.gov

Development & Results of an Energy Assessment Protocol

Brain Kauffman/John Plodinec – DIAL - Mississippi State
Cheryl Richards/John Connors – PPG Industries, Inc.
John Latter/Dan Wishnick – Eclipse/Combustion Tec

Where We Are Today…

Where We Want To Be Tomorrow…

Objectives

- Monitor & characterize furnace operations
- Identify potential energy inefficiencies
- Recommend energy saving changes
- Implement changes & re-evaluate energy consumption

*Energy Assessment Protocol**

- Determine nature of assessment
  - Identify project goals
- Identify measurement locations
  - Determine ability to access locations
  - Determine availability of utilities
- Identify measurement techniques
  - Sensor type & sensor requirements

***Combustion/Thermo Engineer Required**

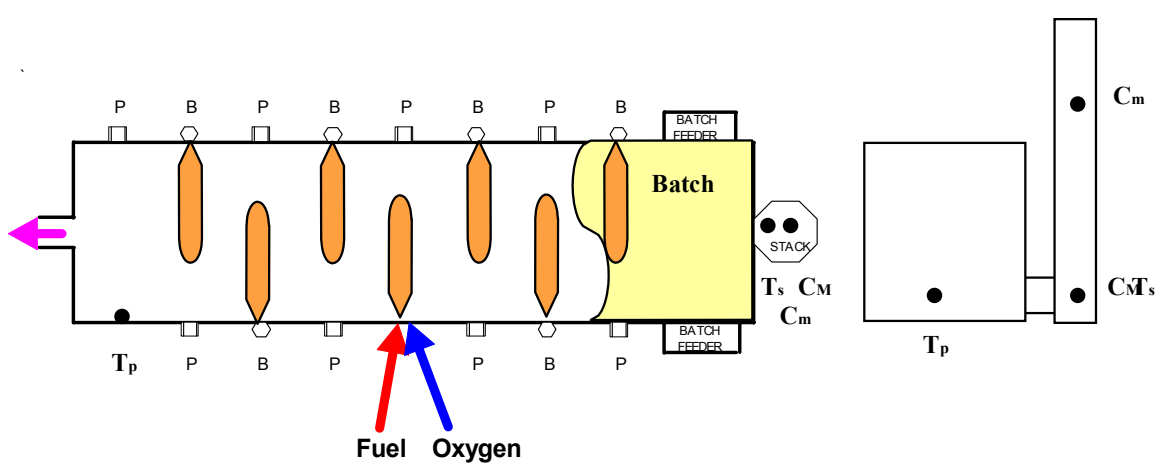
Energy Assessment Protocol

- Make initial EA measurements
- Analyze data
  - Perform comprehensive mass and energy balances
  - Recommend changes
- Address EA findings
- Re-evaluate furnace

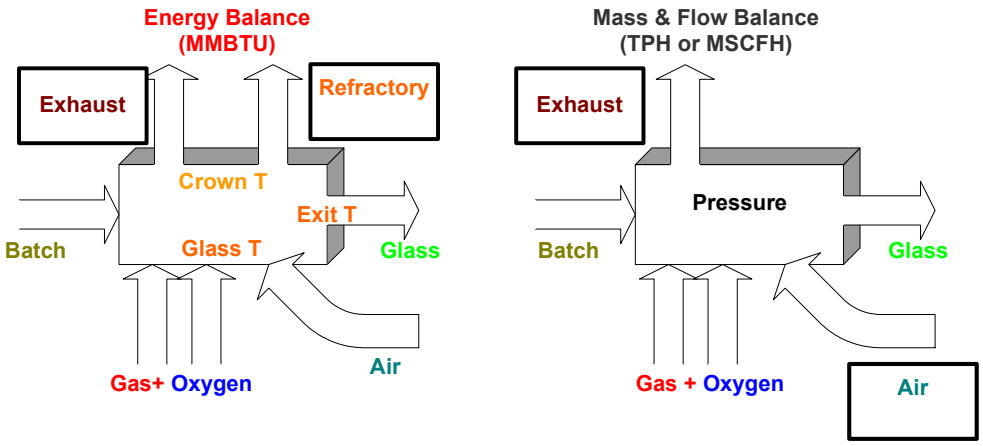
Measurement Systems

- Pyrometers
  - Suction - Gaseous Temperature (T_s)
  - Ratio - Interior Wall Surface Temperature (T_r)
- Thermal Imaging
  - Flame and Glass surface
- Extractive Gas Analysis
  - Major Species Concentration (C_M)
  - PPG and DIAL
- High Temperature Pitot
  - Gas Velocity

Measurement Points



Mass & Energy Balance



Date: June 2003 Pull: T/day
Gas: MSCFH Oxy: MSCFH O/G:
Efficiency: % Energy/Glass: MMBTU/Ton

Accomplishments – Operations

- Oxy & Gas flow calibration & monitoring
- Identified discrepancy in oxy-gas ratio
- Opportunity - furnace pressure control

Accomplishments - Burner

- Burners – Primefire 400
  - Burners developed using NICE^3 DOE funding
  - Installed 2 Primefire 400 burners
- Results of new burner operation
  - Batch line movement – 2 ft
    - Heat transfer improvement
  - Energy transfer into glass – 10% improvement
    - Energy saved
  - NO_x – 21% reduction
    - Emissions reduction

Accomplishments - Diagnostics

- In-furnace O_2 measurements
  - Discrepancy in presence of high CO_2
- Validation of measurement techniques
  - Able to get CO_2 and 'O_2' agreement using two different analytical sensors
- Recommended method for performing mass balance
  - Measure CO_2
- Better O_2 sensors needed

Commercialization Plans

- Energy Assessment
  - Quote supplied to Glass manufacturer by DIAL and Eclipse/Combustion Tec
- Burner Technology
  - Currently used in 4 locations industry-wide
  - Similar results observed

HIGH-LUMINOSITY, LOW-NO_X OXY-NATURAL GAS BURNER FOR GLASS FURNACES

David Rue, Sergei Nester, Hamid Abbasi
Gas Technology Institute

Dan Wishnick, Valery Smirnov, Bill Hobson,
John Latter, Kevin Cook
Eclipse / Combustion Tec

ACKNOWLEDGEMENTS

TEAM MEMBERS

Gas Technology Institute
Eclipse- Combustion Tec
Owens Corning
PPG Industries

SPONSORS

U.S. Department of Energy OIT
Gas Research Institute
GTI Sustaining Membership Program
New York State Research and Development Authority

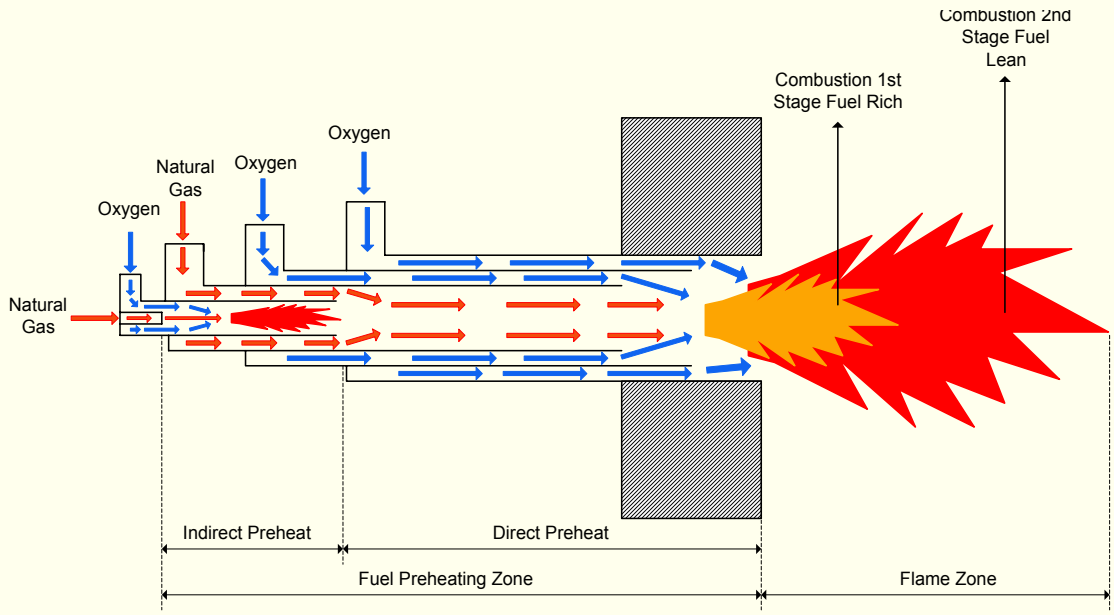
GETTING MORE FROM OXY-GAS

- Oxy-gas flames release more heat to glass if:
  - **Combustion is slowed** and flames are made larger
  - **Flames are brighter** or more luminous
- Ways to incorporate these features:
  - 'Flat flame' burner designs
  - Controlled momentum and mixing
  - Staged combustion
  - Separate injection jets for oxygen, gas
  - Creating soot precursors and soot particles in the flame
    - the **High Luminosity Burner (HELN)** approach

HIGH LUMINOSITY BURNER: BACKGROUND

- Laboratory demonstration of increased luminosity:
  - by adding hydrocarbons to a flame
  - by preheating the fuel to a flame
  - IGT verified boost in heat transfer and luminosity by adding externally generated soot (from a cracker)
- Development of High Luminosity Burner concept
- Patent on burner concept granted March 1998
- Current program: develop, commercialize burner
  - DOE, SMP, GRI, NYSERDA

HIGH LUMINOSITY BURNER - CONCEPT



FUEL PREHEATING AND FLAME ZONE MODELING RESULTS

- Soot concentrations increase from 0.1 to 2.0% at optimum Fuel Preheat Zone conditions
- Soot concentrations in fuel and furnace inlet affect furnace thermal performance
- Thermal efficiency of luminous flames can be increased by 25%
- Flames covering a large part of the glass surface enhance thermal performance
- Short flames produce non-uniform profiles
- Increasing soot concentration lowers temperature and decreases NO_x

COMMERCIAL PROTOTYPE HIGH LUMINOSITY BURNER DESIGN

- Flat flame burner
- Inlets reduced to one for gas and one for O_2
- Burner length reduced by using the block as part of the direct mixing zone
- HELN 'A' multiple jets
  - Center preheated fuel slot
  - O_2 slots above and below fuel slot to create fuel-rich and fuel-lean flame zones
- HELN 'B' single jet
  - Proprietary means of staging combustion using a single slot
  - Burner capacities from 1 to 20 MMBtu/h

FLAT FLAME OXY-GAS BURNERS AT 1.75 MM/Btu/h

Combustion Tec
Primefire 300 burner

HELN 'A' Prototype burner
8% O_2 precombustion

BURNERS FOR INITIAL DEMONSTRATION TESTS

- Burners have been designed to cover the range commonly used in glass melters
  - Small 1 – 4 MMBtu/h
  - Medium 2 – 8 MMBtu/h
  - Large 5 – 20 MMBtu/h
- Burners for demonstration tests
  - Fiberglass – Owens Corning – 7 burners (mix of small and medium
  - Flat glass – PPG – 10 burners (all large)

DEMONSTRATION TESTING

PPG – Meadville, PA

- Testing funded by DOE NICE3 and PPG
- Furnace is a new flat glass melter using 10 large burners firing >10 MMBtu/h
- Long-term combustion system performance will be evaluated and documented
- All burners have been fabricated and installed on Meadville, PA furnace and began operation in Sept. 2002

COMMERCIALIZATION PATH

- Demonstration testing by GTI and Combustion Tec with Owens Corning in Sept.-Nov. 2002
  - Burners and burner blocks at Delmar, NY plant ready for installation on full furnace
- Demonstration and long-term performance by GTI with PPG beginning in Oct. 2002
  - Burners already installed in Meadville, PA furnace
- GTI holds the initial technology patent. A second joint GTI/Combustion Tec patent is in preparation
- Combustion Tec will sell, fabricate, install, and support the high luminosity burner as Primefire 400, the upper end of their oxy-burner line
- Technology will be extended to other industries with GRI and NYSERDA support

HISTORICAL PERSPECTIVE

- Industrial glass production over last century:
  - 2000ºF+ air-fired, refractory-lined furnaces
  - 50 to 700 tons/day
- Improvements have included:
  - heat recovery regenerators
  - more efficient burners
- Since 1990, lower oxygen costs have allowed use of oxy-firing to:
  - meet tight NO_x rules
  - improve efficiency
  - lower capital cost
  - increase glass quality

U.S. Department of Energy
Energy Efficiency and Renewable Energy

industrial technologies program

Energy Efficiency Opportunities in Glass and the Role of Public-Private Partnerships

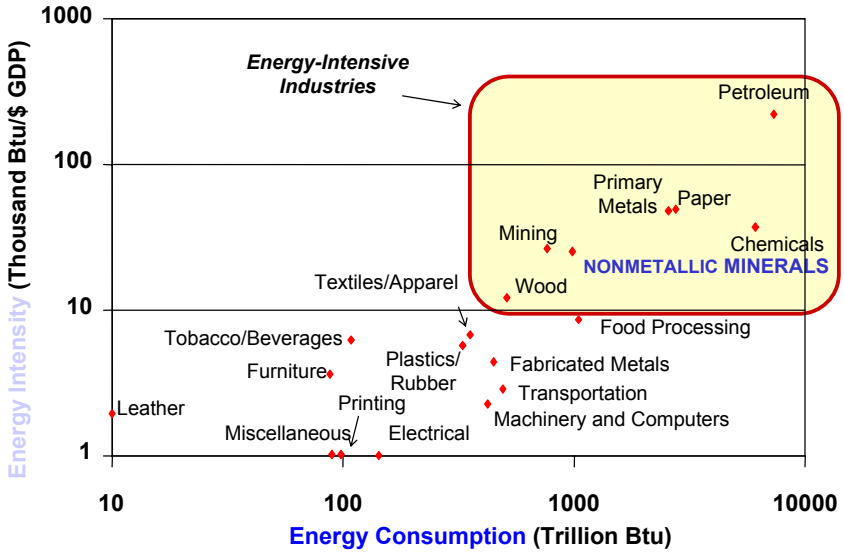
Glass Project Review
September 9, 2003

Buddy Garland
Industrial Technologies Program
U.S. Department of Energy

U.S. Department of Energy
Energy Efficiency and Renewable Energy

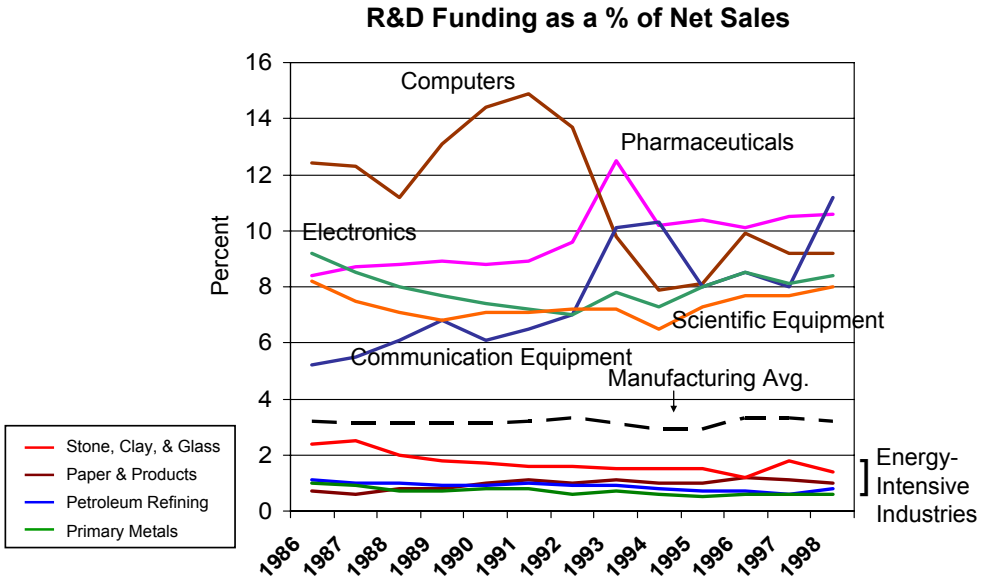
Our Focus: Major Energy-Intensive Industries, Including Glass

Industrial Energy Intensity vs. Energy Consumption



Sources: EIA 2001, 1998 Manufacturing Energy Consumption Survey; U.S. DOE 2002, Energy and Environmental Profile of the U.S. Mining Industry

R&D Intensity in Manufacturing 1986-1998



Source: NSF 2002, Research and Development in Industry

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Current Situation

- Large efficiency opportunities exist in the energy-intensive industries
- Technical challenges are complex and varied
- High technical and financial risk inhibit investment in efficient process technology
- Severe private underinvestment in efficiency R&D
- U.S. manufacturers face fierce global competition
- Large capital investments required for new technology commercialization
- Capital stock turnover is slow

Positive Impact Manufacturing

- Economy - jobs
- Education - 21st Century workforce
- Resource conservation/recycling
- Technology growth
- Energy
- Environment

U.S. Department of Energy
Energy Efficiency and Renewable Energy

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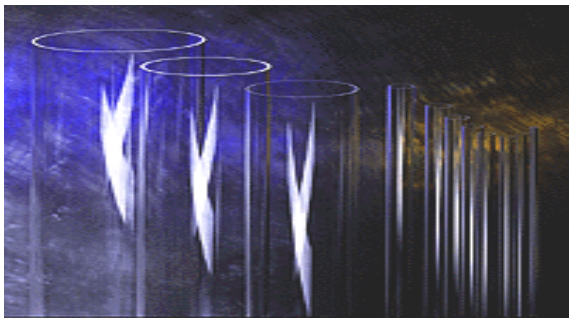
Visit our Web site:
www.eere.energy.gov/industry

EERE Clearinghouse
800-DOE-3732

Energy Efficiency Opportunities in the Glass Manufacturing Industry



presented by

Mark D'Antonio

ENERGY & RESOURCE SOLUTIONS (ERS)

ACEEE Summer Study on Energy Efficiency in Industry
August 2003

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Presentation Overview

- Overview of Glass Manufacturing in the US
- Glass-Making Process and Materials
- Recent Advances in Technology
- Energy Use Opportunities for Energy Efficiency Improvements
- Case Study: Osram Sylvania Glass Manufacturing Plant
- Key Findings and Opportunities for Energy Savings

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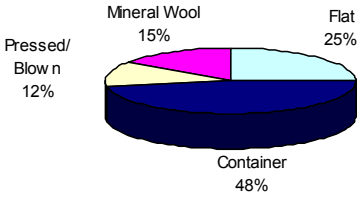
Glass Manufacturing in the US

➢Key Statistics

Sector	Shipments ($million)	Tons	Establishments	Employees	Capital Expenses ($millions)
Flat	2,746	5,000,521	36	11,053	322.7
Container	4,215	9,586,500	61	19,220	349.3
Pressed/Blown	5,787	2,484,182	515	35,013	636.8
Mineral Wool	4,844	3,04,000	298	22,823	285.8
Purchased Glass Products	10,847	not avail.	1,657	62,405	not avail.
INDUSTRY TOTAL	28,439	20,111,203	2,567	150,514	1,594.60



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Industry Energy Usage

U.S. glass industry energy use, MECs estimates (Trillion BTU)*

	Purchased Electricity	Fuels	Net Energy	Losses	Total Energy
Flat	5	47	52	10.4	62.4
Container	15	68	83	31.2	114.2
Pressed/ Blown	11	52	63	22.9	85.9
Mineral Wool	12	39	51	24.9	75.9
INDUSTRY TOTAL	43	206	249	89.4	338.4

*The most recent complete data available by sector is from 1994.
In 1998, total energy use was 293 Trillion BTU.

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Glass Manufacturing Process and Materials

- ***History:*** **7000 year old process**
- ***Raw Materials:*** **Silica, Limestone, Soda ash, etc.**
- ***Batch/Continuous Processing:*** **Proportions and Mixing Affect Product Outcome**
- ***Properties:*** **Chemical, Electrical, Mechanical, Thermal**
- ***Melting:*** **Temperature, Dissolution, Volatization, Oxidation**
- ***Furnaces:*** **Variations in size, type, purpose**
- ***Refining:*** **Impurities, Conditioning, Properties, Inefficiencies**
- ***Forming:*** **Process, Time, Cooling, Blowing, Casting, etc.**

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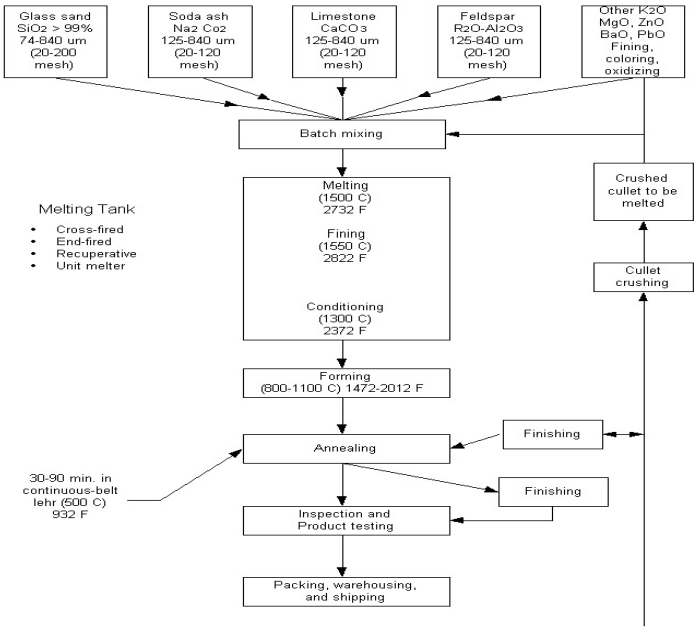
Glass Manufacturing Process



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Recent Advances In Technology

- Burner Optimization - Minimization of Excess Air and Proper Burn Position
- Batch or Cullet Preheating - DOE fact sheet
- Oxy-fuel Furnaces - optimized oxygen content
- Increase in Use of Recycled Glass
- Energy Management – process optimization, cross cutting technology advances

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Energy Efficiency Opportunities

- Process Optimization
  - Controls
  - Technologies
- Heat Reclamation
  - Melters
  - Annealing
- Plantwide Opportunities
  - Compressed Air
  - HVAC
  - Lighting
  - Drive Systems
  - Other

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Case Study: Osram Sylvania Glass Manufacturing

- DOE IOF Plant Wide Assessment
- Facility Overview
- Osram Glass Manufacturing Process Overview
- Measure Opportunities
- Key Findings and Opportunities for Energy Savings

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Case Study: Facility Description

- Two Buildings – 170,000 square feet
  - Quartz Operations
  - Ceramic Operations
- 24/7 Operation
- Purchased Gases
  - Oxygen
  - Hydrogen
  - Nitrogen
  - Argon
  - Helium
- Transformers (low voltage, high amperage) for Melters

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Case Study: Process Overview

- Sand Processing – cleaning, cracking
- Glass Melters – nine melters, 2000 deg Celsius
- Vacuum Bakers – four bakers, 1000 deg Celsius
- Re-Sizing
- Packaging

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Case Study: Energy Usage by End Use

End-Use	Electric (kWh)	Gas (MCF)
Glass Manufacturing	58.9%	10.0%
Transformers	12.3%	-
Compressed Air	2.8%	-
HVAC	4.8%	60.0%
Process Cooling	4.4%	-
Clean Room HVAC	3.7%	30.0%
Motor Systems	4.9%	-
Lighting	8.2%	-
Totals	100%	100%

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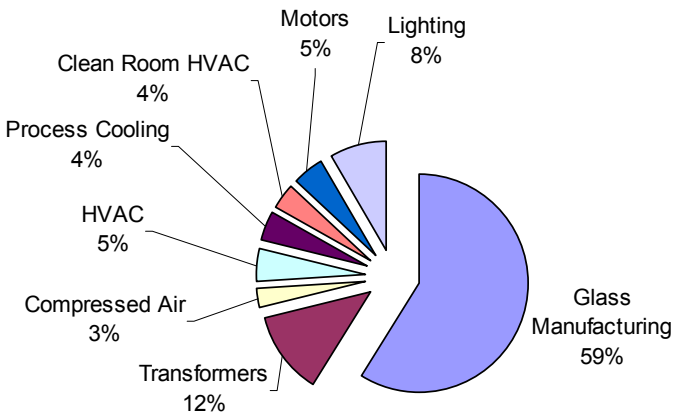
Case Study: Electric Usage by End Use



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Case Study: Efficiency Measures (EMs)

- **EM-1: Glass Production Process Optimization**
- **EM-2: Installation of High Efficiency Transformers**
- **EM-3: Purchased vs. Site Manufactured Gases**
- **EM-4: Compressed Air System Evaluation**
- **EM-5: High Efficiency HVAC Systems**
- **EM-6: Clean Room/Process Heat Recovery System**
- **EM-7: Process Cooling System Optimization**
- **EM-8: Motor Driven System Optimization**
- **EM-9: High Efficiency Lighting Controls**

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Case Study: Energy Savings

		Exeter Glass Manufacturing Facility			Projected Osram Glass Energy Savings
Energy Efficiency Measure		Annual Electrical Savings (kWh)	Annual Natural Gas Savings (MMBTu)	Annual Energy Cost Savings	Annual Energy Cost Savings (MMBTu)*
EM-1	Glass Production Process and Efficiency Improvement	687,062	na	$57,588	7,003
EM-2	Installation of High Efficiency Transformers	286,276	na	$23,995	1,459
EM-4	Compressed Air System Evaluation	164,250	na	$13,767	1,674
EM-5	Install High Efficiency HVAC Systems	202,125	2,340	$32,154	1,545
EM-6	Installation of Clean Room Heat Recovery System	129,938	1,003	$17,410	331
EM-7	Process Cooling System Optimization	154,589	na	$12,957	1,339
EM-8	Motor Driven System Optimization	57,255	na	$4,799	496
EM-9	Install High Efficiency Lighting Controls	95,813	na	$8,031	1,953
	Total	1,777,307	3,343	$170,702	15,802

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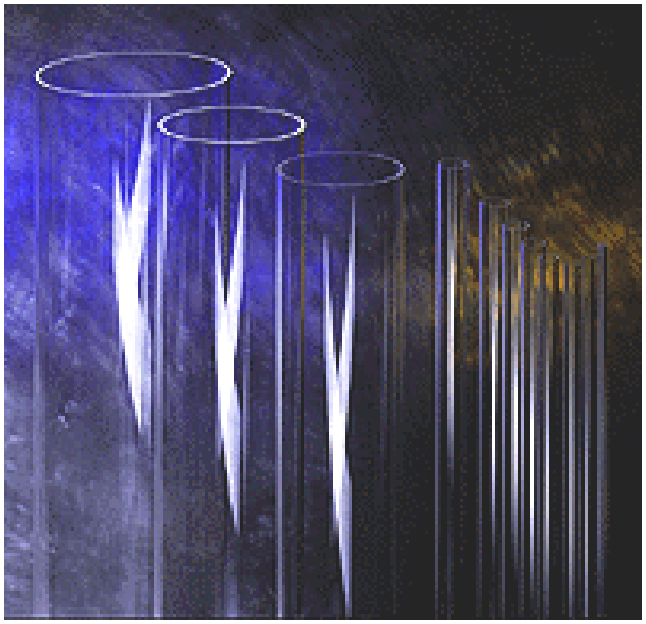
Questions?



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C

Appendix C

Attendees

Attendees

U.S. Department of Energy

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Golden, Colorado

September 8-10, 2003

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Appendix D

EERE Program Posters

GLASS FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

BUILDINGS

Windows of Opportunity in Energy-Efficient Buildings

In 2000, Americans spent approximately $265 billion for energy for buildings. This energy use is responsible for 35% of the nations's CO_2 emissions, 47% of SO_2 emissions, and 23% of NO_x emissions. These emissions are expected to increase by more than 25% between now and 2010. In 2000, buildings consumed more primary energy in the U.S. than either the industrial or the transportation sector, and buildings consume over twice as much electricity as the industrial sector.

The EERE *Building Technology Program* has three strategies to improve building energy efficiency:

- Research and development;
- Building codes, appliance standards, and guidelines; and
- Technology transfer and financial assistance.

The R&D strategy includes support for advanced research to develop new energy-efficient technologies for windows, building envelopes, and lighting. DOE has developed a technology roadmap for each of these glass-related building product areas. In addition, the Solar Program is pushing development of other glass-using technologies in its Zero Energy Building Initiative.

FACTOID

Commercial and residential window sales total 1.2 billion ft^2 ($7 billion) annually.

TECHNOLOGIES

LED light bulbs: just one of many new efficient lighting technologies for buildings.

LIGHTING RESEARCH PRIORITIES

- **Optical fibers**
- **Light Pipes**
- **LEDs, LEPs and ceramics**
- **Incandescent and flourescent bulbs**
- **Light Panels**
- **Daylighting**
- **Area Panels**

BUILDING ENVELOPE RESEARCH PRIORITIES

- Variable R-value insulating materials for glazings
- Glass and opaque double-envelope systems with integral energy collection and distribution
- Roof and/or wall assemblies that collect and supply energy to the building envelope
- Wall systems that integrate photovoltaics, similar to new roof shingles
- Simple, mass-producible wall and roof systems that can act as solar thermal collectors
- Daylighting system that has almost no heat gain and distributes light evenly

BUILDING WINDOW RESEARCH PRIORITIES

- **Imaging:** displays, holograms, electrochromics
- **Energy Production and Supply:** PV panels (clear, colors, thin film, coatings, environmentally benign materials), integral wind power
- **Light Transmission:** electro-, photo-, and thermochromics; holograms; low-e coatings; interior lighting; and daylighting rating
- **Insulation:** aerogels, monolithic transparent insulating materials, vacuum glass, gas retention, insulating coatings and alternate glazing materials
- **Analytical Tools:** thermal modeling, life-cycle analysis, solar heat gain
- **Manufacturing:** laser imprinting, recyclability, markets for process waste
- **Design:** stronger sealants, high security, glass-frame ratio, blast resistance, fire-rated, sun-screening, modular windows, ventilation
- **Electronics:** integral wiring, communications protocols

Large-area, thin-film PV modules used in a building facade.

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GLASS FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

SOLAR-THERMAL

Concentrator Solar Power
The EERE *Solar Energy Program* supports a range of applications including large-scale power production, on-site electricity generation, and thermal energy for space heating and hot water.

Concentrating solar power is on the brink of commercial viability, and U.S. industry is actively seeking several commercial project opportunities where financial incentives are being offered to buy down the cost of early systems. Over the last decade 354 MW of parabolic trough solar power plants installed in the 1980s operated successfully in the Southern California desert. These plants used 20 million square feet of mirrored glass reflectors.

Based on a recent report to Congress, U.S. industry has developed a plan for deploying 1,000 MW of concentrator solar thermal power in the Southwest. Industry indicates that 250 MW could be installed by 2006 with contracts to be signed for an additional 750 MW by that time.

Solar reflecting mirrors require special manufacturing to meet reflectivity, specularity, and durability requirements. U.S. glass companies have an opportunity to work with U.S. solar manufacturers to develop a strong position in the domestic and international markets for solar thermal power systems.

FACTOID

100 megawatt solar thermal power plant = About 8 million ft^2, 14.4 million pounds of glass

TECHNOLOGIES

Parabolic Trough Concentrators
Parabolic trough concentrators are most suitable for larger applications ranging from electricity generating systems delivering 50 kW to 160 MW, to industrial applications with 1,000 m^2 to 15,000 m^2 of collector area down to commercial applications as small as about 80 m^2. Arizona Public Service Company has solicited proposals for a one megawatt trough organic Rankine cycle power system to comply with State portfolio standard requirements for solar power.

Parabolic Dish Concentrators
Single parabolic dish systems with thermal engines, most often Stirling cycles, can produce 10 to 25 kW of electricity in stand-alone applications, or many dishes can be co-located to provide megawatts of power for distributed generation or village power systems. Several next-generation dish/Stirling systems are scheduled to be installed in Nevada next year.

Central Receivers
Central Receiver Systems will be installed in units of 100 $MW_{electric}$ and larger. U.S. companies Boeing and Nextant (Bechtel) are participants in fabricating a new system in Spain with a 45 MW–solar array and rated capacity of 15 MW_e due to the addition of 16 hours storage for round-the-clock operation.

MARKETS

Utility Scale Power Systems
Remote Electric Power Systems
Small Grid –Connected Power Systems
Industrial and Commercial Thermal Systems

Projected Near-Term Market for Concentrator Solar Power
To begin to meet the current 1,000 MW installation goal for solar themal power in the southwestern United States, parabolic trough systems will be the most likely technology to be deployed in the first stage. LUZ International was installing 80 MW-parabolic trough plants in 12 to 15 months in the late 1980s and a large portion of the first 250 MW of capacity is expected to be trough systems. Dish/Stirling fields in megawatt increments should be ready to be deployed as the project advances. In addition, companies developing U.S. central receiver technology overseas could organize a follow-on project in the U.S. as the cost of replication declines.

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GLASS FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

TRANSPORTATION

Lightweight Window Glazing Alternatives for Vehicles

The EERE *Freedom Car and Vehicle Technologies Program* is supporting development of lightweight glass for vehicles. The objective is to develop new glazing that helps meet a 30% weight reduction target for a next generation of more fuel-efficient vehicles.

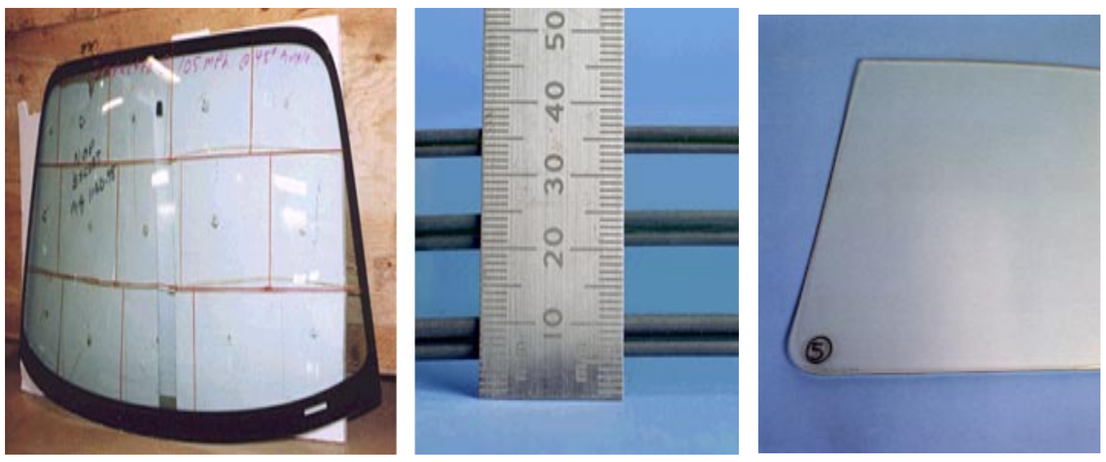
Current production vehicles have an average of 150 pounds of window glass. The key to development of a new glass product is to maintain structural integrity of the vehicle while cutting the weight of windows as much as 50%. A Cooperative Research and Development Agreement with glass industry companies and the Pacific Northwest National Laboratory has produced a new glazing with thin glass layers and asymmetric construction. To date, windshield and side-body glasses have been made that are 30% lighter than conventional glazing.

This program has also developed new numeric models to study behavior of automotive glass under impacts and performance and reliability as a structural element in a vehicle.

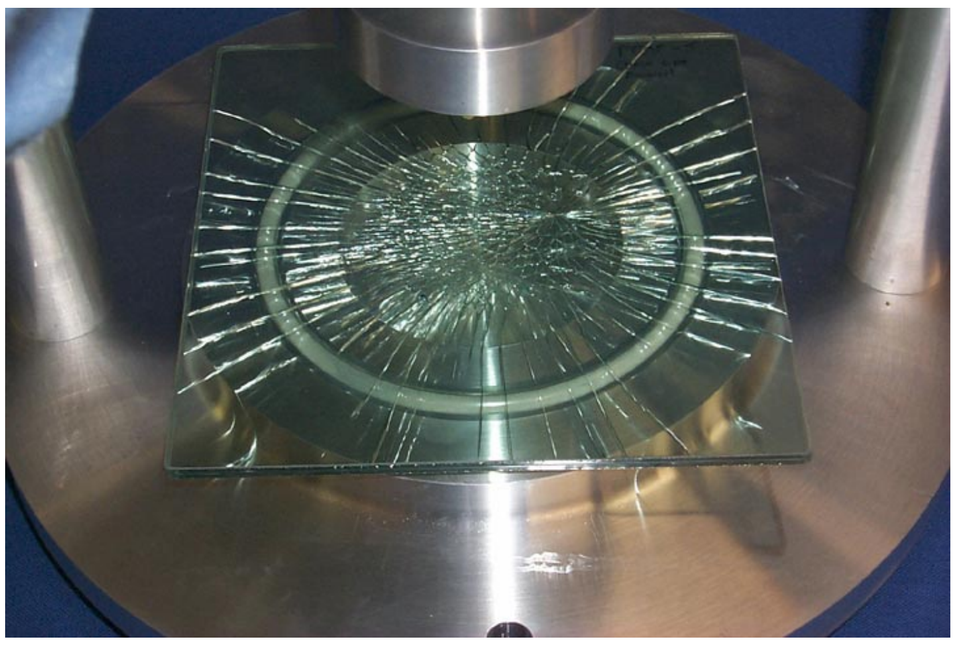
FACTOID

Current production automobiles contain an average of 150 pounds of glass.

TECHNOLOGIES

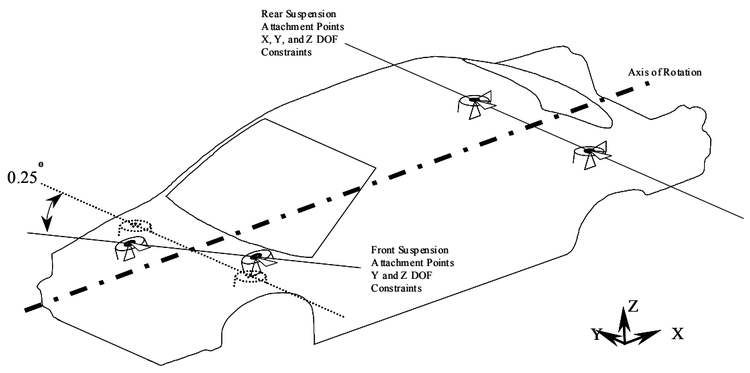


The plies used to fabricate conventional auto glass range between 2.4 and 2.6 mm thick. DOE has fabricated windshield glass using plies of 1.6 to 2.1 mm thick. It is also working on hardening coatings and studying asymmetric constructions. Results to date have reduced weight by 30%.



DOE developed a unique ring-on-ring testing apparatus to test strength of curved glass segments. The tests created a tool for determining failure probabilities as a function of design, thickness, service life, and temperature.

Torsional Loadcase



Structural Rigidity and Strength Characterization are two key factors supporting work on glass and lighter weight vehicles. Working with Ford Motor Company, DOE has modeled torsional rigidity of a particular car design and found that reducing glass thickness by 50% should only lower torsional rigidity a small amount.

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