

**Program, Registration Form & Collected Abstracts**

 **GlassTrend-ICG seminar & workshop – registration before 1 March 2013!**

**“INNOVATION IN GLASS PRODUCTION”**

**10.-12. April 2013 Eindhoven, the Netherlands**

**Objective of the meeting**: Bringing together the Technical Committees of the Cluster Glass Production of the International Commission of Glass (TC11, TC13, TC14, TC15, TC18, TC21, TC25: www.icglass.com) and glass industry (GlassTrend) to exchange information of TC activities, to promote cooperation between the TC’s, to address new developments in Glass Production and to discuss the formation of new technical committees. Furthermore, analyzing further needs and driving forces for innovation in glass production.

**Target Group**: members of TC11, TC13, TC14, TC15, TC18, TC21 and TC25 and GlassTrend members / registration limit about 100 persons.

Official members of the ICG-Technical Committees TC11, TC13, TC14, TC15, TC18, TC21 & TC25 and maximum 2 members from GlassTrend companies have free access to the seminar.

**Venue of meeting:** Van Abbe Museum, Eindhoven, the Netherlands

 Bilderdijklaan 10, 5611 NH Eindhoven, the Netherlands

[www.**vanabbemuseum**.nl](http://www.vanabbemuseum.nl)

**Time Schedule (draft):**

Wednesday 10. April 9.00 - 13.00 TC13 internal meeting

 13.45 - 16.10 Welcome & Special Session on Innovation

 16.10 - 18.30 Time slot for internal TC meetings

 18.30 - 20.15 Welcome Reception in Van Abbe Museum

 20.15 - 21.00 CTC Core team meeting

Thursday 11. April 8.30 - 10.35 Session Energy & Environment (organized by TC13)

 11.00 - 12.45 Session Refractory Materials (organized by TC11)

 12.45 - 13.50 Lunch

 13.50 - 16.20 Session Glass quality (organized by TC14 & TC18)

 16.20 - 18.50 Time slot for internal TC meetings

 16.45 - 18.15 **GlassTrend Council meeting**

 19.15 - 22.30 Joint Dinner in City Centre Eindhoven (info be given in March)

Friday 12. April 8.30 - 12.15 Glass Furnace Design & Operation (organized by TC21 & TC15)

 12.15 - 13.20 Lunch & Separate lunch CTC core group

 13.20 - 14.50 Forming Process (organized by TC25)

 15.00 - 16.00 ICG Panel discussion: Cooperation TC’s & formation new TC’s

 16.00 Closure of seminar & workshop

 **REGISTRATION FORM**

**GlassTrend - ICG seminar & workshop**

**“INNOVATION IN GLASS PRODUCTION”**

**10.-12. April 2013 Eindhoven, the Netherlands**



For ICG and/or GlassTrend members only

Name: ………………………………………………………………………………..……

Company: ..……………………………………………………………………………..…

Address: ……….………………………………………………………….………………

 ……..……………………………………………………………………………

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E-mail address: …………………………………………………………………………..

Will join dinner on April 11: Yes / No Diet restrictions: Yes / No
(sponsored by GlassTrend)

 …………………………………..

Member of ICG-TC: Yes/No Member of GlassTrend: Yes / No

Remarks: …………………………………………………………………………………

 …………………………………………………………………………………

Send your completed registration form before 1st March 2013 to: elize.harmelink@celsian.nl (telephone number: +31 888662501)

**As there is a limited capacity we will register on a first come first served basis.**

**Hotel information/recommendations**

***Best Western Premier Art Hotel Eindhoven***
Lichttoren 22
5611 BJ Eindhoven
+31 40 7513500

Room rate: about € 103,- pp pn excl. breakfast (€ 21,50)

[www.**arthoteleindhoven**.com](http://www.arthoteleindhoven.com)

***Holiday Inn Eindhoven***Veldmaarschalk Montgomerylaan1
5612 BA Eindhoven
+31 40 2358235

Room rate € 115,- pp pn excl. breakfast (€ 22,-)
For reservations call (+31 40 2358235)

or email (reservations@eindhoven.holiday-inn.com)

**and use Reference code: CELSIAN EVENT**

[www.**holidayinn**.com/**Eindhoven**](http://www.holidayinn.com/Eindhoven)

***Hampshire Hotel Parkzicht***Alberdingk Thijmlaan 18
5615 EB Eindhoven
+31 (0)40-2146640

Room rate € 97,50 pp pn excl. breakfast
For reservations call +31 (0)40-2146640
or via reception@hotelparkzicht.nl

**and use Reference code: CELSIAN EVENT**

[www.**hotelparkzicht**.nl/en/](http://www.hotelparkzicht.nl/en/)

<http://www.hotelparkzicht.nl/en/index.html>

**or use for hotel booking:** [**http://www.hotels.nl/poi/treinstation/station\_eindhoven-216244/**](http://www.hotels.nl/poi/treinstation/station_eindhoven-216244/)

 

Celsian Glass & Solar

Please use one form per room and send this form to Best Western Premier ART Hotel Eindhoven. Please make your reservation before the 25th of February 2013. After that date the reserved rooms will be canceled.

**Guest details**

Name: …………………………………………………………………………………………………………………………………………………

Address: ………………………………………………………………………………………………………………………………………………

Zip code: ……………………………………………………………………………………………………………………………………………..

City: ……………………………………………………………………………………………………………………………………………………..

Country: ………………………………………………………………………………………………………………………………………………

Telephone: …………………………………………………………………………………………………………………………………………..

Email: …………………………………………………………………………………………………………………………………………………..

Arrival date: …………………………………………………………………………………………………………………………………………

Departure date: …………………………………………………………………………………………………………………………………..

Number of guests: ………………………………………………………………………………………………………………………………

**Block ID: 394981**

**Guarantee**

 Mastercard American Express Visa

Cardnumber: ……………………………………………………………………………… Valid until: ……/……

Name on the card: ……………………………………………………………………………………………………………………………….

Signature: …………………………………………………………………………………………………………………………………………….

**If you have any questions, please do not hesitate to contact us.**

Best Western Premier ART Hotel Eindhoven
Lichttoren 22 (Mathildelaan 1)
5611 BJ Eindhoven

: +31 40-751 3500
: +31 40-751 3600
: reservations@arthoteleindhoven.com
: [www.arthoteleindhoven.com](http://www.arthoteleindhoven.com/)

**Provisional Scheme:**

**Details in Program may change**

**Wednesday afternoon 10th April, 2013**

**9.00 - 13.00 hrs. TC13 meeting (internal)**

**13.45 - 16.15 hrs. Welcome & Special Session on Innovation**

13.45 - 14.00 Welcome & Introduction

 Ruud Beerkens CelSian Glass & Solar, Eindhoven, The Netherlands

Hande Sesigur, ŞiŞecam, Istanbul Turkey

14.00 - 14.30 *“Hardglass” – An innovative technology for container glass production.*

Guenter Lubitz, Vetroconsult/Vetropack, Bülach, Switzerland

14.30 - 15.00 *From glass waste to glass foam, a path for sustainable reuse of natural resources*

Dr. Arjen Steiner, Schaumglas Global Consulting GmbH, Zell am Main, Germany

15.00 - 15.35 *Gaps in Glass Melting Technology – what are we searching for?*

*& Energy Efficiency in Glass Melting*

Ruud Beerkens, CelSian Glass and Solar, Eindhoven, the Netherlands

15.35 - 16.10 *Duo-Paper from glass manufacturers on needs for R and D in the glass industry for the next 10 to 15 years*

Roland Langfeld, Schott AG, Mainz, Germany

& Jaap van der Woude, PPG Fibre Glass, Hoogezand,

*Needs for R&D in the glass industry: perspective of a specialty glass manufacturer*

R. Langfeld, H. Römer, SCHOTT AG, Mainz, Germany

*NL Roadmap 2030. Is 50% Energy Efficiency Improvement in Glass Product/ Production Chain Feasible?*

Jaap van der Woude, PPG Industries Fiber Glass bv, Hoogezand, The Netherlands

16.10 - 18.30 Time slot for short internal TC meetings

There are two or three rooms available in the Van Abbe museum for an internal TC session, TC’s have to make a reservation (ruud.beerkens@celsian.nl)

18.30 - 20.15 Welcome Reception in Van Abbe Museum

20.15 – 21.00 CTC Core team\* meeting

CTC Core-team\*: chairs of TC’s plus CTC coordinator and chair

\*Proposed Core-team:

1. Rene Vacher
2. Ruud Beerkens
3. Hande Sesigur
4. Guy van Marcke
5. Detlef Köpsel
6. Michael Dunkl
7. Erik Muijsenberg
8. Adnan Karadag
9. Wilfried Linz
10. Jaroslav Kloužek
11. Jaap van der Woude

**Thursday 11th April, 2013**

**8.30 - 10.35 Session: Energy & Environment (TC13), Chairs: Simon Slade & Guy van Marcke**

8.30 - 8.55 *An introduction to the work of ICG-TC13, with reference to practical studies and recent environmental legislation,* Simon Slade, Pilkington NSG, Lathom, UK

8.55 - 9.20 *Operating experience of the ceramic candle waste gas filter in the glass industry*

*Air Pollution Control in Glass Industry, a System for DeNOx, DeSOx & filtration*

Denis Lalart, Arc international, Arques France & Andreas Kasper, Saint Gobain, Herzogenrath, Germany

9.20 - 9.45 *Evaporation from glass melts – boron and selenium species*

Hans van Limpt, CelSian Glass and Solar, Eindhoven, the Netherlands

9.45 - 10.10 *Environmental legislation driving TC13 activities*

Guy van Marcke, AGC Europe, Brussels, Belgium

10.10 - 10.35 Problems, developments and energy performances of glass melting furnaces.

A. Unsal, L. Kaya, B. Orhan, Şişecam, Istanbul, Turkey

10.35 - 11.00 *Short Coffee Break*

**11.00 - 12.45 Session: Refractory / Glass Contact Materials (TC11), Chair: Michael Dunkl**

11.00 - 11.30 *Recommended Test Methods of the TC11 for Refractories*

Dipl.-Ing. B. Fleischmann,Hüttentechnische Vereinigung der Deutschen Glasindsutrie e.V. (HVG), Offenbach am Main, Germany

11.30 - 11.55 *Refractory solutions for the new challenges in glass furnace construction*

Stefan Postrach, Rongxing Bei, RHI GmbH, Wiesbaden, Germany

11.55 - 12.20 *Experimental regenerator refractory studies*

Stef Lessmann1, AnneJans Faber1, Rongxing Bei2, 1CelSian Glass and Solar, Eindhoven,

the Netherlands, 2RHI Refractories, Wiesbaden, Germany

12.20 - 12.45 *TC11/TC14 – RRT Blistering behavior of fused cast Materials at glass contact.*

Michael Dunkl, Meerbusch, Germany & Detlef Köpsel, Schott AG, Mainz, Germany

12.45 - 13.50 Lunch

**13.50 - 16.20** **Session: Glass quality (TC14 & TC18), Chair: Detlef Köpsel & Jaroslav Klouzek**

13.50 - 14.15 *Formation of sulphur deposits in bubbles*

Detlef Köpsel, Schott AG, Mainz, Germany

14.15 - 14.40 *TC14 activities on water measurement in technical glass*

Jan Hermans, Philips Lighting, Winschoten, The Netherlands

14.40 - 15.05 *Diagnostic determination of bubble defects in float glass furnaces*

Mustafa Oran, A. Otken, Şişecam, Istanbul, Turkey

15.05 - 15.30Break

15.30 - 15.55 *Replacement of calcined lime in the place of limestone in a container glass batch*

B. Arslan, H. Sesigur, M. Orhon, Şişecam, Istanbul, Turkey

15.55 - 16.20 *The processes controlling glass melting*

L. Němec, J. Kloužek, M. Jebavá, P. Cincibusová

Laboratory of Inorganic Materials, Joint Workplace of the Institute of Chemical Technology, Prague, Czech Republic

16.20 - 18.50 Time slot for short internal TC meetings

16.45 - 18.15 GlassTrend Council meeting in auditorium

19.15 - 22.30 Joint Dinner in City Centre Eindhoven sponsored by GlassTrend

**Friday 12th April**, **2013**

**8.30 – 12.15 Session: Glass Furnace Design & Operation (TC15, TC21)**

 **Chairs: Erik Muijsenberg, Wilfried Linz**

SENSORS & OPERATION (TC15)

# 8.30 - 8.55 *Controls and Sensors for Glass Melting:  A Look Backwards and Forward*

Aaron M. Huber, Ph.D., Johns Manville Technical Center, Littleton, Colorado USA

8.55 - 9.20 *Electrochemical sensors for high temperature application in mass glass production: available techniques, possibilities and limitations*,

Hayo Müller-Simon, HVG-DGG, Offenbach, Germany

9.20 - 9.45 *In-line oxygen sensors for the glass melt and the tin bath*
Paul Laimböck, Read-Ox & Consultancy B.V., Valkenswaard, the Netherlands

9.45 - 10.10 *Furnace Erosion and Health Monitoring Sensor (FEHMS)*

Yakup Bayram1, Eric K.  Walton1, Alexander C.  Ruege1, Jonathan Young2, Robert Burkholder2, Gokhan Mumcu3, Elmer Sperry4, Dan Cetnar4, Thomas Dankert5

1PaneraTech, Inc., Columbus, OH, 2The Ohio State University, Columbus, OH

3University of South  Florida, Tampa, FL, 4Libbey Glass, Toledo, OH , 5Owens-Illinois, Perrysburg OH, USA

10.10 - 10.35 *Real time visualization of temperatures and mass flows in the full 3D volume of a glass melter tank by soft sensors*

Piet van Santen, Anton Koenraads, Heike Gramberg, CelSian Glass & Solar BV, Eindhoven, the Netherlands

10.35 – 10.55 Coffee Break

# GLASS MELTING MODELLING (TC21)

# 11.00 - 11.25 *ICG TC21 Modeling of Glass Melting Processes*

How reliable and validated simulation tools can help to improve glass melting efficiency and productivity

 Erik Muijsenberg, Glass Service, Vsetin, Czech Republic

11.25 - 11.50 *Future Applications of CFD Modeling of Glass Furnaces*

Adriaan Lankhorst, CelSian Glass and Solar, Eindhoven, the Netherlands

11.50 - 12.15 *Mathematical Modelling Analysis of Increasing Furnace Performance with Improvements in Design & Operation*

L. Önsel, Z. Eltutar, S. Özel Ucar, Şişecam, Istanbul, Turkey

12.15 - 13.15 Lunch (lunch of small coordination group\* separately)

**13.15 - 14.55 Session Glass forming (TC25) Chair: Adnan Karadag**

GLASS FORMING & GLASS PRODUCTS (TC25)

13.10 - 13.20 *Short introduction*

 Adnan Karadag, Şişecam, Istanbul, Turkey

13.25 - 13.45 *Short review of TC25 activities in period 2000 till 2010*

Christopher Berndhäuser, Schott AG, Mainz, Germany

13.45- 14.10 Glass Forming Simulation in 3-D for container glass industry

Alfons Moeller, Nogrid GmbH, Bodenheim, Germany

14.10 - 14.35 *Tin and iron concentration profiles at float glass surfaces*

David Gelder of Math for Manufactures, UK

14.35 - 14.55 *Finite Element Analysis of container's geometry*

*Alberto D'Este, Mirko Silvestri, Roberto Dall'Igna*

*Stazione Sperimental del Vetro, Via Briati 10, Murano-Venice, Italy*

15.00 - 16.00 Panel Discussion with TC members & GlassTrend delegates

 Discussion steered by a panel from Core team\*

* Development needs for future glass production
* Formation of new technical committees for important themes:
	+ Energy Efficiency of Glass Production
	+ Chemical Engineering in Glass Technology
	+ Combustion Processes

±16.00 Closure of workshop

The power point presentations will be collected and formatted into PDF for proceedings on ICG and GlassTrend websites

\*Proposed Core-team:

1. Rene Vacher
2. Ruud Beerkens
3. Hande Sesigur
4. Guy van Marcke
5. Detlef Köpsel
6. Michael Dunkl
7. Erik Muijsenberg
8. Adnan Karadag
9. Wilfried Linz
10. Jaroslav Kloužek
11. Jaap van der Woude

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# Description : IC Glass Logo

# ICG - GlassTrend

# COLLECTION OF RECEIVED ABSTRACTS

# INNOVATION IN GLASS PRODUCTION

# 10.-12. April 2013

# Eindhoven

1. **“Hardglass” – An innovative technology for container glass production**

G. Lubitz

Vetroconsult/VetropackBülach, Switzerland

guenter.lubitz@vetroconsult.ch

For centuries container glass has continued to be a traditional and familiar packaging material. The main favorable product properties are clarity, inertness, gas-tightness, taste preservation, environmental integrity, and 100% unlimited recyclability. However, weight and fragility still offer opportunities for improvement, but each are dependent on the other. Clearly, glass strength increase is a prerequisite to achieving further weight reductions. This presentation describes an innovative approach to reach these targets and to take a remarkable step forward in container glass production.

The technology to significantly increase container glass strength is a tempering process which has been successfully applied in the flat glass and tableware industry. Emhart Glass is conducting a project called “Hardglass” to develop a reliable industrial application for the thermal strengthening of bottles and jars and is currently operating an initial installation at its Research Centre in Windsor, Connecticut. Several types of glass containers have been thermally strengthened and test results have shown a significant increase of resistance to internal pressure, impact, thermo shock, and vertical load, and excellent drop test results.

Now, Emhart Glass and Vetropack have decided to work together and to commercialize the “Hardglass” process for industrial production conditions. A pilot line will go into operation at the beginning of 2013 at Vetropack’s Pöchlarn plant in Austria. This presentation describes the “Hardglass” process and shows results from the initial trials at Emhart.

In summary, “Hardglass” is an effective new technology for increasing strength and producing a more robust glass container. It offers considerable benefits to fillers and consumers, including reduced weight, a smaller carbon footprint and enhanced durability. We believe that this technology is an industry milestone that over time promises to become the industry standard.

*Keywords: tempered glass, glass strength, CO2 footprint, light-weight containers, internal pressure, vertical load resistance, impact resistance, thermo shock.*

**2. From glass waste to glass foam, a path for sustainable reuse of natural resources**

Dr. Arjen Steiner

Schaumglas Global Consulting GmbH

Josef-Bechold-Str. 31, D- 97299 Zell am Main, Germany

a.steiner@sgg-consulting.com

The recycling of waste glass is important for sustainable reuse of our natural resources. Recycling of waste glass produces material streams that, until lately, had no significant field of application. They are mostly dumped. Foam glass from waste glass is an ecology minded and environmentally friendly product with sales to the construction industry of more than 700.000 m3 in Germany, Switzerland and Austria

Waste glass with impurities, e.g. CSP > 5%, which cannot be reused in the container or fiber glass industry can be used to produce foam glass gravel. The glass must be transferred to a powder with 90% <100μm and a d50=40μm. The powder is then mixed with solid or liquid foaming agents, depending on the process and the final application and heated treated in a tunnel kiln having a defined heat profile. The endless produced foam ribbon breaks into pieces by thermal shock after the kiln and the final product can be stored outside without any specific protection.

The material is mainly use for heat and sound insulation as well as road construction.

Other fields of applications are landscaping and gardening.

In addition to the gravel material also foam glass blocks can be produced, however because of the nature of the recycling glass, showing alterations in glass composition and impurities, the quality of the blocks is not comparable to existing foam block qualities.

# *Keywords: foam glass, heat insulation, road construction, sound insulation, glass powder, foaming agents, recycling glass waste*

**3. Gaps in Glass Melting Technology – what are we searching for?**

**& Energy Efficiency in Glass Melting**

Ruud Beerkens,

CelSian Glass and Solar, Eindhoven, the Netherlands

ruud.beerkens@celsian.nl

Analysis of industrial glass production shows that commonly used technologies to melt glass, & to shape glass articles or products from this melt, could be potentially improved with respect to:

* Process control to be able to fabricate glass with high production yield, low reject and within tight product specifications;
* Emissions, to lower environmental impact of glass production especially in the glass melting process. It includes primary measures and secondary measures. In several countries, specific emissions of dust, NOx and SOx have been decreased by 65-75 % over the last 20-25 years. Further, decreases in emissions, e.g. by better combustion systems and process control are expected. Primary measures are preferred above secondary measures.
* Flexibility, the market asks for various different products and glass industries have to address and respond swiftly and quick on changing market requests. Many glass production systems are directed on large scale production and product, glass composition and glass colour changes both needs longer transition times and consequently produces “waste” glass during such transition without a market for it.
* Energy efficiency; although glass melting (typically responsible for 40-85 % of total energy demand for glass production) processes have become much more energy efficient, especially in the container glass sector in the last 100 years, there is still a potential for energy efficiency improvement. Parallel to that CO2 emission reduction can be achieved. For example, the recent energy efficiency benchmarks show that the average container glass furnace typically consumes 20-22 % more energy than the best practice. Even without revolutionary glass melter design and process changes, there is on average this 20 % energy efficiency improvement potential. Most energy input in glass melting is lost by flue gas heat contents. Energy Modelling studies show that for container glass production, including partial recovery of energy from flue gases, energy consumption of 2,9 – 3,6 GJ/ton molten glass, depending on cullet% is possible.

Analysing conventional glass melting processes we can observe some weak points or issues that should be more intensively addressed:

* Poor control of the melting history in a melting tank, by badly controlled flow patterns of the melt in the glass melting tank.
* Variable input in the furnace by the batch, chemistry is not controlled or even not known, due to variations in cullet quality and cullet composition.
* Heat transfer to the batch is strongly dependent on glass melt flows, bringing refined hot glass to the batch blanket for supplying the required energy for batch melting. This recirculation flow leads to wide residence time distributions and long average residence times in the melters.
* Non-expected or non-predictable outbreaks of glass defects are occurring frequently and disturb glass production. Often the sources or cause of these production problems are poorly understood. Relationships between glass defect characteristics and causes of such defects need to be further explored.
* The control of temperature and position/orientation of a gob entering the blank mold is poor. Temperature distributions of gobs arriving in the moulds is asymmetric and gobs may not fall exactly vertically and centric in the parison mould. This leads to glass distribution differences (glass thickness differences) and limits the possibilities for reduction of glass mass in hollow glassware.
* In the combustion processes, which are strongly turbulent and not steady, locally and temporarily conditions exist with high temperatures, nitrogen and oxygen at the same time and place. This leads to NO formation. Modelling studies and new burners and combustion control systems have been developed and are still in development to obtain conditions of high heat transfer intensity and lower level of NOx formation.

Glass industries are rather competitive and are reluctant in sharing R&D results and innovative technologies. However, technological tools can be developed to support glass companies in further developing technologies for energy efficient, low emissions, high quality and flexible glass production. Among these tools, we count for example:

* Computational Fluid Dynamic models (glass furnace simulation models) to optimize furnace design and to determine furnace settings that give best results.
* Energy balance modelling for designing insulation, regenerators and to identify potential energy savings.
* Laboratory and pilot test facilities to test new raw materials and batches for improved melting and fining, at conditions simulating industrial circumstances.
* Sensors in combination with advanced process control, to stabilize throat, canal, gob temperatures or sensors to measure oxidation state and (indirectly) glass colour in the melter of feeder systems. Sensors for combustion control are currently in development, e.g. for in-situ monitoring in exhaust gas or combustion space: CO, O2, NO contents.
* Optical systems to monitor the gob size, gob position and gob orientation and even to detect glass defects or glass distribution problems in the just formed glass containers (e.g. using IR cameras).
* Systems that can recover the energy contents in flue gases in a cost-effective ways, examples are batch/cullet preheating, application of TCR (Thermo Chemical Recuperation), gas and oxygen preheating, batch pelletizing and pellet preheating.
* Development of new high-duty refractory materials or refractory metals or combinations thereof.

This presentation will give some examples of innovative technologies that help glass industries to further improve their performance and will identify gaps in our understanding of the complexity of converting raw materials finally in homogeneous high quality glass products at lowest costs and energy demand.

*Keywords: innovation, glass melting, energy efficiency, technological tools, environment, product quality, production flexibility, troubleshooting, process control, modelling, sensors.*

**4. Duo-Paper from glass manufacturers on needs for R and D in the glass industry for the next 10 to 15 years**

Roland Langfeld, Schott AG, Mainz, Germany

& Jaap van der Woude, PPG Fibre Glass, Hoogezand, Netherlands

**4a. Needs for R&D in the glass industry: perspective of a specialty glass manufacturer**

R. Langfeld, H. Römer

SCHOTT AG, Mainz, Germany

roland.langfeld@schott.com, hildegard.roemer@schott.com

The main drivers for innovation in glass industry are costs and quality. Glass making is capital intensive, main cost drivers are energy and raw materials. These challenges together with a further increasing demand for higher product quality in a globally competitive environment, and the threat of substitution by other materials can only be met by innovation.

Specialty glass industry has additional boundary conditions which require specific attention in R&D compared to soda lime glass production:

* higher melting and refining temperatures;
* broader variety of raw materials;
* broader range of tank-size, melting and hot-forming technologies;
* refractory material limitations and cooling limitations;
* slower reaction rates for melting and especially for (re)fining;
* significantly higher demands to glass quality in terms of homogeneity and freedom of solid inclusions and gaseous inclusions

The direction for R&D is clear, improvements on the material side and on the process side have to be made:

* Improved/new glass compositions to reduce costs, to improve glass quality, and to enable new applications;
* Substitution of rare and/or costly raw materials;
* Reduction of energy costs in glass melting and post processing;
* Preparing for ever increasing environmental concerns;
* Improved/new melting technologies for optimized tank lifetime and flexibility;
* Improved sensors and controls;
* Better multi-scale simulation tools to support material and process development;
* Finding new applications for glass.

Specific examples for R&D requirements will be given. Any kind of innovation will only find its way into industrial practice if stringent economic criteria are fulfilled. New glass compositions, melting technologies, or production processes must not increase production costs !

*Keywords: specialty glass, R&D requirements.*

**4b. NL Roadmap 2030.**

**Is 50% Energy Efficiency Improvement in Glass Product/Production Chain Feasible?**

J.H.A. van der Woude

PPG Industries Fiber Glass bv

vanderwoude@ppg.com

The Glass Industry in the Netherlands is diverse, including production of: container, tableware, flat, insulation and continuous glass fiber as well as specialty glass. Over the last 20 years, the industry as a total has improved its energy efficiency in joint programs under long term agreements with the government between 20 and 25% and the Dutch glass manufacturers are among the most efficient glass producing industries globally. This includes the fact that the industry operates under a strict environmental regime and high glass quality standards. A new national (Dutch) covenant (voluntary agreement), specific for companies under EU-ETS has set new targets for energy efficiency for 2030. To achieve this, the NL glass industry has selected focus areas that allow effective joint cooperation in order to meet energy efficiency improvement objectives i.e. by optimization of production processes, strengthening the sustainability of the product chain and improvement of innovation power. Each segment was thoroughly analyzed as to its potential and technical viability for short, mid and longer term. Actionable initiatives were formulated like workshops, technical programs, co-operations, need for better agreements on recycling and recycling technologies as well as initiatives to maintain up to date know how to allow integration of developments abroad. It was concluded that 50 % energy efficiency improvement until 2030 may not be achievable, but that substantial improvements are still possible based on both evolutionary and longer term revolutionary developments.

In this paper, the NL Roadmap 2030 for the glass industry and its targeted results will be reviewed in more detail. It will be clarified how the industry will improve energy efficiency of production and energy efficient use of our glass products. It will be demonstrated that cooperation, both national and international, with suppliers, research institutes, other glass producers and government is essential to guarantee that glass products are the effective solution for a sustainable future of our society.

*Keywords: energy efficiency, roadmap, Netherlands, glass industry, recycling, process optimization, production chain, innovation, education*

**5. An introduction to the work of ICG-TC13, with reference to practical studies and recent environmental legislation.**

Simon Slade, Pilkington NSG, UK

Simon.Slade@nsg.com

TC13 is the ICG’s environmental technical committee. Its members are drawn from industry, consultant bodies, research institutes and academia from around the world.

The presentation will explain the range of subjects covered by TC13 with particular reference to some of its active areas of work driven by the diverse environmental legislation currently affecting glass-makers. For example, legislation affecting the use of chemicals such as the European REACH regulation has driven much of the practical studies conducted by TC13 in recent years. Other work has focussed on emission control technology; both considering the potential of new techniques and assessing the effectiveness of established abatement technology and characterisation of emission by flue gases.

*Keywords: glass production, emissions, environment, air pollution control, REACH, flue gas, emission measurements*

**6. Operating experience of the ceramic candle waste gas filter in the glass industry**

**- Air Pollution Control in Glass Industry, a System for DeNOx, DeSOx & filtration -**

Denis Lalart, Etienne Sénéchal, Arc international, Arques France;

denis.lalart@arc-intl.com

Hugues Abensour, Saint-Gobain Conceptions Verrières, Aubervilliers, France &

Andreas Kasper, Saint-Gobain Sekurit, Herzogenrath, Germany

A new type of air pollution control system (APC) has appeared on the market in the recent period. Equipped with ceramic catalytic filtration candles, this technology is able to treat acid gases, dust, heavy metals and NOx in one single unit. Since 2010, two catalytic ceramic filters are in operation in the glass industry in Europe: one in float glass production, and the other in the domestic glass sector for the production of soda-lime-silica glass*.* End of 2012, another application of the same kind of technology has been done in the US, and some others are at project phase.

The first results obtained are good, in terms of observed low emissions. But the practical side, both in technical and economical point of view, has also to be considered. Our conclusion is that the technology is promising, but has still to be considered as “emerging”, its technical and economical assessment being possible only after a full campaign.

*Keywords: ceramic candle filters, DeNOx, scrubbing, filtration, air pollution control, glass furnace*

**7. Evaporation from glass melts – boron and selenium species**

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Glass melts in industrial glass furnaces often contain intentionally added volatile components or may contain impurities, originating from cullet or some type of raw materials. CelSian developed dedicated laboratory equipment to simulate evaporation processes from model glass melt compositions and industrial glass compositions. In this laboratory scale set-up, the effect of:

* glass composition,
* impurities in the used batch materials,
* furnace atmosphere, temperature and
* gas flow intensity,

on the evaporation of several components can be studied.

Information about the mechanisms of evaporation from batch and melt and the impact of different operational parameters, such as temperature, gas atmosphere, glass composition will help glass companies to select raw materials and to develop new batch recipes that show less evaporation losses of expensive raw materials such as selenium and boron carriers.

Evaporation studies can be very supportive to find the relevant evaporation reactions and mechanisms and ways to limit losses during glass melting processes. The studies provide data for modeling the kinetics of evaporation processes in industrial glass furnaces.

Selenium and boron evaporation from the melting-in batch and from the molten glass can be measured dependent on the type of selenium and boron raw materials used.

Studies showed that evaporation of boron species very much depend on the glass composition and water vapor pressure above the molten glass. The boron evaporation loss behavior appears to be far from proportional with boron oxide content of the glass. Increased boron losses start above a certain threshold concentration level in the glass.

Selenium evaporation depends strongly on the type of selenium raw material and the kinetics of batch melting.

*Keywords: evaporation, simulation studies, furnace atmosphere, raw material selection, selenium, boron species, evaporation mechanism.*

**9. Problems, Developments and Energy Performances of Glass Melting Furnaces**

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This paper covers the experiences of the authors based on the studies and developments made within the company over the years. Improvements on furnace design have always been a major issue. Developments have been achieved by driving forces like requirements for higher glass quality, different products, and increased number of product changes, energy efficiencies, lower investments and environmental challenges.

Although in the glass world today, there are studies and projects to develop different radical melting techniques, like plasma melting, submerged combustion, segmented melter and vacuum refiners being the most promising among the many, the progress going from pilot to full scale is slow and not all the glass manufacturers are giving many funds to support these projects. On one hand the conventional furnace technology is quite mature and energy performances of the most energy efficient furnaces [1] and pull rates are approaching near to the limits, there are still differences between the energy consumptions, pull rates and life of furnaces in glass industry today. Many small steps can be taken at different areas like optimizing furnace design criteria, refractory selection, use of additional equipment, development of sensors to control the operating parameters, better combustion equipment and, advanced control systems.

These all add to continuous incremental developments for each project and give us opportunity to progress with feedback from onsite applications to target to be within the best performing furnaces.

*Keywords****:*** *Furnace design, Melting, Energy Efficiency, Environment, Refractory, Process Optimization*

**10. Recommended Test Methods of the TC11 for Refractories**

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In the last three decades the TC11 elaborated different testing methods for refractories and carried out round robin tests to validate them amongst other activities. As a result of this work the following test methods are recommended by TC11:

* rotating cylinder face area to investigate the forced convection (throat)
* static plate corrosion test to investigate the convection due to density variation
* static plate corrosion test to investigate the metal line corrosion and the glass defect potential of the refractories
* dynamic blister test to investigate the seed potential on the boundary refractory/glass melt
* exudation to investigate the exudation behavior of fused cast AZS

The mode of operation of the different methods as well as sample preparation will be introduced and the conclusions for the choice of refractories as well as the corrosion behavior during the furnace campaign will be presented.

*Keywords: TC11, tank refractory, glass melt, static test, dynamic test, blistering, metal line corrosion, exudation test, forced convection, free convection, sample preparation, corrosion behavior*

**11. Refractory solutions for the new challenges in glass furnace construction**

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As a result of the ongoing tendency to reduce the energy consumption in the glass production process, the operation conditions, for the already highly stressed refractory materials, further worsen. Especially, the superstructure is affected as strong insulation decreases the thermal gradient within the refractories. Also new techniques, for example for batch pre-heating, are changing the conditions of batch carry-over and therefore change to a more corrosive environment.

In this presentation, the influence of ‘energy saving measurements’ on refractory materials in glass furnaces will be discussed. Important material characteristics will be presented.

*Keywords: refractory corrosion, LowNOx, carry/over, insulation, furnace lifetime*

**12. Experimental regenerator refractory studies**

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Clogging of the regenerator checkers and corrosion of the regenerator refractories are common problems in the glass industry. This paper is focused on simulating the refractory corrosion process of regenerator checkers of container glass furnaces by sodium vapors combined with sulfur dioxide at different conditions (temperature, oxygen excess, concentration levels, types of refractory).

In this presentation the dedicated laboratory equipment for testing (candidate) regenerator checker refractory materials will be described.

The set-up of the experiment is a combustion chamber connected (downstream) to a laboratory scale tube furnace. The gases used for the flame inside the combustion space are adjustable (natural gas with air or oxygen) and are generally set to normal oxidizing conditions. But also near stoichiometric or slightly reduced conditions can be set.

Inside the tube furnace a temperature gradient is formed by the heat of the incoming combustion gases. The refractory samples, to be investigated, are placed inside the tube furnace over a temperature range with flue gas cooling from about 1000 - 650°C (corresponding to the condensation zone inside the regenerator). A sodium hydroxide solution is injected inside the flame, resulting in sodium vapors inside the system. Sulfur dioxide is injected near the connection point of the combustion space and the tube furnace. These two components create an atmosphere inside the tube furnace rich in SO2 (high temperature) and sodium sulfate (formed at low temperature from sodium vapors and SO2). These concentrations are much higher than in an industrial regenerator. The test conditions are more severe to approach long time duration behavior of the refractory exposed to these vapors and condensation products. After exposure to the corrosive components the samples are tested on weight gain and are analyzed with SEM/EDX to check the depth of the corrosion process. Mechanical strength and porosity can be tested also.

Experimenting with different refractory materials will show the best resistant checkers to these conditions. Other corrosive agents can be used to check the resistance of the refractory materials under various conditions.

*Keywords: regenerators, refractory attack, glass melt vapors, condensation, refractory selection, simulated flue gases*

**15. TC14 activities on water measurement in technical glass**

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Water is one of the key components when studying dissolved gases in glass. Its influence on glass properties, evaporation, infrared absorption and exchange with the atmosphere is well known.

In the past 10 years, the TC14 committee has studied the properties and measurement methods for dissolved water in glass. Measurement methods have included infrared spectrometry and nuclear reaction analysis (NRA).

A standard set of samples (float glass from Pilkington, now NSG) was collected, and measured by several laboratories. From this study, also a TC14 recommended method for measurement of water in glass was derived and published. The results have been discussed in the meetings of the TC14 committee and also in the forums on water in glass, organized by TC14.

Besides normal soda-lime glass, the TC14 study extends to CRT panel glass (a complex barium/strontium glass), borosilicate glass and quartz glass.

The presentation for this workshop will give an overview of these TC14 studies on water in glass.

*Keywords: water in glass, infrared spectroscopy, nuclear reaction analysis (NRA), TC14, glass properties*

**16. Diagnostic Determination of Bubble Defects in Float Furnaces**

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Bubble defects are one of the major glass defect types for float glass as well as in all other glass production processes. The quality of a float glass product is mostly degraded if the gas bubbles remain in the molten glass as it is being pulled of the furnace. The new quality standards require lower number and smaller sizes of bubbles in the float ribbon, especially for automotive, mirror and other glass products requiring more transparency. Beside the bubbles remaining in the glass melt due to poor melting/fining conditions, another major source for the bubble defect is the de-vitrification phenomena in the float furnaces. Devitrification of a glass means that some of molten glass has crystallized at a limiting temperature during some time. Tiny bubbles are created in the colder zones of the furnace when crystalline material so-called “devit” is re/melted unintentionally due to the furnace operations.

This paper reviews the investigations on the determination of major bubble sources in float process, containing a statistical study for the classification of bubbles based on mass spectrometric analysis. Diagnostic activities to support the removal of the bubble defects using the data of furnace operations are also summarized in the paper.

*Keywords: bubble analysis, bubble types, bubble composition, bubble origin, devitrification, float glass quality*

**17. Replacement of calcined lime in the place of limestone**

**in a container batch**

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Calcination is a thermal treatment process in the presence of air applied to [ores](http://en.wikipedia.org/wiki/Ore) and other solid materials to bring about a [thermal decomposition](http://en.wikipedia.org/wiki/Thermal_decomposition), [phase transition](http://en.wikipedia.org/wiki/Phase_transition), or removal of a volatile fraction. Calcined lime is produced from limestone by heating to 1100oC, forming [calcium oxide](http://en.wikipedia.org/wiki/Calcium_oxide) (quick [lime](http://en.wikipedia.org/wiki/Lime_%28mineral%29)) and [carbon dioxide](http://en.wikipedia.org/wiki/Carbon_dioxide).

Calcined lime which can be a by-poduct of carbon dioxide production in order to be used in other fields, is increasingly becoming known as a beneficial calcium oxide source in glass industry, due to its ability to reduce energy consumption during melting via decreasing melting temperatures and to reduce CO2 emissions.

Details of an industrial trial of calcined lime in a green container furnace at Sisecam’s Yenişehir plant are presented. Calcined lime was introduced to a 400 tpd furnace with electrical boosting, in 25% portions up to 100% of the limestone weight, replacing limestone as the calcium source in the batch, resulting in reduction in energy costs.

The introduction of calcined lime drastically improved the melting behavior of the batch with no extra energy requirement for the decomposition of limestone. During the trial furnace bottom temperatures increased, allowing a 15% reduction in electrical energy consumption. In addition, the natural gas consumption decreased by 3%, resulting in a 3.5% reduction in the total energy consumption. A decrease in CO2 emission to 11% below the previous furnace emission was obtained.

Besides these positive achievements, some disadvantages were also observed. Dust formation at the doghouse and the adhesion of batch due to the exothermic hydrolysis reaction of the CaO were the two main problems. Other than them, batch costs became higher and it had minimal effect on glass color parameters during the trial.

*Keywords: calcination, quick lime, energy efficiency, melting behavior, batch costs, batch behavior*

**18. The processes controlling glass melting**

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Glass melting is a complex phenomenon including several homogenization processes. In the continuous melting operation, the batch conversion runs in series with mostly parallel processes occurring in the melt, dissolution of solid with liquid inhomogeneities and bubble removal. Two aspects play a significant role in the energy consumption and melting performance of glass melting, the process kinetics and utilization of the space.

The separated batch conversion area is characterized by the optimal area utilization for the process and the set up beneficial thermodynamic conditions open a way for the rapid conversion kinetics if the batch conversion is the controlling process. In addition, the capacity increase of the conversion area by its rational enlargement can prevent from melting control by batch conversion.

The impact of process kinetics and space utilization on the energy consumption and melting performance in the melt can be separately defined for each process and the critical aspect of the melting can be thus defined in detail. The utilization of the space, resulting from the character of melt flow, becomes frequently the controlling process of glass melting. The uniform melt flow or controlled melt circulations (helical flow) lead to the high space utilization in horizontal melting spaces, but the beneficial circulations cannot be practically set up in the spaces with the main vertical flow. The beneficial melt flows show similar features for both dissolution and bubble removal process. The uniform flow is sensible to small changes of temperature, whereas the helical flow character is more stable. But, the optimal value of the space utilization in the space with circulations depends on the mutual and absolute intensities of transversal and longitudinal melt circulations, the process kinetics and the length of the space. If bubble nucleation occurs, the dissolution and removal of nucleated bubbles are in series and share in the process control at the above-mentioned efficient melt flow conditions.

The optimal natural circulation flows enhance dissolution kinetics owing to temperature equalization in the space and melt convection with high velocity gradients. The application of forced convection would enhance the dissolution kinetics but the space utilization may become the critical aspect of melting. The kinetics of the bubble removal process can be expressed by the bubble growth due to chemical reaction releasing a gas in the melt. The long and intensive bubble growth in the period from accomplishing dissolution till the end of the bubble removal is desirable to optimize and control bubble removal.

The definition of controlling processes helps to intensify the melting process in its weak point.

*Keywords: flow patterns, space utilization, melting kinetics, fining, bubbles, forced convection, free convection, helical flow, residence time*

# 19. Controls and Sensors for Glass Melting:  A Look Backwards and Forward

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Glass has existed as a manufactured product for over 5,000 years and it has been a continuous effort to improve the glass making process.  Control schemes and sensors to provide feedback for control are crucial to effective and efficient glass manufacturing.  A general overview of control schemes will be discussed from the author’s experience over the past 24 years in the glass industry along with future possibilities.

One of the limits of control systems is sensors.  A general overview of sensors and some of the issues and needs will therefore be covered.  Application examples of control and sensor performance and related issues will be presented.

*Keywords: glass melting control, sensor for glass furnaces, thermocouples, process control*

**20. Electrochemical sensors for high temperature application in mass glass production: available techniques, possibilities and limitations**

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The prevailing glass melting process is highly effective with respect to economy as well as ecology. As such it requires real-time information about important process parameters like partial pressures or concentrations of critical components in melts, for instance sulfur which is commonly used as a refining agent during melting. But, sulfur species are simultaneously unwanted components of the emitted waste gases of the melting process or in the protective gas of float chambers. Some of this information (concentrations in melts or gases) can be achieved even at high process temperature by means of electrochemical sensors. In recent years electrochemical sensors became increasingly available for that purpose.

Applications in gases and melts will be demonstrated for the float glass and container glass production.

The different working modes - potentiometric or amperometric -, signal reliabilities, control properties, corrosion behavior and lifetime will be discussed.

*Keywords: polyvalent ions, electrochemical sensors, oxygen activity, sensor robustness, glass melt, tin melt, flue gases, sulfur*

**21. In-line oxygen sensors for the glass melt and the tin bath**

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# Measurements using in-line oxygen sensors for the glass melt and tin bath (in float glass production lines) are presented, showing the benefits of these sensors for the industrial glass melting and glass forming process.

A small and economical disposable oxygen sensor has been developed for the continuous measurement of the redox state of the glass melt in the feeder (container glass), forehearth (fibre glass) or canal (float glass) using a water-cooled lance. Redox monitoring and control is especially useful

* in furnaces melting a high share of recycling cullet,
* during a colour conversion or
* for evaluating the redox effect/effectiveness of new batch components

The allowed redox ranges of green glasses with an amber color component, like olive green or antique green are very narrow. The smallest variation in air/fuel ratio, COD of the recycling cullet or even residence time in the furnace (pull) may already shift the color to green or amber. Moreover, these colors are sensitive to over-reduction, at which the amber color component disappears again. A daily spectrometer measurement of the glass product appears often insufficient for necessary fast redox corrections.

Emerald green glass can be melted in a relatively large redox window, ranging from Fe2+/Fetot of 0.15 to even as high as 0.55, close to the onset of amber color formation. This is due to the stability of the Cr3+ ion over a large redox range, responsible for the typical emerald green color. However, the best heat transfer of the melt and the lowest seed count are obtained in the more reduced range. An in-line sensor will help to keep the melt as reduced as possible, without risking the formation of amber cords, even if a large share of recycling cullet is used.

Oxygen sensors are presented for the continuous monitoring *of* the oxygen activity of the molten tin and atmosphere in the tin bath *chamber* of float glass production lines. By monitoring the oxygen activity of the tin, oxygen related surface defects such as bloom, tin pick-up and tin dripping can be reduced. Moreover, the effectiveness of side wall sealing activities are optimized, as the sensors are able to detect even the smallest air leaks. By a combined measurement of the oxygen activity of the atmosphere and the oxygen activity of the molten tin, the driving force for de*-*oxidation of the tin melt can be monitored, enabling optimization of the required hydrogen level *in the gas mixture*. Hydrogen consumption can be reduced without compromising on glass quality.

*Keywords: glass color, oxidation state, oxygen activity, oxygen equilibrium pressure, sensor, color change, amber chromophore, emerald green, tin bath, tin defects, heat transfer, hydrogen control*

**22. Furnace Erosion and  Health Monitoring Sensor (FEHMS)**

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PaneraTech, in collaboration with the Ohio  State  University,  Libbey Glass, the University  of   South Florida, and Owens‐Illinois, has recently demonstrated the feasibility of a non‐destructive sensor technology to deterministically identify furnace wall erosion, while the furnace is operational. A  key  component   of   the  sensor   technology   is   efficient  & effective coupling   and  sensing  of  radio  waves  within  the  wall structure.

We also demonstrated that the same sensor system is capable of detecting voids and defects in cold refractories before  the  installation.

Erosion of the refractory lining in glass melting furnaces is a major problem for the glass manufacturing industry.

When erosion on the walls is not detected early enough, it may lead to molten glass, leaking through the refractory lining & resulting in suspension of production for several weeks and in  some cases, resulting in catastrophic accidents.

Accordingly, glass manufacturers have to shut down their furnaces, based on  a conservative schedule to avoid any  catastrophic  molten glass leakage.

Currently, there is no technology that can deterministically measure erosion of furnace walls.

The underlying fundamentals of the Furnace Erosion & Health Monitoring Sensor, the measurement results pertaining to the feasibility of the sensor and in-situ tests and the path forward to an integrated sensor system for structural health monitoring of furnace walls will be discussed.

*Keywords: residual refractory thickness, sensor, refractory health monitoring, furnace lifetime, glass furnace*

**23. Real time visualization of temperatures and mass flows in the full 3D volume of a glass melter tank by soft sensors**

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Nowadays, Computational Fluid Dynamics (CFD) models are broadly accepted to calculate the temperatures, mass flows and glass properties in a glass melt for the purpose of furnace design, optimization and trouble shooting.

The CFD package GTM-X by CelSian Glass & Solar is capable of detailed, fast and accurate simulation of the time dependent behavior of the glass melting process as well as able to cope with complex geometrical structures. In a single effort, these models can have multiple applications: the design and optimization of the melter or forehearth, the configuration of model based supervisory process control systems and the design of so called soft-sensors\* that are capable to provide real-time information on local temperatures and mass flows in the melter or forehearth.

\*Soft-sensors have been given that name, because a soft-sensor does not show process values from direct physical measurements, but through feeding a detailed 3D model with the actual process inputs and measurements and estimating accurately the time dependent process values (e.g. temperatures or flow or redox state) at arbitrary spots in the simulated 3D space. CFD models for complex structures as a glass melt tank or a forehearth are too complex to run much faster than real-time. Dedicated model reduction techniques are developed and applied to convert the complex CFD models to much faster models without losing accuracy.

The paper gives results of the application of a soft-sensor for the real time visualization of temperatures and mass flows in a container glass furnace. Results are shown of methods to keep the model on track by using a limited number of physical temperatures.

*Keywords: CFD modeling, model reduction, soft sensors, model-tracking, glass furnaces, stability, furnace performance, temperature, glass melt flows.*

# 24. ICG TC21 Modeling of Glass Melting Processes

**How reliable and validated simulation tools can help to improve glass melting efficiency and productivity**

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Mathematical modeling of glass furnaces started around 1965. The question is what can these models do and how reliably are the prediction of such models? In 1990, the ICG (International Commission on Glass) started the TC number 21 focusing on “Modeling of Glass Melting Processes”. The aim of TC21 is to share and exchange current practice and to develop the theory and application of mathematical modeling of glass furnaces. The activities of TC21 are carried often our as round robin tests where model results of members are compared to each other and in some case with actual measured data. A step wise validation of different components of the models related to the whole glass furnace is undertaken. The idea is to come up with improvements to improve the mathematical modeling of each member. The paper will show some validation experiments carried out by several authors over the years within, but also without TC21. These validations show a fairly good agreement between measurements and models. Certain errors are more likely to come from unknown glass properties and boundary conditions, than from the mathematical model itself. As example we show the error that can be caused when we do not know the glass properties very well.

*Key words: ICG, TC21, Modeling, reliability, validation, furnace optimization, glass quality, bubbles*

**25. Future applications of CFD Modeling of Glass Furnaces**

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Nowadays, in the glass industry, Computational Fluid Dynamics (CFD) simulation modeling of the glass melting process is completely accepted as integral part of the design process, optimization efforts and trouble-shooting of industrial glass melting furnaces. Most glass furnace simulations today still focus on prediction of glass temperature distributions and glass flow patterns only, although these are strongly influenced by the combustion process, supplying most of the energy required for batch fusion and glass melt heating. Also, currently, the Rosseland radiation transfer model often is used for clear glass melts, although for these transparent glasses the validity and accuracy of the model is questionable. Therefore, the production of special transparent glass types, such as low iron ultra-clear glasses for solar applications, requires more accurate models for the radiative heat transfer in the glass melt itself.

Secondly, there is an increasing drive to increase the energy efficiency and to reduce the emissions of glass furnaces. Most of the energy and emissions reductions are to be achieved by improving the design of the combustion process. This typically necessitates the use of accurate combustion, NOx formation and radiation models.

Thirdly, the efficiency of regenerators and recuperators has a large influence on the overall energy consumption of the complete glass furnace, but it generally is too time-consuming to completely model the glass tank, combustion space and the regenerator(s)/recuperator(s) by detailed CFD.

For these future applications of modeling of glass melting processes, CelSian Glass & Solar B.V., adopted a dual-track policy strategy, in which smart combinations are made between accurate and detailed CFD models on one hand and more global macroscopic energy balance models on the other hand.

The presentation will address this successful strategy for a variety of glass furnaces. Results will demonstrate that by using a smart mix of models and modeling tools CFD modeling of (entire) glass furnaces is possible and yields accurate results, also when focusing on more than glass temperature distributions and glass flow patterns, enabling the user to improve and optimize the production process.

*Keywords: Glass Furnace, CFD Simulations, Radiation Modeling, Ultra-clear Glass, Energy Efficiency, Energy Balances, Low NOx emissions, Combustion Chamber Design, Quality, Minimum residence time*

**26. Mathematical Modeling Analysis on Increasing Furnace Performance**

**with Improvements in Design and Operation**

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With requirements for higher glass pull rates, lower energy consumption and higher glass quality along with environmental concerns, research and development studies have been undertaken to improve the design and operation parameters of different types of glass furnaces in Şişecam with Şişecam Mathematical Model.

In glass furnaces, many parameters related to design and operation interact and it is not possible to distinguish the role of each parameter on the results. Modeling enables to see the effect of each parameter separately. Then, according to the extent of the advantage provided by each of the specific parameters, collective effects can be evaluated.

In the analyses related to glass bath and combustion space, it is seen that glass depth, crown height, burner positions and port geometry are critical design parameters besides main furnace dimensions. Bubbling and electric boosting are used as auxiliary systems to improve the process and add flexibility in operation. These investigations are, then, used to optimize different types of glass furnaces for higher thermal efficiencies and lower emissions. Results related to furnace performances have been followed during operation for the progress achieved. Moreover, providing these criteria at higher capacities has been a challenge each time.

Research on new concepts in glass melting and glass furnaces is supported from the outcomes of productive furnace design and furnace operation in Şişecam.

*Keywords: Glass furnace, mathematical modeling, furnace design*

**28. Short review of TC25 (Modeling of Forming Processes) activities, period 2000 till 2009**

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**Objectives of TC25**

* Identification and/or development of appropriate software for glass forming processes to correctly describe the relevant process physics (e.g. treatment of free surfaces in drawing processes, large grid deformations in pressing processes, radiative heat transfer).
* Development of models to describe product quality as result of relevant process parameters. This requires specific techniques to handle totally different length scales relevant for the glass product specifications.
* Determination of specific, critical material properties relevant to glass forming processes, such as stress- and structural relaxation data.
* Model validation.

**Work-plan**

* Definition and accomplishment of bench marking (Round Robin tests) for specified forming processes
* Identification of necessary model enhancements/improvements and initiation of developments
* Sensitivity studies to identify material properties critical to simulation results
* Definition and accomplishment of experiments for model validation

**Bench Marks / Round Robin Tests**

TC25 has defined and ran three Round Robin Tests for different glass forming applications

RRT-I TV panel pressing

RRT-II Single and triple gob forming

RRT-III Single and multi-fibre forming

**Round Robin Test - I “3D TV-Panel-Pressing”**

A RRT-I-definition document including all required geometry information, boundary conditions, initial conditions, material parameters, output data requirements was prepared.

Several reviews and updates of the RRT-I-definition document became necessary to finally

describe a model process that could be simulated by different software codes and that

provides valuable and comparable results.

Calculations finally have been completed by three different codes (TNO-GPP, Ansys-

Polyflow, NoGrid-FPM)

Comparison of available results have been presented in November 2008 (GlassTrend

Meeting, Eindhoven) and May 2009 (EFONGA Workshop, Montpellier).

**Round Robin Test - II “Gob Forming”**

A RRT-II-definition document for a ***single gob forming*** application including all required

geometry information, boundary conditions, initial conditions, material parameters, output

data requirements was prepared.

Calculations finally have been completed only by two different codes (Ansys-Polyflow,

NoGrid-FPM).

A brief comparison of available results had been presented in November 2008 (GlassTrend

Meeting, Eindhoven)

Beyond that, possibilities for model validation have been evaluated: at Emhart Glass an

experimental program for a ***triple gob feeder*** aimed at developing an experimental database

of gob forming and delivery data had been initiated and Emhart kindly agreed to provide data,

to be used for TC25 activities.

To meet Emhart experiments an extended RRT-II.2-definition document for a ***triple gob***

***forming*** application was prepared.

A draft version of the definition document was discussed during the November 2008

meeting in Eindhoven. To achieve the best possible conformity with the current set up some

fine tuning of the definitions had been done and the final definition document was distributed

in summer 2009.

**Round Robin Test - III “Continuous Fibre Drawing”**

A RRT-III-definition document for a ***single fibre forming*** application including all required

geometry information, boundary conditions, initial conditions, material parameters, output

data requirements was prepared.

Calculations were performed by two different codes (Polyflow, Fidap) and a brief comparison

of the results had been presented and discussed

But, this first single fibre forming RRT was not of real interest for industrial TC25 participants,

because several physical phenomena of the real process were not taken into account.

Beyond that, possibilities for model validation have been evaluated: at Cleveland State\

University (CSU), an experimental program for a ***multi tip fibre forming process*** aimed at

developing an experimental database of fibre forming was initiated.

Prof Simon Rekhson of CSU joint TC25 meetings twice to present the SU experimental set

up and related results and to advise preparations of an extended multi-fibre modelling case.

A draft version of an advanced RRT-III.2 definition for a multi tip set up was discussed

and reviewed in Trencin, June2008 - the final version was then presented at the Glass Trend

meeting in November 2008.

Due to the attained complexity of the current definitions the identification of suitable software

Packages for this case was difficult and could not be finalized.

**Conference Sessions & Workshops**

TC25 has initiated and co-organized sessions and workshops on international conferences / meetings:

* Session “Modelling of Glass Forming” at ESG conference in Sunderland, UK 2006
(13 papers)
* Joint modelling session TC21/25 “Heat transport phenomena in furnace and
forming modelling” at the ICG Congress in Strasbourg, France 2007
(20 papers)
* Co-organisation of Glass Trend Workshop “Conditioning of Glass Melts & Forming of Glass Products in Eindhoven, NL 2008” (12 papers)

**Papers & Publications/Presentations of TC25:**

###### TC25 – a platform to benchmark software capabilities for glass forming

GlassTrend Seminar, Eindhoven, NL, November 2008

C. Berndhäuser, D.Hegen

*Keywords: Modeling, Heat radiation, free surface, Round Robins, Fibre drawing, TV panel pressing, gob forming, tripler gob, multiple fibers*

**29.** **Glass Forming Simulation in 3-D for container glass industry**

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The real world is 3-D and nearly all containers produced do have unsymmetrical thickness distribution, even though the mold shape is axis-symmetric. In order to reduce the container weight or to achieve the increasing product quality by simultaneously reducing the costs it is fundamental to understand all mechanisms in glass forming processes. Some mechanisms are hidden and coupled with each other and therefore it is very difficult to distinguish between them by experiments. For instance, when one experiences a certain unexpected bottle wall thickness distribution (e.g. too much glass in the neck area), it is sometimes not clear, what are the reasons:

- neck mold area too cold

- glass contact time too long

- gob temperature not high enough

- gob shape not correct

- or other causes.

In production you cannot simply increase the gob temperature, because also the gob shape will change. So one cannot distinguish what is the effect of temperature and what is the effect of gob shape. In simulation we can change the gob temperature and the gob shape remains the same. That means, with modeling one can investigate each cause of defect independently from others.

Fortunately in computer simulations we are able to separate the conditions and as a result we are able to investigate the dependencies step by step.

The most sensible material property for the glass forming process is the viscosity, which depends on temperature. Unfortunately glass temperatures are often entirely unknown and can be measured only with considerable effort. For that reason one important question very often is: What is the influence of the gob temperature on the container wall thickness distribution and what happens if the temperature distribution within the gob is not homogeneous? Beside inhomogeneous temperatures a non-symmetric gob load is also a major reason for an irregular wall thickness distribution.

In this paper we will give some answers to these questions. As in reality, the simulation starts with gob loading and ends at take out. All process steps are integrated into one computer model and all walls are switched on and off at the corresponding time step given by the IS machine time data: The walls for the plunger, blank mold, blank mold bottom and final mold are combined to one single geometrical model. The software switches the corresponding faces on and off according to the IS time data.

The shape of the container can be each possible 3-D shape. Thus, there are no limits regarding container design and we can test and evaluate a design without any restrictions. The asymmetric conditions are applied to typical glass containers and the process type used in this paper is the blow and blow process.

*Keywords: container glass simulation, glass forming, CFD, container wall thickness, container weight reducing*

**30. Tin and iron concentration profiles at float glass surfaces**

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The importance of minimising surface and near surface transmission losses in float glass panels intended for solar energy applications is accepted.

However the reaction diffusion equations controlling the tin and iron effects are not easy to use to optimise the processing.

This is partly just a general lack of important materials properties, but a careful investigation is also needed of the dominant mobile species in the regime considered to avoid misinterpreting what data there is.

Modelling techniques for the development of the iron and tin oxide profiles are developed and used both within and beyond the bath (where advantageous regimes both during cooling and in any subsequent thermal processing are of interest) will be investigated.

*Keywords: surface properties, iron concentration profile, tin concentration profile, solar glass*

**31. Finite Element Analysis of container's geometry**

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FE Analyses of glass containers are usually carried out for 3 main purposes: verification, design or optimization of glass containers.

**Verification** aims to determine the level of the stress field induced by external loads on a given containers and to verify whether it is allowable. Together with fracture analysis, verification analysis may also assess the load or stress at which a failure occurred.

We talk about **design** analysis when a new container's geometry (i.e. thickness or shape) is sought in order to achieve stress lowering or glass weight reduction. As the verification approach, also design is usually based on limiting the local stresses peaks.

A more advanced procedure to define both the geometry and weight of a glass container can be referred to as **optimization** analysis, in which the bottle's shape ranking is not simply based on the reduction of the tensile stress peaks. Indeed, the main target is to achieve minimum failure probability in service, which depends on the extension and the location of the zones under tensile stress. This evaluation is carried out by means of the Weibull statistics, using the parameters derived from breakage tests and fracture analyses on containers that have undergone the degradation resulting from normal manipulation.

This work elucidates the fracture probability assessment under a multi-axial stress state. The way to estimate the Weibull parameters through burst testing and FEA of the tested bottles is also discussed. Previous topics are combined in order to evaluate the geometry of a glass container which is deemed capable of withstanding internal pressure. Some practical case studies will be reported.

*Keywords: FEM analysis, strength, tensile stress, shape optimization, Weibull statistics, burst testing, fracture analysis, failure identification*