On the Threshold of the **Third Millennium**

On the occasion of the 150th anniversary of the birth of company founder Otto Schott (1851 – 1935), Schott organized a glass science colloquium at the Friedrich Schiller University in Jena in December 2001.

Internationales glaswissenschaftliches Kolloquium

To pay tribute to the founder of the modern science of glass and glass technology nine well-known scientists from the United States, Japan and Europe delivered papers on the results of current research under the heading of “The Science of Glass and Glass Technology on the Threshold of the Third Millennium.”

The following scientists presented the results of their research work:

Prof. Denise Krol, University of California, USA, one of the world’s leading scientists in the development of planar wave-guides;
Prof. Kazuyuki Hirao, University of Kyoto, Japan, the inventor of and expert on the structuring of glass with the femto-second laser;
Prof. Setsuhisa Tanabe, University of Kyoto, Japan, a proven expert on the design of rare-earth-doped optical intensifiers;
Prof. Ruud Beerkens, University of Eindhoven, Netherlands, who was awarded the Otto Schott Research Prize in 1997 for his research into the modeling of glass melting tanks;
Prof. Christian Rüssel, Head of the Otto Schott Chemistry of Glass Institute at the University of Jena, the world’s leading developer of electro-chemical methods for the characterization of glass melts;
Prof. Reinhard Conradt, Aachen College of Technology, winner of this year’s Otto Schott Prize for the calculation of physical and chemical properties from thermodynamic data;
Dr. Ulrich Fotheringham, Mainz, a well-known Schott scientist and winner of the internal research prize on many occasions;
Prof. Hideo Hosono, Tokyo Institute of Technology, Japan, who was awarded the 1991 Otto Schott Research Prize for his investigations into the interaction of radiation and glass;
Prof. Georg Müller, University of Erlangen-Nuremberg, who enjoys great recognition worldwide for his developments in connection with computer modeling of crystal growth processes.

Some of the topics covered by the speakers at the colloquium are found on the following pages (6 to 14).

Klaus Jopp
Scientific journalist, Hamburg

Optimizing Melting Processes

What happens in the glass melting process is extraordinarily complex. Computer models and simulations, in addition to new measuring probes, provide a better understanding of the process and how to continually improve glass production.

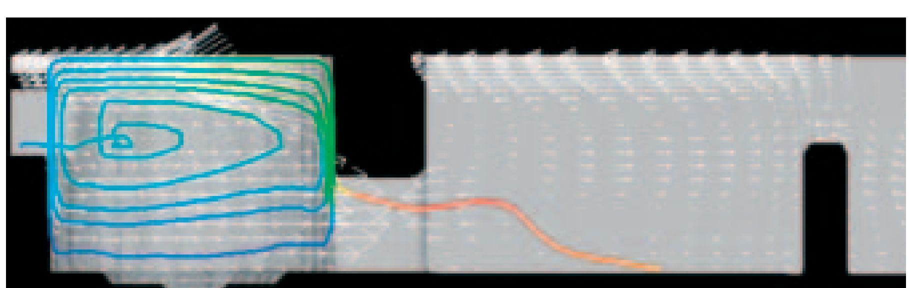
In addition to its occurrence in nature, glass is principally a material artificially created by the hand of man, a process that has been uninterrupted for more than five millennia. Although this material has not given its name to any age in the history of the world, glass has made its way from a craft into industrial production, and is the material of choice for many high-tech applications.

Man has long been acquainted with the material glass and yet there is still much to learn about the manufacture of this material. There are many questions that are only being raised now and can only be answered with the help of the latest measurement and computing processes. This was demonstrated most emphatically by an international scientific symposium entitled “The Science of Glass and Glass Technology on the Threshold of the Third Millennium” that was staged in Jena to commemorate the 150th anniversary of the birth of Otto Schott, the scientist considered to be the founder of modern, scientifically-based glass technology.

Simulation as the essential tool

Increasing demands on quality present glass producers with a difficult task. They have to produce a high-quality glass, as demanded by the market, and at an acceptable cost. Modern technologies and innovative methods are helpful in facing this challenge. Up until very recently glass production, from the design of the melting furnace to the daily operation of the process, was based mainly on traditional methods and practical values. Important data and information about the melting process – for example the temperatures and the development of the glass melt in the tank – can, however, hardly be obtained with conventional experimental processes. CDF models (Computational Fluid Dynamics) provide a solution. **Prof. Ruud G. C. Beerkens of the Institute of Chemical Engineering and Chemistry at Eindhoven Technical University** (Netherlands), an expert on the modeling of glass melting processes explains this process. “With these mathematical simulations it is possible to predict what will happen in an industrial melting furnace. For example, amongst other things the temperatures, flow patterns and transfer of heat from the flames into the glass melt can be calculated fairly accurately.”

Tracing back a refractory found in the end product. With the help of the backtracking process the origin of an imperfection in the glass can be pinpointed exactly.



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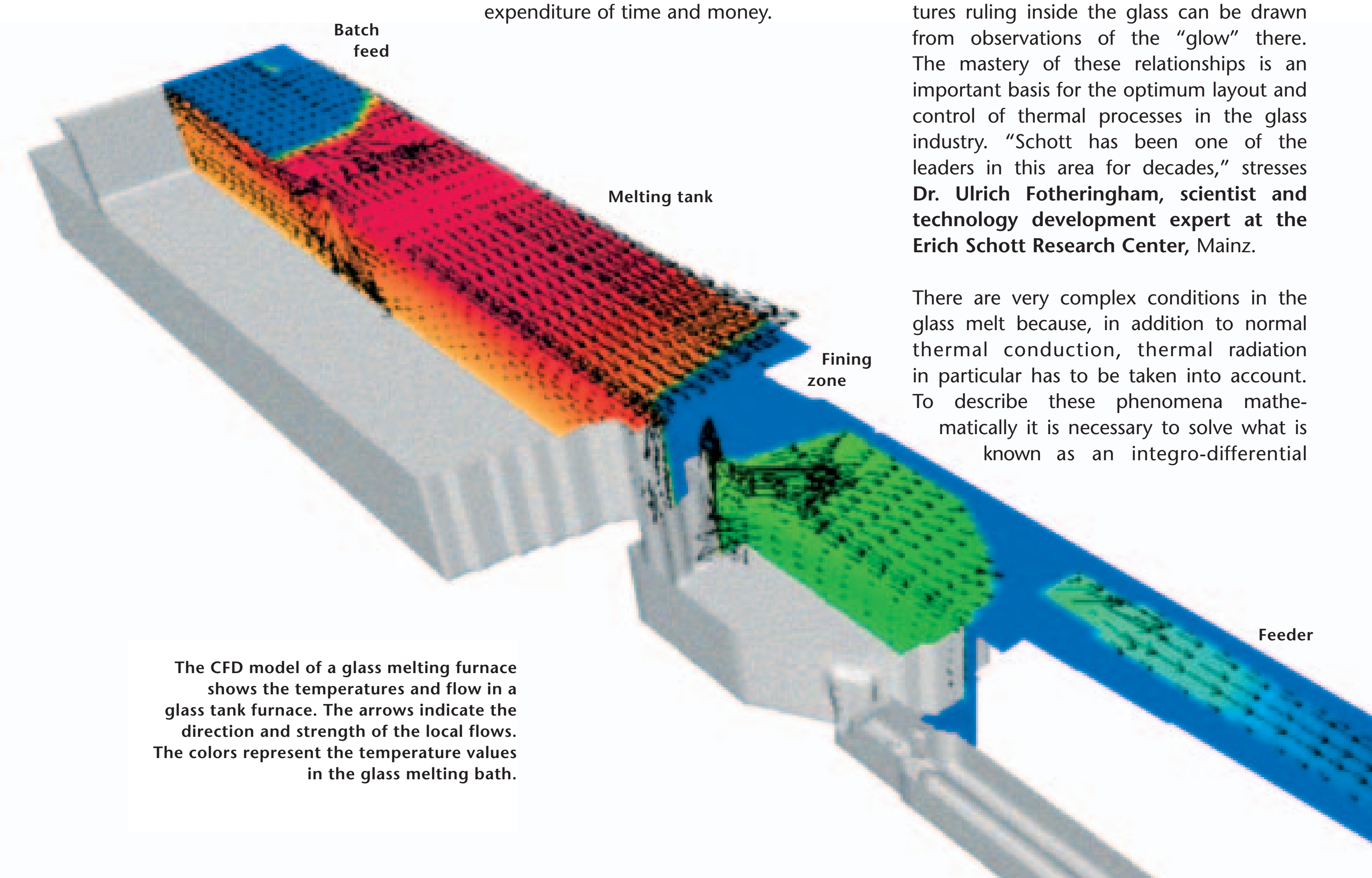
CFD-modeling is of special importance in determining the probable effects of furnace design, the composition of the batch, energy input and distribution, as well as throughput. “It is important to develop an optimum furnace design and to create the best process conditions to prevent the occurrence of severe impurities in the glass melt caused by corrosion products from refractory materials or the inclusion of a differing glass composition from the upper layer of the melt,” says Prof. Beerkens. The production of an optimum melt is made more difficult by the fact that the majority of the conditions that are favorable to the running of the melting, refining and homogenization processes, have undesirable side effects. For example high temperatures and vigorous mixing encourage the melting and homogenization process, but at the same time they cause wear and tear of the refractory walls and this results in impurities in the melt through corrosion products. This makes CFD-modeling even more important since it can be used to foresee the contrary effects. Overall it is now an essential tool for developing an appropriate furnace design and for analyzing and overcoming process-engineering problems with the minimum expenditure of time and money.

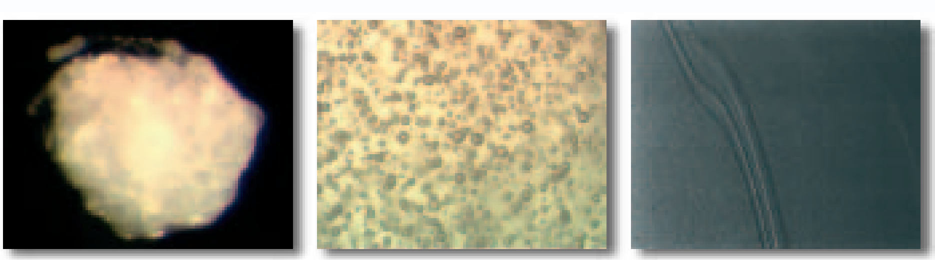
Progress in computing heat flow

Mathematical and physical modeling is also used for the quantitative calculation of heat flows and temperature fields in glass melts from the given material properties and measurement data. Glass is frequently a semitransparent material. In other words the greater part of the electromagnetic radiation, as distributed across the whole volume, is gradually absorbed. To put it another way: Heat radiation can penetrate deep into the glass and further expand via a chain of alternating absorption and emission. Conclusions about the temperatures ruling inside the glass can be drawn from observations of the “glow” there. The mastery of these relationships is an important basis for the optimum layout and control of thermal processes in the glass industry. “Schott has been one of the leaders in this area for decades,” stresses **Dr. Ulrich Fotheringham, scientist and technology development expert at the Erich Schott Research Center,** Mainz.

There are very complex conditions in the glass melt because, in addition to normal thermal conduction, thermal radiation in particular has to be taken into account. To describe these phenomena mathematically it is necessary to solve what is known as an integro-differential



The CFD model of a glass melting furnace shows the temperatures and flow in a glass tank furnace. The arrows indicate the direction and strength of the local flows. The colors represent the temperature values in the glass melting bath.



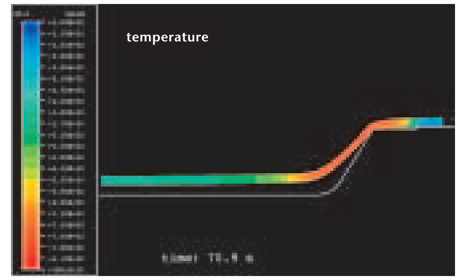
Batch stones (unmelted batch), bubble seeds and cords. Some typical imperfections in glass, caused by incomplete melting, incomplete fining and insufficient homogenization (from left to right).

equation – despite the power of today's computers, it has not yet been possible to achieve this in practice for the geometries which occur in the production of hot glass. For this reason, the story of mathematical and physical description of heat transmission through radiation in hot glass is the product of improved approximations, in which Schott Glas has had a large share.

In the glass industry an important aspect of product manufacturing using thermal processes is the intermediary and permanent mechanical stresses that are formed. These can be either unintentional – as in the case of optical glass – or deliberate, as for example in the case of toughened "Duran" borosilicate glass. Decisive for these stresses are temperature gradients inside the glass that are set up in the course of the process. If these gradients can be calculated dependent on the process control, they can be optimized on the computer. In this way it is possible for example to produce glass panels with the required degree of toughening by heating them up significantly above the glass transition temperature and then subjecting them to massive cooling. With the appropriate heat source, thermal radiation can be deliberately used for extremely effective heat transmission and thus for very rapid hot forming purposes as in the case of manufacturing ovenware.

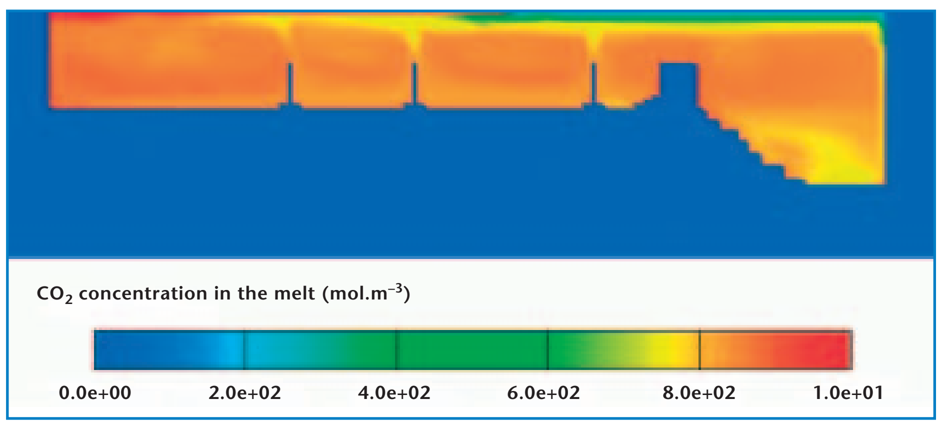
Measuring probes for glass melts

Computer modeling of glass melts is one way to better understand the complex activity that goes on in the tank. An

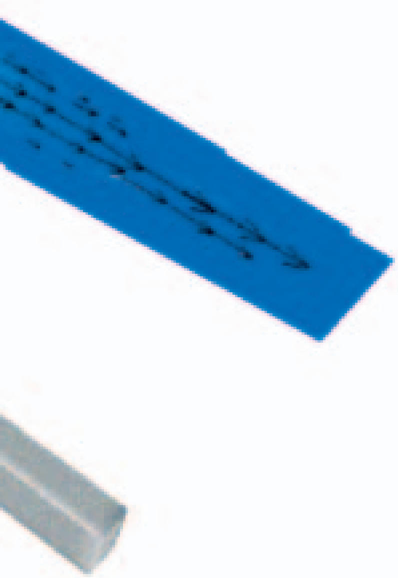


An accurately timed and geometrically accurate simulation of rapid hot forming can be achieved with the aid of a good approximation for the heat transport by radiation.

important prerequisite for this is obtaining data directly from the melt. In the past decade investigations have been carried out into fining reactions – the removal of dissolved gases and bubbles – in particular by means of electrochemical processes, specifically square-wave voltammetry. "This involves taking measurements directly in the glass melt at high temperatures," explains **Prof. Christian Rüssel, Head of the Otto Schott Institute for the Chemistry of Glass at the University of Jena,** the world's are thermoelements for temperature control and vent gas sensors. Three other sensor types are necessary for the measurement of oxygen activity (oxygen is given off as a product of the reactions of a whole range of fining additives), voltammetry sensors and probes to pick up the light spectrum emitted from the melt. Oxygen measuring instruments, which consist of an air-washed zirconium probe and a large platinum electrode, have been commercially available for some years. Voltammetry and optical



Calculated distribution of dissolved CO_2 in a melting tank (concentration contours in the vertical cross-section of a melting tank.)



leading developer of electrochemical methods for the characterization of glass melts. Three electrodes are needed for this: a platinum wire as working electrode, a platinum plate as counter electrode and a zirconium probe as reference electrode. The curves produced in this way show maxima for defined redox reactions, for example reduction from iron^{3+} to iron^{2+}. Important thermodynamic values can be derived from these maxima.

However, unlike in other industrial types of production, the use of monitoring and control systems is still far from common in glass melting. "That is mainly because of the lack of suitable sensors", says Prof. Rüssel. Virtually all that is used at this time sensor arrays are already in the development and trial stage as well. Powerful systems are anticipated in the foreseeable future that will make early control of the fining possible, which in turn will permit corrections to be made to the batch composition and process parameters respectively. Knowledge about the complex problems involved in glass melting continues to expand, as was impressively demonstrated by the Otto Schott symposium. ◀