Upgrading glass melting technology by model-based processing[1)]

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1. Introduction

Glassmaking is undergoing rapid changes. Today's requirements or challenges, so to speak, are increasingly demanding: both glass quality and production output need to be increased to higher levels, while, at the same time, reducing energy consumption, lowering emission levels, and increasing the ratio of cullet used. The basic questions are, of course: the technology is to fulfil all these requirements and are the solutions cost-effective? Looking at the technological developments over the past ten years, it becomes clear that the glass industry is indeed involved in many new technologies. The glass industry and its suppliers have begun to use advanced tools to optimize production and products. A striking example is the use of numerical simulation tools for the design and control of the glass melting and glass forming processes as well as for the design and improvement of glass products. These simulation models have now reached such a degree of reliability and applicability that industries not only use them for the purpose of gaining insight, but actually perform optimization studies directly linked to existing processes and product designs. Prediction of glass quality, glass tank performance and product behaviour are key elements.

2. Modelling the glass melting process

About 15 years ago, TNO-TPD started its modelling activities in the field of glass melting technology. For a glass melting tank, in fact a chemical reactor with many complex subprocesses, an adequate process description requires a full synthesis of all melting-related subprocesses. With the support of many national and international glass industries, TNO-TPD has addressed over 80 man-years in the past 15 years towards both mathematical modelling of the melting process as well as towards fundamental experimental research in glass melting chemistry. This has resulted in a glass tank model wherein the specific glass melt-related process models have been fully coupled being linked as submodels(figure 1).

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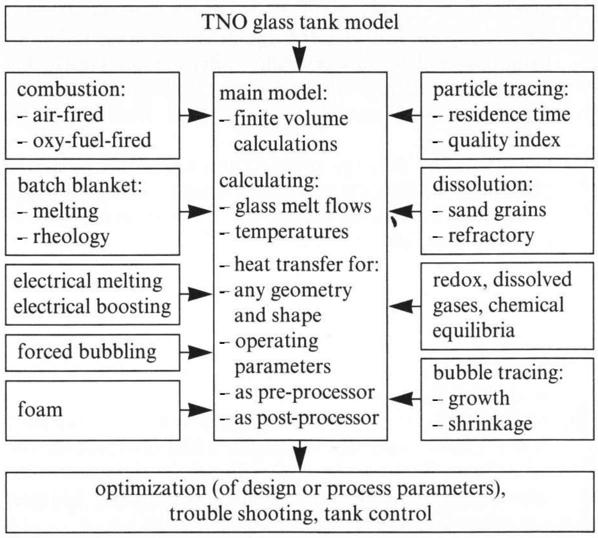

Figure 1. Schematic of TNO glass tank model with submodels.

Standard 3D computational fluid dynamics for modelling flow and temperatures in the melt and combustion space is basic, but is insufficient to assess the effects of process conditions and furnace design on glass quality and tank performance. Therefore, the authors' focus has shifted more and more towards modelling of the specific glass melt-related chemistry and physics, leading to submodels for e.g. redox, dissolved gases, (re)fining, particle (sand grain, alumina, knots) dissolution, homogenization, volatilization, batch melting, glass defect backtracing etc. Important issues are model verification both on laboratory and industrial scale as well as measurement of the required input data, chemical and physical constants such as diffusion coefficients, chemical equilibria and solubilities.

3. Output of glass tank modelling

Glass tank modelling has proven to be a powerful optimization tool. It is now being used both by R&D experts as well as by tank operators in the plants. The track record of TNO-TPD glass tank model covers optimization studies in more than 70 industrial glass tanks, ranging from container, float, TV, special, sodium silicate to fiber glass tanks. Different combustion systems, gas or oil, air or oxy-fuel firing, end-port or side-port can be handled. Criteria for optimization usually are first, glass quality versus pull rate, second, process stability, flexibility and efficiency, third, temperature load of refractory, fourth, fast job changes, and fifth, reduction of energy and emissions. Both stationary as well as transient situations can be taken into account. The output of glass tank modelling usually is a set of optimal characteristics or best scenarios: improved tank design, burner system (kind and position of burners), operational settings (e.g. heat distribution, pull rate, boosting and bubbling location and intensity, fining agents), location of sensors, job change strategy or diagnosis of probable causes of glass defects.

4. Constraints on use

Although some models come very close to reality, models are by definition simplified descriptions of reality. Verification of their "fit for use" is often preferred before going into optimization runs. This can be done e.g. by running base-case simulations against existing glass tank operations. Process data such as bottom/crown temperatures and residence time distributions from existing melting operations are of course a necessity. Often such data lack accuracy or appear not reliable. On the other hand, some of the required model inputs are also not very well known unless the experimental effort in the laboratory: there is an ongoing need for accurate measurement of glass melt data and properties.

5. Trends and future developments

With the continuously increasing computer speed, doubling every 1.5 years, the number of gridpoints is increasing simultaneously: ten years ago, a typical melter simulation was carried out using 10 000 gridpoints, nowadays 300 000 to 1000 000 gridpoints are being used featuring more accuracy and details. Fully coupled combustion-chamber melter calculations or coupled melter/working end/feeder simulations are performed. Instead of mainframe computers, now workstations are being used and even fast PC's. Within the next coming years, full 3D simulation models will run fast enough to use them for model-based predictive control of glass melting tanks. Coupling these models to control systems is one of the areas where TNO is active in at the moment. Continuous model-based analysis of the running melting process by checking the process output data against the virtual model environment will lead to more intelligent monitoring and control of the process. Next to that the simulation code is still under further development. Specific submodels are being further improved: batch modelling, foam production and destabilization, glass homogeneity. Also in the area of glass defects a coupling between glass defect analysis and glass melting modelling is in development in order to obtain an improved defect source analysis system including corrective actions.

6. Spin-off: up-to-date database for melting technology

The success of the glass melting model is strongly based on the quality of the glass melt-specific submodels describing the characteristic glass melting phenomena. These submodels determine how close the real process can be predicted. Assessment of existing melting know-how together with additional fundamental research in these areas has led to improved descriptions for all melting-related phenomena. These descriptions are constantly updated and structured to fit in the virtual environment of the melting model. The model itself has become a database wherein latest developments and insights in melting technology are stored. It therefore also plays a role in the dissemination and updating of melting know-how for all the internal and external users of the model. To keep the experts experts, to keep glass technologists good technologists.

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