Advanced mathematical modeling of special glass furnaces

Petr Schill, Miroslav Trochta
Glass Service, Inc., Vsetin, Czech Republic

The advanced mathematical modeling of GS-Glass Furnace Model (GFM) will be demonstrated on two examples: (a) GS-Simulator which uses new Graphical User Interface (GUI) and (b) Waste glass melter modeling coupled with particle settling. (a) The GS-Simulator is an interface between solvers and graphical user interface (GUI). The Simulator runs normal GFM-solvers and GUI periodically displays all output variables and, moreover, it enables to modify selected input data during calculation. When all iteration criteria are satisfied, the Simulator stops the solvers and starts GS-Tracer that performs particle tracing. An example of industrial float furnace simulation is presented. (b) The waste glass melter model covers simulation of flow, temperature and electrical fields within glass space, feed and plenum space. The water evaporation from feed is involved. Moreover, this model enables automatic control of glass temperature by adjusting the electrode voltages and on-line coupling with dynamic model of particle precipitation and settling in glass melt (GS-Paco program). A model example of a complete HLW melter is shown.

Introduction

The Glass Furnace Model (GFM), a code developed in Glass Service Inc., is used for mathematical modeling of the flow, temperature, electrical, concentration, chemical and radiation quantities in glass furnaces. The GFM consists of two parts, the glass space (glass model, GM) and the combustion space (combustion model, CM). The GM and CM are bounded by special coupling procedure which periodically transfers surface heat fluxes and temperatures between the two spaces. The GM involves batch melting procedures and the CM involves turbulence, radiation, chemistry and flame calculations. The GFM normally runs on common PC under Windows (NT or W2000). The GFM is base for special extensions as GS-Simulator or Waste glass melter particle settling-calculation.

GS Simulator

The Simulator was developed in order to help the users to apply the mathematical model in glass industry and to predict the furnace behavior directly after operation conditions change . Using the interactive Graphical user interface (GUI) it is possible to modify input data and boundary conditions during calculation. The response can be seen immediately on graphs and other incorporated postprocessors.[1]

The complex coupled model of typical float furnace is presented as an example here. The furnace parameters follows: pull ranges from 400 to 500 t per day, 8 adjustable charging gates, adjustable batch- and waist-coolers, 6 ports with under-port burners, two oxy burners above batch and two air burners in working end. The GUI contains control screens to modify glass space operating parameters (Fig.1a) and gas flows (port, burners, exhaust) in combustion space (Fig.1b) and postprocessors screens to display temperature pattern in all 2D-cuts, temperature check-points (Fig.2), flow pattern and quality indexes.

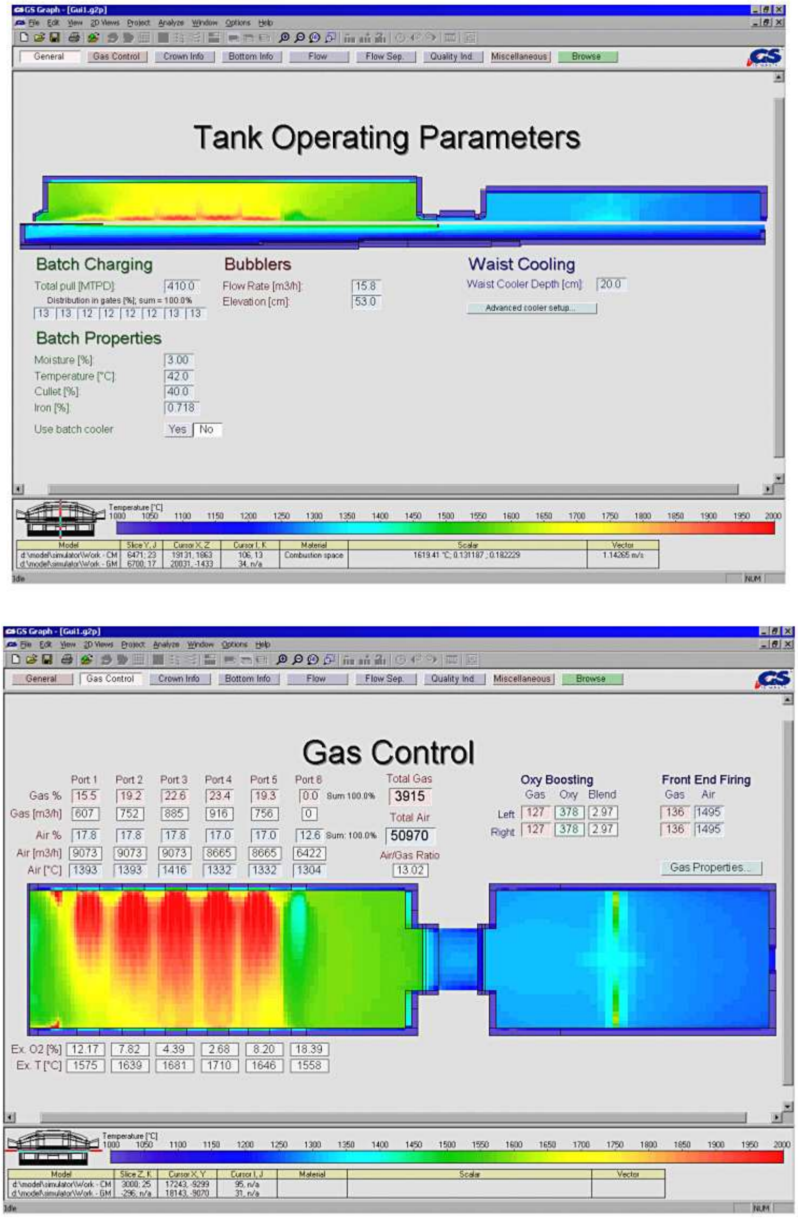

Fig.1. GUI input: On-line setting the operating parameters and boundary conditions

The flow is displayed by two ways: (a) streamlines animation together with temperature distribution and (b) streamlines animation together with scalar U-velocity component which enables to identify flow separation points . The Quality index screen shows animated critical trajectory and displays minimum- and mean-residence time and melting index [1] .

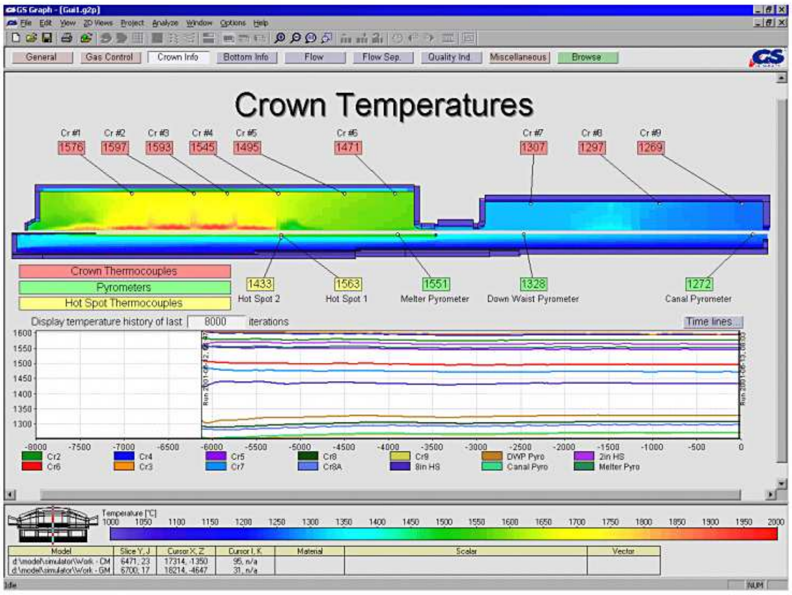

Fig.2. GUI graph: Displaying the resulting temperatures in given check-points

Waste glass melter model

The waste glass melter is a special small glass furnace for vitrification of radioactive waste. It is heated by two or three block electrodes and the batch (feed) is delivered by pipe from top in form of slurry. This slurry involves glass forming oxides, radioactive waste components and large amount (about 50 %) of water. This water evaporates in the plenum space and a dry cold-cap is formed which is further converted into glass-melt (see Fig.3). During this process, various kinds of particles (noble metals, spinel) are precipitated and settled on walls and bottom. In case this sludge layer grows rapidly it may damage the melter. Model prediction of sludge layer can help to enhance the melter lifetime

The GFM was extended to cover a semi-transient approach that couples two processes: The dynamic calculation of noble metals (NM) behavior (in case of spinel the nucleation is considered, as well), settling and concentration fields with stepwise updating of the glass properties (being modified by NM concentration and glass temperature) is periodically followed by recalculation of flow- and temperature-distribution in the melter. Using this procedure, the buoyancy term in the Navier-Stokes equation involves both temperature and concentration contributions. NM is fed into glass from cold cap in form of defined size distribution divided into size classes. For each size class transport equation is solved and the particles are redistributed among the existing classes before next time step. The settling calculation is based on small Re (order of –8) which enables to use only Stokes velocity near the bottom. The size classes are taken in account and resulting sludge layer can be simply estimated by thin layer approximation using value of maximal settled NM concentration [2].

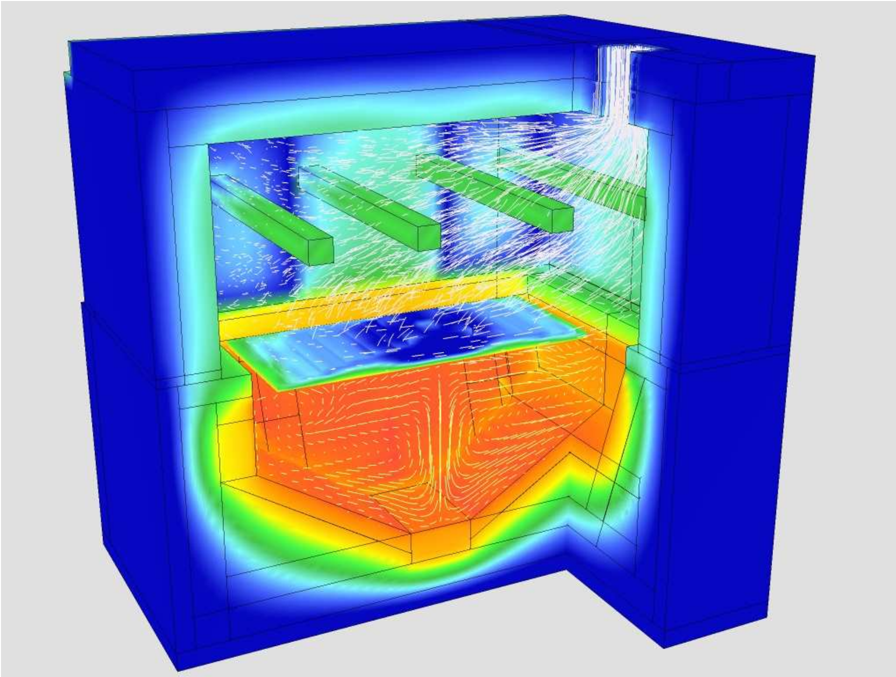

Fig.3.Coupled model of High Level Waste Melter

This complex mathematical model is being used for study of the various stages and waste glass melter operation possibilities. The present HLW melter example involves

(a) comparison of 3 heating modes: 2 active electrodes, 2 active electrodes with forced bubbling , 3 active electrodes and
(b) comparison of 3 initial NM size distributions among 3 classes (total conc.=0.15 wt % = 0.0523 vol %):

  NM2 (uniformly all fractions): size[μm]=15 : 50: 100, mass [rel.wt]=10 : 10 : 10
  NM3 (major small fraction): size[μm]=15 : 50: 100, mass [rel.wt]=10 : 5 : 2.5
  NM4 (major big fraction): size[μm]=15 : 50: 100, mass [rel.wt]=2.5 : 5 : 10

Two stages were calculated (under same thermal boundary conditions) :

(a) continuous feeding and pouring using left riser : glass pull=45 kg/hr, slurry water content=60%=67.5 kg/hr, heating control maintains 1135 ^{o}C average glass tem.
(b) idling without feeding and pouring: heating control maintains 1135 ^{o}C average glass temperature

NM concentration time development inside glass (in 26 various locations) started from 0 during feeding and from max. value 0.0523 vol % during idling are shown on Fig.4. The 26 curves for each of the 3 NM size distributions keep together which implies the melter behavior is not far from ideal mixer. NM sludge layer development for NM2, NM3 sizes represented by 9 locations on bottom electrode and calculated for all 3 heating modes are displayed on Fig.5. The 2 electrode-heating with bubbling causes the highest non-uniformity of the layer height (see the middle group of curves). The 2 electrode-heating without bubbling produces the lowest layer thickness.

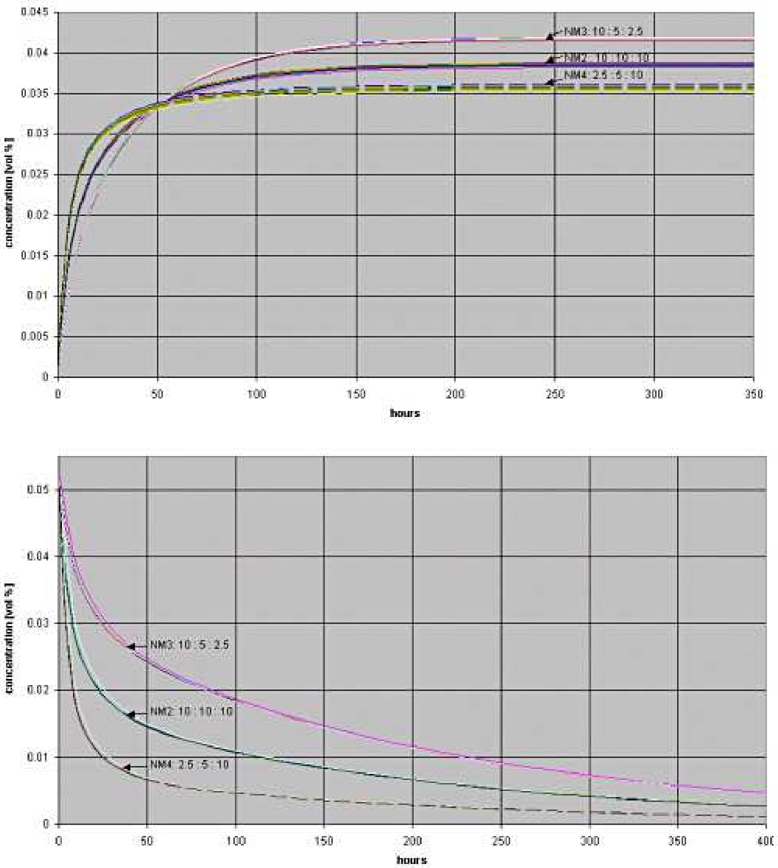

Fig.4. Noble metals concentration for NM2, NM3, NM4 inside glass during : (a) feeding and pouring ; (b) idling

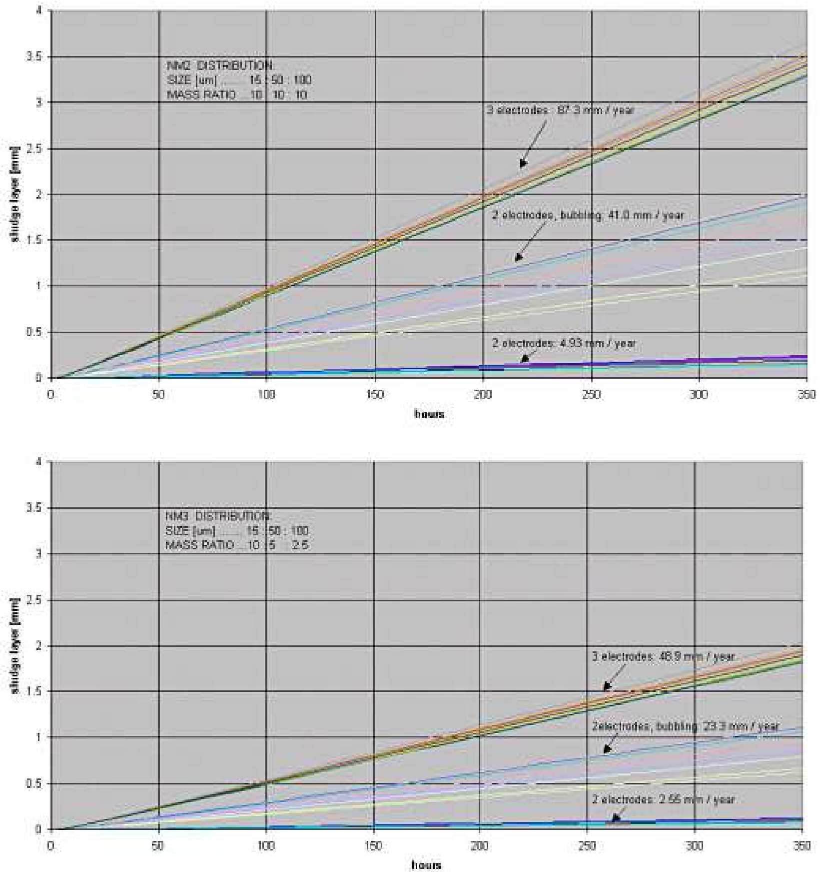

Fig.5. Noble metals sludge layer at 9 points on bottom electrode by heating modes for : (a) NM2 ; (b) NM3

Heating mode	NM2= 10 : 10 : 10	NM3 = 10 : 5 : 2.5
3 electrodes	87.3 mm/year	48.9 mm/year
2 electrodes with bubbling	41.0 mm/year	23.3 mm/year
2 electrodes without bubb.	4.93 mm/year	2.55 mm/year

Tab.1. Prediction of the sludge layer thickness

Many interesting conclusions can be conducted from such a type of case study. For example, the above results (Fig.5, Tab.1) indicate the using of forced bubbling is not directly advantageous for particle settling as could be estimated by simple consideration.

Conclusions

- The two extensions of the GS-Glass Furnace Model, The GS-Simulator and The Waste glass melter particle settling model, were presented
- The Simulator serves for on-line response prediction of furnace parameters-changes
- The Simulator is a model means for furnace engineers who do not need to have CFD experiences
- The Waste glass melter particle settling model enables to provide huge case studies for various operation conditions and particle distributions in vitrification furnace.
- The particle behavior simulation covers precipitation, nucleation, combined forced and buoyancy particle flow, settling, developing the sludge layer and prediction of the layer thickness in any location and prediction of the particle retention.

---

[1] Trochta M., Viktorin P., Muysenberg E., Novackova M. in *6th International Seminar on Mathematical Modeling,* 2001, edited by Glass Service Inc., (Glass Service, Inc, Vsetin, 2001), p. 117.

[2] Schill P, Trochta M. in *WM'01 Proceedings* , 2001, Tucson AZ, 2001