Towards the Mathematical Modeling of Cold Cap During Vitrification of Nuclear Waste

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1. Introduction

Various factors impact the performance of glass processing during vitrification process in an all-electrical melter. One of the most significant, and also one of the least understood, is the process of batch melting. The cost and schedule of nuclear waste treatment is highly dependent on the rate of waste glass production. A better understanding of batch melting is thus of great importance. Studies are being conducted to develop a fundamental understanding of the glass conversion reactions, in particular those that strongly influence the rate of melting, and models are being developed to predict the impacts of composition and other key parameters on the melting rate.

In the simplest case, one can consider a steady vertical melting of a typical waste glass batch, floating on the surface of glass melt, the so-called "cold cap". In such a batch layer, various processes are taking place – water evaporation (slurry feed contains as high as 60% of water), gas evolution, the melting of salts, the formation of borate melt, reactions of borate melt with molten salts and with amorphous Fe_2O_3 and Al_2O_3, the formation of intermediate crystalline phases, the formation of a continuous glass-forming melt, the growth and collapse of primary foam, and the dissolution of residual solids. To this list, we also need to add the formation of secondary foam originating from molten glass, but accumulating on the bottom of the cold cap.

Little attention has been paid to the conversion process within the cold cap in the past because the heat transfer to the cold cap rather than the batch-to-glass conversion itself has been considered as rate-controlling. However, the melting becomes conversion-controlled if the heat flux to the batch blanket is high enough [1].

This study presents the latest developments in the mathematical modeling of the cold cap behavior during batch melting. As the first step, we have developed a preliminary one-dimensional (1D) model. To represent more fully the situation that exists in an all-electrical melter, our final goal is to develop a 3D model that will represent the melt-rate affecting processes more realistically.

2. Results and discussion

In the simplest melting situation considered in this study, a cold cap of uniform thickness rests on a pool of molten glass from which it receives a steady uniform heat flux. Thus, as the feed-to-glass conversion continues, the temperature, velocity, and extent of feed reactions are functions of the position along the vertical coordinate, and these variables do not change with time.

The version of the 1D model presented in this contribution describes the progress of feed melting reactions in a vertical direction with the constitutive equations and key parameters based on data obtained for a high-alumina high-level waste (HLW) melter feed that has been subjected to a thorough investigation [2-4]. The interfaces with glass melt and the plenum space of the melter are defined by simplified boundary conditions. The results of feed melting crucible studies, in addition to literature data, were used as input data for the model.

Using this model, we present the sensitivity analyses on the effects of key parameters on the cold-cap behavior. For example, Figure 1 displays the effect of upper heating on the temperature profile within the cold cap and shows that the thickness of the cold cap increases as the heat flux from above increases.

The model demonstrates that batch foaming (Figure 2) has a decisive influence on the melting rate and shows that understanding the behavior of the foam layer at the bottom of the cold cap and the heat transfer through it is crucial for a reliable prediction of the melting rate as a function of feed properties and melter conditions.

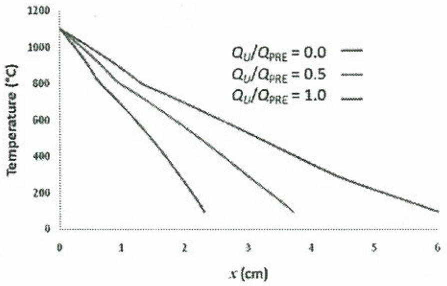

Fig. 1. Temperature profiles within the cold cap versus the intensity of upper heating (Q_U is the heat flux from above and Q_{PRE} is the heat flux needed for turning the melter-feed slurry to dry batch)

The objective of this contribution was to set a background for advanced modeling. Although the study is focused on a batch for waste vitrification, the authors hope that the outcome will also be relevant for commercial glass melting.

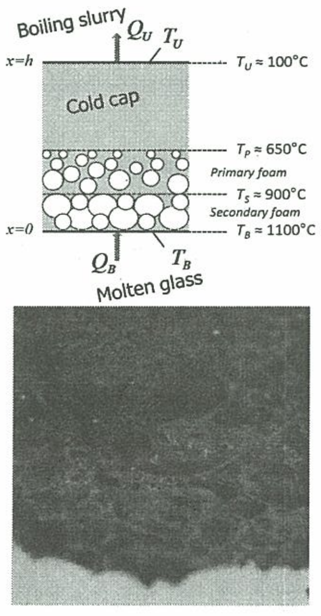

Fig. 2. Cold cap structure and a photograph of the cold cap bottom with the foam layer

3. Conclusions

1. A 1-D model of the cold cap is being developed to predict the impacts of key parameters on the waste glass melting rate.
2. Sensitivity analyses has been performed to quantify on the effects of key process parameters on the cold-cap behavior.
3. The model demonstrates that batch foaming has a decisive influence on the melting rate.

4. Acknowledgment

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5. References

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