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Advancements in Cold Crucible Induction Glass Melting: Enhancing Glass Homogeneity and Thermal Dynamics through Numerical Modeling

E. Sauvage, P. Brun, R. Didierlaurent

Abstract

Vitrification is used in France to provide long-term containment of high level liquid radioactive waste from the reprocessing of spent nuclear fuel. Vitrification is an atomic-scale incorporation of the waste into a glass. After melting and homogenization, the nuclear glass is poured into metal canisters that will be stored underground in a deep geological repository. In France, the technology used for vitrification has been based on induction melting for 40 years. This technology enables high power, low gassing and high cooling/heating rates. The induction furnaces were developed at CEA Marcoule on an inactive full-scale pilot plant

A cold crucible induction melter has been in operation at the La Hague plant, operated by ORANO since 2010, for vitrifying high-level radioactive waste resulting from decontamination and decommissioning operations, as well as from the reprocessing of old fuel with a high Molybdenum content. The well-established advantages of the cold crucible over the hot metallic inductive melter include (i) a higher processing temperature, (ii) an extended operational lifespan, and (iii) improved homogeneity achieved through mechanical stirring and gas bubbling. Consequently, it is anticipated that both the overall production capacity and the particulate matter concentration in the glass will be higher.

Part of the development of this technology involves leveraging numerical simulations of glass flow and direct Joule heating effects using a high-frequency induction power unit. This paper provides a detailed account of the latest efforts in the 3D modeling of Platinum-Group-Metals (PGM) particles' behavior within the glass and their interaction with the magnetic field.

During the melting process, the glass typically exhibits a homogeneous liquid phase interspersed with non-soluble heavy platinum-group-metal particles, primarily composed of palladium and ruthenium dioxide. Previous studies [1] have documented spatial variations in the local volume fraction of particles within the melt due to particle settling over time. This migration of particles towards less-agitated bottom portions of the crucible impacts the dynamic, electrical, and thermal state of the melt, influenced by concentration-dependent electrical conductivity and viscosity of the suspension. A theoretical one-fluid transport model was developed based on small-scale experiments conducted with a glass simulant. The model is integrated with existing 3D inductive and thermo-hydraulic numerical codes, thereby enhancing the precision of heat flux predictions between the melt and the crucible.

References

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