Coupling Electromagnetic and Thermo-hydrodynamic Simulations to Optimize a Vitrification Furnace Heated by Direct Induction

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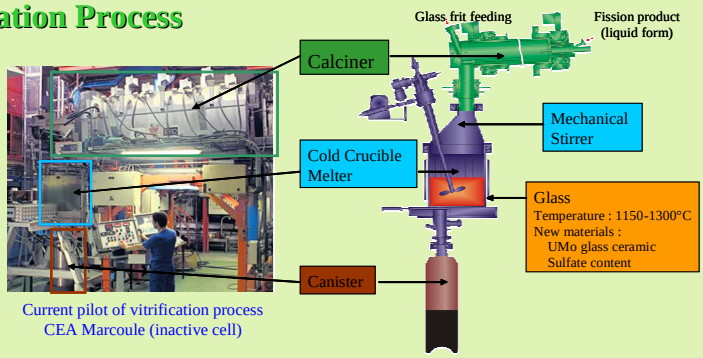
Abstract:

This study deals with the optimization of a cold crucible melter where electric currents are directly induced in a glass charge. Designs of experiments are used to determine the factors of the crucible design which have an impact on the efficiency, and result in an optimized configuration. Numerical tools are used to lead the experiments: a finite volume software, used to solve hydrodynamics and thermal equations, is coupled to a finite element software which computes the Maxwell equations. The optimized configuration is then studied comparing numerical simulations and experiments in an industrial unit.

Vitrification Process

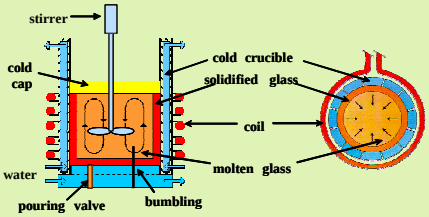
Cold Crucible Induction Melter:

- Direct induction heating by a high-frequency electromagnetic field
  - No electrodes
  - High temperature
  - High thermal power release to the melt and high specific throughput rates
- Water-cooled metallic crucible
  - Protective inner glass surface (Skull)
  - No refractory
  - Allows corrosive glass melting
- Improved mixing and glass product homogeneity
  - Mechanical stirrer
  - Bubbling/sparging capabilities



Current pilot of vitrification process
CEA Marcoule (inactive cell)

Cold Crucible Technology Simulation



Purpose

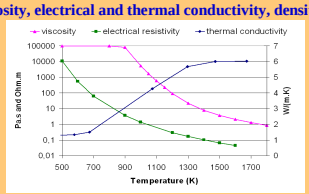
- Optimization of thermal and chemical homogeneity
- Use results of temperature and mixing in chemical model

Issues

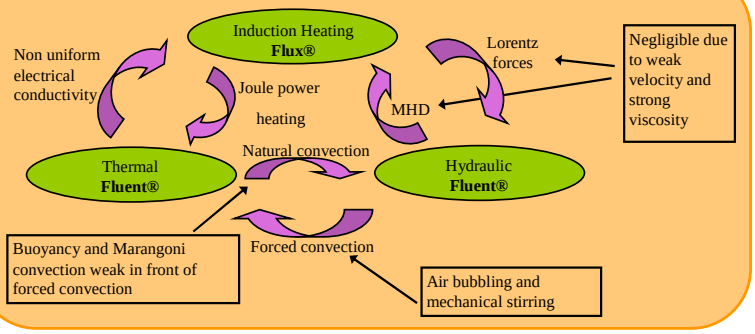
- Complex design
- High temperature gradient take place in the skull melter
- All physical properties of the glass are temperature dependent
- Many 'physics' are involved in the process : induction, forced and natural convection, radiation …

Physical properties

High temperature characterization of glass: Viscosity, electrical and thermal conductivity, density …



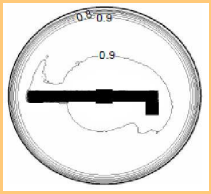
Coupled physics within the molten glass



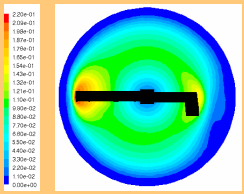
Mechanical stirring

→Numerical method: Sliding mesh (Fluent®)

→ Improve global homogeneity of the melt



Dimensionless temperature distribution in a horizontal plane intersecting the stirrer



Distribution of the glass velocity in a horizontal plane intersecting the stirrer (m/s)

Design of Experiment Definition

Thermo-hydrodynamic Mesh: 750 000 elements

Elementary computation Times: ≈ 3 weeks

Problem size Reduction to 13 parameters => L27 (3^{13}) Taguchi Table : 27 experiments

3 Objective Functions:

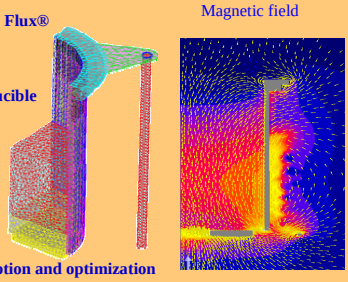
- Hydraulic homogenization,
- Mixing intensity,
- Convection in the arrival of products.

Electrotechnics

→ Software Flux®

Magnetic field

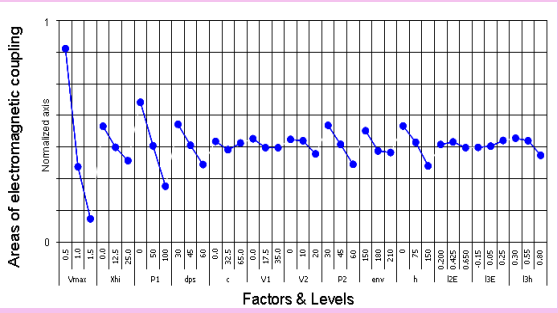
Cold crucible



→ Conception and optimization

We wish to thank the Cedrat company for the loan of Flux®

Factors influence on areas of electromagnetic coupling



Parameters:

- Stirrer Velocity,
- Geometrical Factors,
- Current,
- Power,
- ….

Conclusion

- Prediction of the hierarchical influence of each factor,
- Stirrer velocity impact.

Industrial applications

- **Conception**
  - Melter design and optimization
  - Scale-up
  - Thermal power balance
- **Process studies**
  - Glass property impact
  - Evaluation of thermal and chemical homogeneity
  - Optimization of operating conditions
  - Reducing number of full scale runs