Homogenisation of electrically heated glass melts by Lorentz forces

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Abstract:
We report a series of experimental investigations about the stirring effect and the homogenisation of Lorentz forces in glass melts. By variation of the electrical current and the magnetic field the interaction of the electromagnetic force and the temperature gradient driven convection is analysed. We verify the capability of Lorentz forces to effectively stir the glass melt, to redistribute the temperature field and to homogenise the material.

Introduction:
The material qualities of glass are very attractive for many applications in industry as well as for domestic purposes. Specifically, attractive properties are its chemical durability, transparency or high electrical resistance, which mainly depend on the chemical composition of the glass and the processing parameters. The homogeneity of the material before the last manufacturing step significantly affects the quality of the production.
In glass melts occur only slow laminar flows due to their high viscosity η and small Reynolds numbers ($Re \approx 1$). Therefore, insufficient mixing causes high concentration gradients produced by solution residuals of the glass tank, surface evaporation or contaminants of feed material. Viewable defects evolve from this inhomogeneities caused by different refraction index from $\Delta n \approx 10^{-4}$ or changes of $\approx 0{,}5\%$ in chemical composition [1].
To provide isotropic properties, mechanical stirring is used, but the corrosion of the stirrer causes material loss and extra impurity in glass melts. The employment of electromagnetic mixing may lead to a new possibility for the homogenisation and processing technique in glass melts.

Experiments:
As stated in the literature [2,3,4] direct electrical heating (by electrodes in the glass melts) enhances the homogeneity of the material due to auxiliary thermal energy and additional effects. With the interaction of an external magnetic field perpendicular to the electrical field Lorentz forces

(1)
$$\vec{f}_L = \vec{j} \times \vec{B}$$

are generated (equation 1), which reinforce or counteract the temperature gradient driven convection. Both physical values, the electric current density j, and the magnetic flux density B, have alternating quantities with the same frequency and direction is adjust with phase angle.
The effect of electromagnetic stirring is currently not used in industrial glass manufacturing processes. Hence, our research project aimed at the determination of the stirring activation by Lorentz forces in highly viscous liquids with small electrical conductivities, as well as at the detection of the homogenisation and change of flow characteristics applied to the refining process in special glass melts [5].
We have systematically explored several experiments characterized by different values of the heating electrical current, the intensity of the magnetic field and the direction of the Lorentz forces. Furthermore, the investigation of material from specimens showed an improved homogeneity at similar optical and physical properties (e.g. density, refraction index, transmission). The used glass composition consists of 30% SiO_2 – 49,275% BaO – 20,725% B_2O_3 (wt%) and showed no crystallisation. To verify the results of the hot experiments we analyse model fluids to get visual information about the changes in the convection flow. In addition to that numerical simulations and analytical modelling complete the research.

Conclusions:
We have systematically explored the potential of electromagnetic forces for the enhancement of mixing and homogenisation in glass melts. By variation of different physical parameters in experiments and additional studies we qualified the interaction of bouyancy and Lorentz forces. The application of our findings may lead to significant improvements in the production of glass and show that extensive further research is necessary in order to make full use of capabilities for the electromagnetic processing of materials (EPM) in glass technology.

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