Numerical Optimization of Heating for High-Speed Rotating Cup By Means of Multiphysics Modeling and Its Experimental Verification

K. Kyrgyzbaev[1], M. Willert-Porada[1], M. Terock[1]

[1]University of Bayreuth, Chair of Materials Processing, Bayreuth, Germany

Abstract

Rotating cup/disk is an important research subject in many areas of engineering like hydrodynamics [1, 2], mass and heat transfer [3, 4] of the fluid in/on a rotating cup/disk. The rotating cup/disk has been employed in many industrial applications such as spin-coating of phosphor on television screens or photoresist films on silicon wafer [5], concentrating solutions by evaporation [2], centrifugal atomization of metal melts [6], and glass flakes production [7, 8]. In this work the heated rotational cup was used to produce very thin glass films from molten glass. To keep the glass within the range of processable viscosity, the rotating cup is heated externally (Figure 1), conventionally with gas burners using methane/air mixture or alternatively with inductive heating. This works aims to optimize the heating method of the rotating cup. For this purpose, COMSOL Multiphysics® with the Heat Transfer and AC/DC Modules was used.

The Heat Transfer Module was used to simulate the energy input into the cup from gas burner flames and the temperature distribution as a result of it. The combination of the Heat Transfer and AC/DC modules serve to simulate the inductive heating of the rotating cup. For the heating with burner flames 2D model was used. And for inductive heating 3D model was used.

Firstly, the heating of the cup with gas burners was simulated (Figure 2) and measured (temperature measurement with high temperature pyrometer) to determine heat transfer coefficients on the cup boundaries including the effect of the rotation. Afterwards these coefficients were used for the modelling of induction heating. The simulation of the induction heating allows us to judge if the induction can heat the rotating cup up to a desired temperature. Moreover, the optimal design of the solenoid was found (Figure 3). Finally, the simulation of the induction was verified with the temperature measurements of the cup.

COMSOL Multiphysics® offers very good possibilities to optimize and design the heating procedure of the rotating cup. This saves time and cost for trial and error experiments. In this work, heat transfer coefficients on the rotating boundaries using experimental and modelling results of the heating with conventional burners were firstly determined. Afterwards, authors used these heat transfer coefficients including rotational effects to simulate induction heating. The induction heating with 2 kW power can heat the rotating cup up to 890°C and more homogenous temperature distribution on the inner surface is possible (maximum temperature difference of

58°C). Five coils placed outside of the cup were found as an optimum design for solenoid. Finally, the rotating cup was heated up with induction heating to verify our simulation results. The simulated temperature on the surface showed very good agreement with the measured temperature with maximum temperature difference of 15°C (Figure 4).

Reference

1. N. Dombrowski, T. L. Lloyd, Hydrodynamics of flow along the wall of a rotating cup, Applied Sciences Research, 28, pp. 278–288 (1973)
2. I. Leshev, G. Peev, Film flow on a horizontal rotating disk, Chemical Engineering and Processing: Process Intensification, 42 (11), pp. 925–929 (2003)
3. A. Aoune, C. Ramshaw, Process intensification: heat and mass transfer characteristics of liquid films on rotating discs, International Journal of Heat and Mass Transfer, 42 (14), pp. 2543–2556 (1999)
4. Jorge C. Lallave, Muhammad M. Rahman et al., Numerical analysis of heat transfer on a rotating disk surface under confined liquid jet impingement, International Journal of Heat and Fluid Flow, 28 (4), pp. 720–734 (2007)
5. R. Usha, R. Ravindran et al., Dynamics and stability of a thin liquid film on a heated rotating disk film with variable viscosity, Phys. Fluids, 17 (10), (2005)
6. Y. Y. Zhao, Analysis of flow development in centrifugal atomization: Part I. Film thickness of a fully spreading melt, Modelling Simul. Mater. Sci. Eng., 12 (5), pp. 959–971 (2004)
7. C. J. Watkinson, (22.04.88): Method and apparatus for glass flakes on 22.04.88. App. no. 88303681.6. Patent no. EP 0289240 A1.
8. Multifunctional Materials from Glass for energy efficient Buildings (Multifunktionale Werkstoffe aus Glas für energieeffiziente Gebäudetechnologien) (2012). Bayreuth: Bayerischer Forschungsverbund FORGLAS c/o Lehrstuhl für Werkstoffverarbeitung, Univ.

Figures used in the abstract

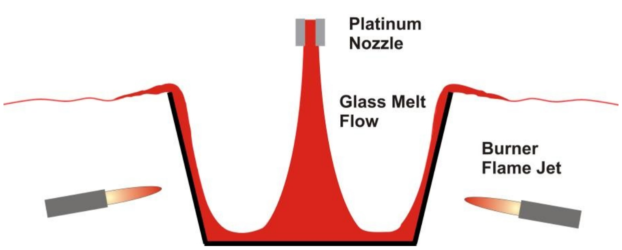

Figure 1: Schematical figure of glass flow development in and out of the rotating cup with external burner flames

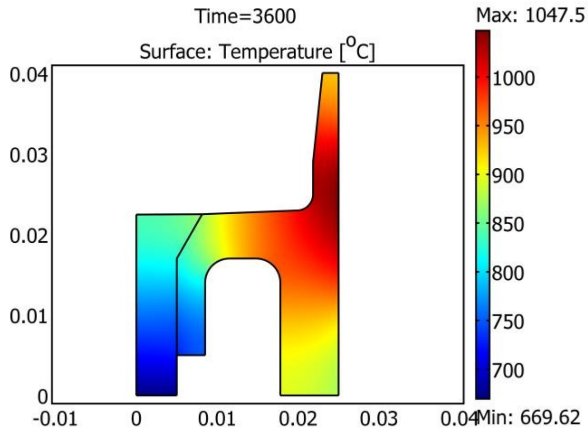

Figure 2: Temperature distribution as a result of heating the cup with burner flame jets

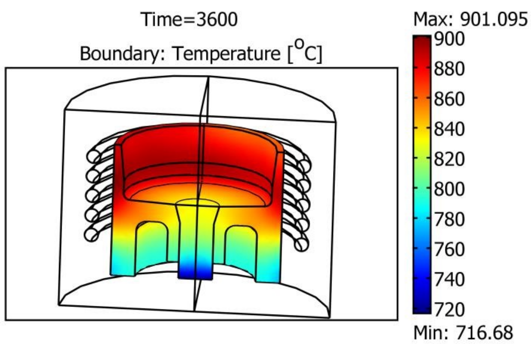

Figure 3: Temperature distribution in the cup with five coils outside

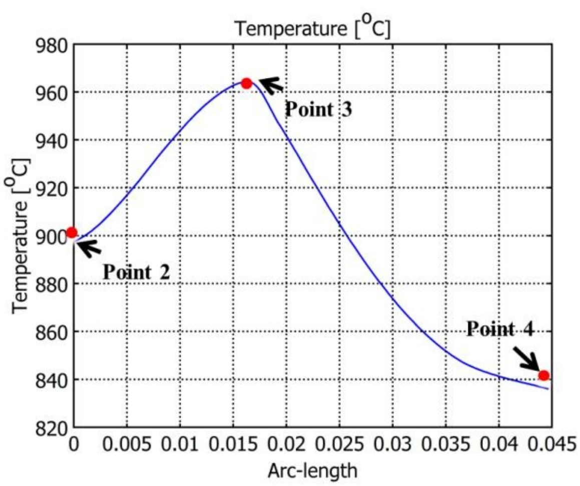

Figure 4:) Comparison between calculated and simulated temperature along the inner side of the cup