Bayerische Forschungsstiftung

UNIVERSITY OF BAYREUTH GRADUATE SCHOOL

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

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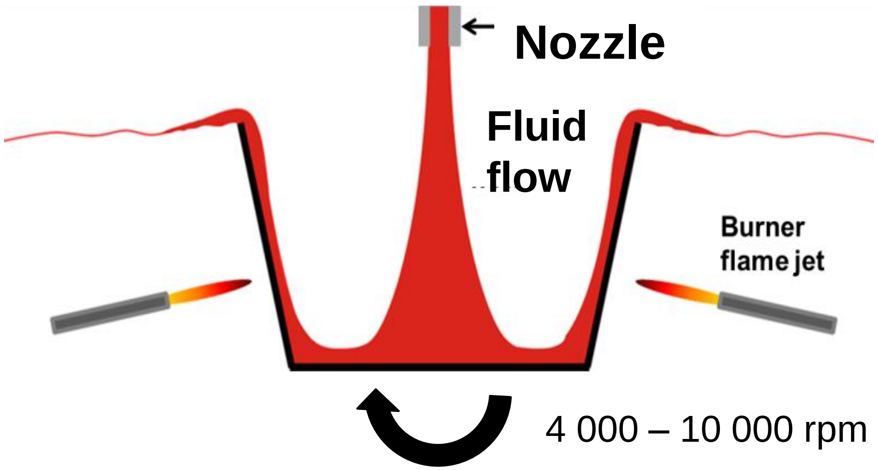
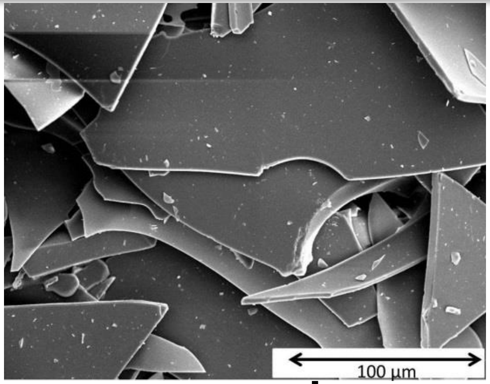
COMSOL CONFERENCE 2014 CAMBRIDGE

Overview

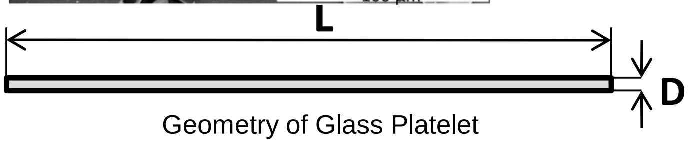
1. Introduction – Spun Method
2. Heating with Burner Flames
3. Induction Heating Simulation and its Experimental Verification
4. Conclusion

Spun Method





SEM Image of Glass Platelets



Geometry of Glass Platelet

Spun method:

– Supply of fluid (glass melt) with constant flow rate on the center of a rotating cup;

– Formation of thin lamella due to driving forces (centrifugal and coriolis forces);

– Solidification and break-up of thin lamella into small glass platelets after leaving the cup edge.

Glass platelets:

– Very thin (1µm) platelets from glass with high aspect ration (1:150)

– Planar and inert surface

Applications:

– Improvement of corrosion resistance:
  Glass-Flakes in polyester and vinylester as coating for corrosion prevention (Offshore plattform, steel in bridge construction, piping)

– Enhancement of barrier properties:
  Liquid and vapour barrier (Plastic container and packaging material);Fire resistance (insulation of cables, floor in airplanes)

– Pigment: Coated glass flakes as additives in paints (plastic, cosmetics and lacks)

– Enhancement of mechanical properties: Polymers (PTFE) with Glass-Flakes as filling agent (household appliance with scratch resistance, shoe soles for less wear)

Heating of the rotating cup

Heating with gas burners (800-1200° C):

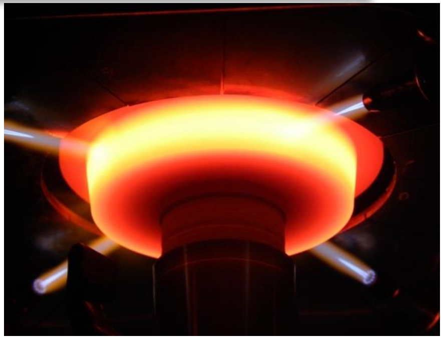
- To prevent the hot glass melt from rapid cooling down;
- To keep the glass within the range of processable viscosity.

Advantages:

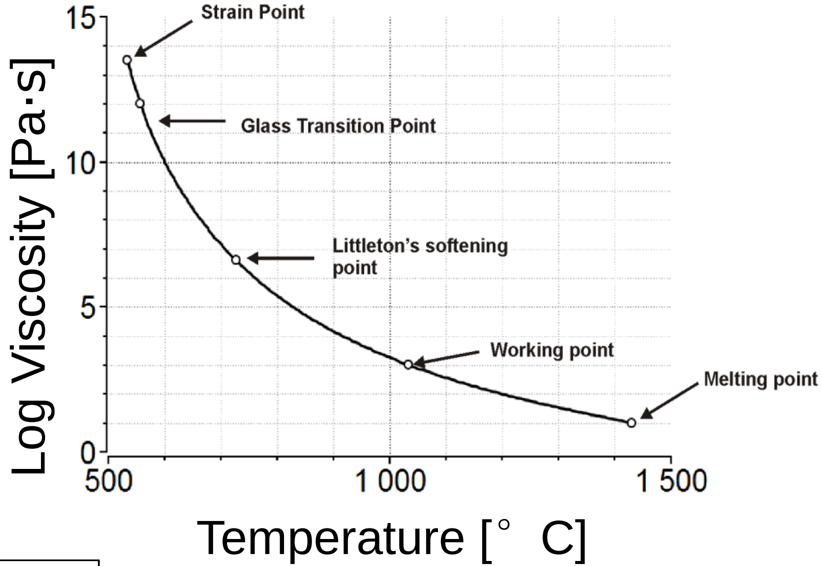
- Easy to install and cost-efficient.

Disadvantages:

- Imprecise adjustment of the temperature, extinction of burner flames due to high rotating speeds of the cup, distortion of glass lamella by burner flame and burner gases, inhomogenous heating of inner surface.

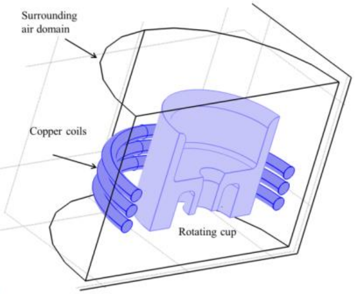


The rotating cup heated with gas burner flames: view from top (left), view from side (right)



[1]: Properties of Glass-Forming Melts, Edited by L. David Pye

Heating with induction coils:



Advantages:

- Clean technique, precise temperature adjustment, no undesirable gases, no risk of extinction, suitable for rotating parts.

Disadvantages:

- Cost-intensive (8 kW – 20 000 $)

Optimization of Heating for Rotating Cup

Aim: Optimization of the Heating for Rotating Cup

- Estimation of heat input (heat flux through burner jets) and output (cooling due to the rotation)
- Simulation of induction heating for rotating cup (check the feasibility)
- Experimental verification of the simulations

Simulation of the heated cup with gas burner flames

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Measurement of the temperatures on the heated rotating cup

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Determination of the heat transfer coefficients

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Modeling of the induction heating of the cup

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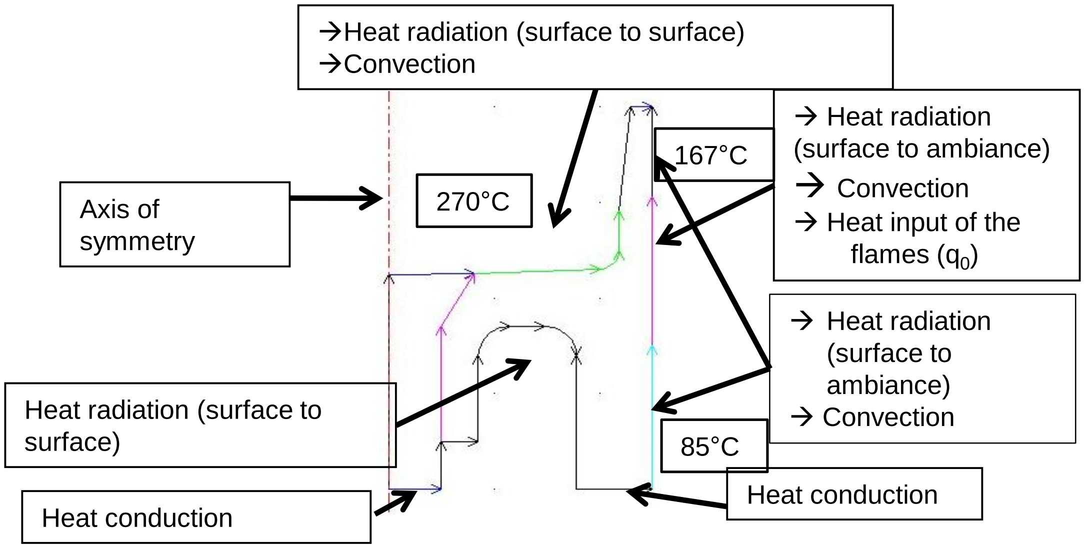
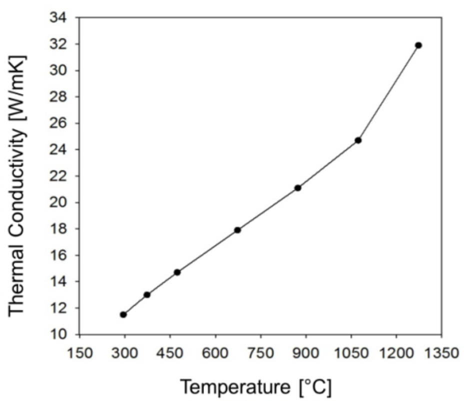
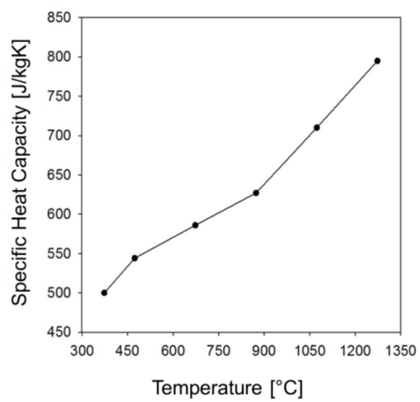
Determination of the coil parameters (position, turns of the coil)

Heating with gas burners

Simulation







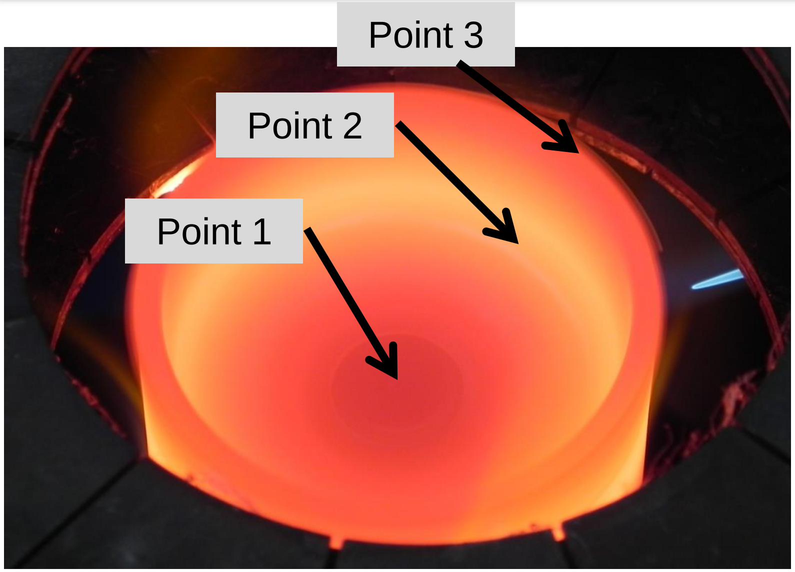
Experimental

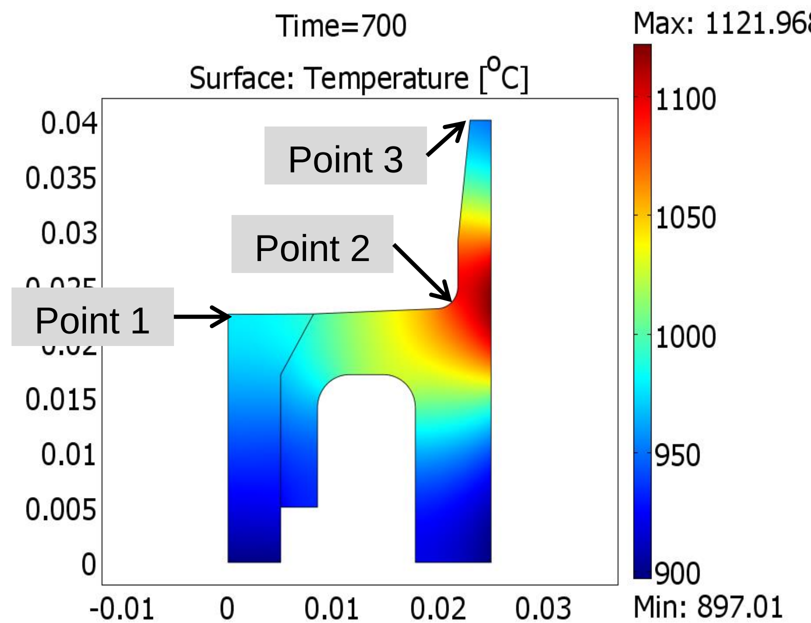
Experimental set-up with high temperature pyrometer (Cella Temp PZ 20, Keller GmbH, Germany).

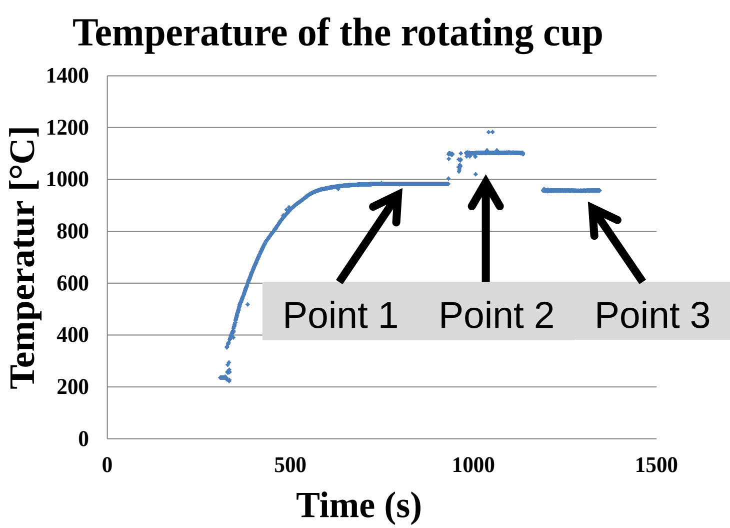
Determination of heat transfer coefficients (h_c):
Fitting the h_c at the boundaries so that the difference of the measured and calculated temperatures is minimal;

$$f(h) = \sum_{k=1}^{4} (T_{m,k} - T_{c,k})$$

Heat Transfer Coefficients





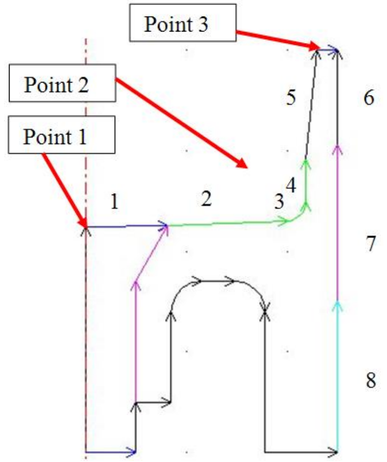


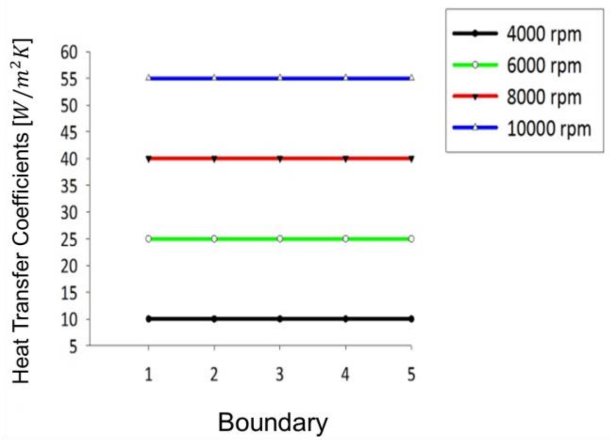
-No rotation in simulation
- Rotational effect (cooling) is hidden in heat transfer coefficients

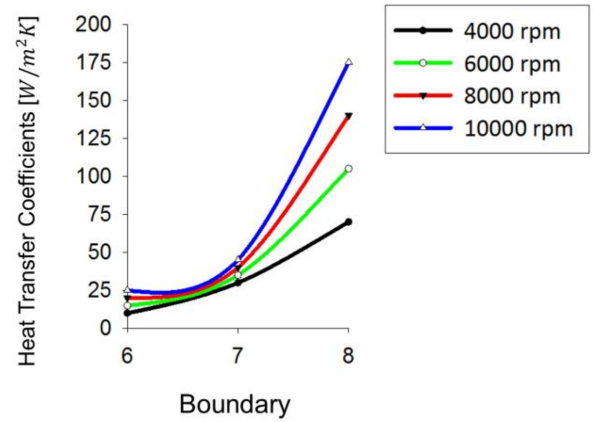
Heat Transfer Coefficients

Comparison of the simulated (T_c) and measured (T_m) temperatures

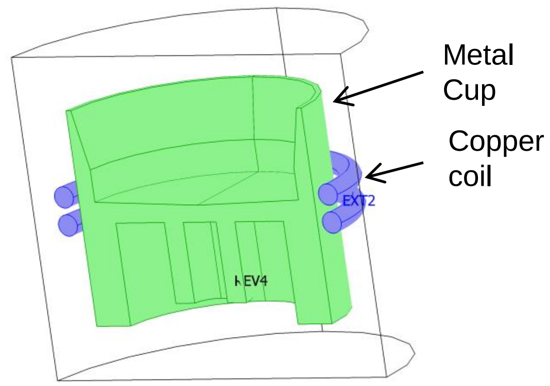
	Point 1			Point 2			Point 3		
	T_m (°C)	T_c (°C)	ΔT (°C)	T_m (°C)	T_c (°C)	ΔT (°C)	T_m (°C)	T_c (°C)	ΔT (°C)
4000 rpm	881	883	2	1055	1055	0	965	965	0
6000 rpm	835	839	4	1009	1012	3	953	968	15
8000 rpm	797	796	-1	978	980	2	897	894	-3
10000 rpm	765	756	-9	941	950	9	869	860	-9

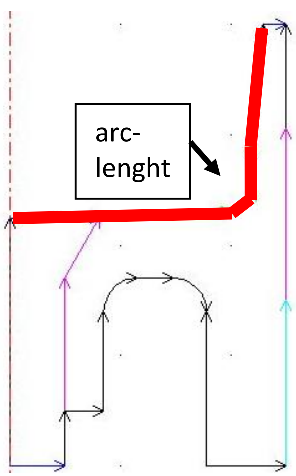






Induction Heating



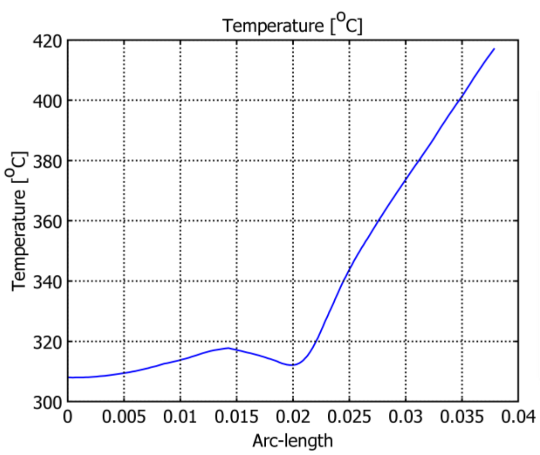


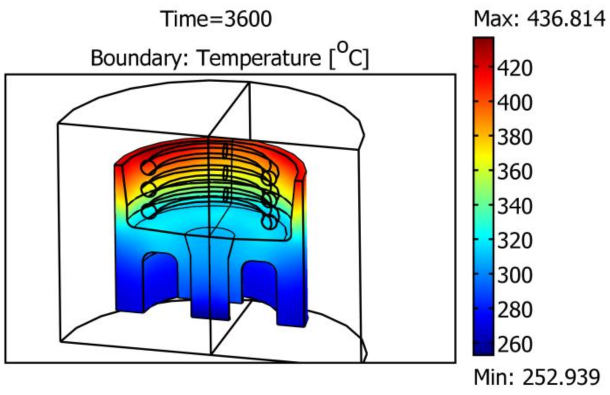
- The copper coils carry RF power;
- The alternating field induces currents in the conductive metal cup;
- Due to the Joule heating the cup will be heated up.

Frequency converter HU 2000 (Himmelwerk GmbH, Germany) :

- HF-power: 2 kW
- Frequency: 0,7 MHz
- Operating current: 400 A

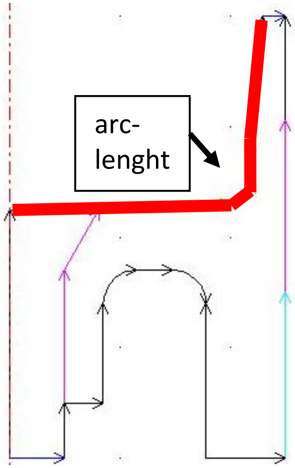
3 coil turns (inside), 4000 rpm

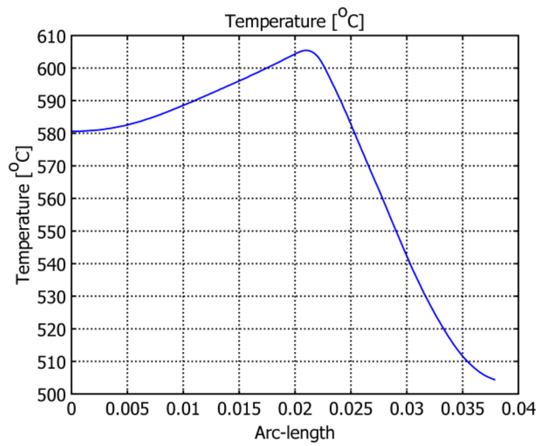




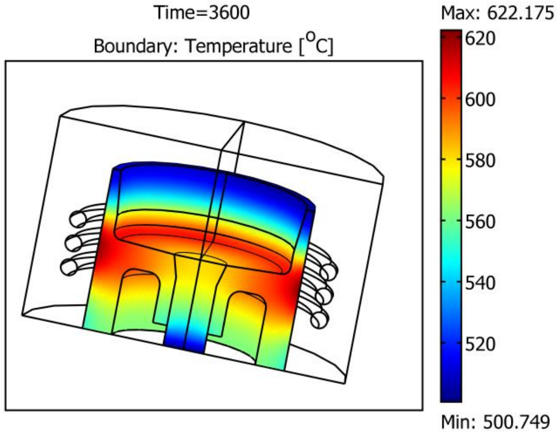
Simulation of Induction Heating

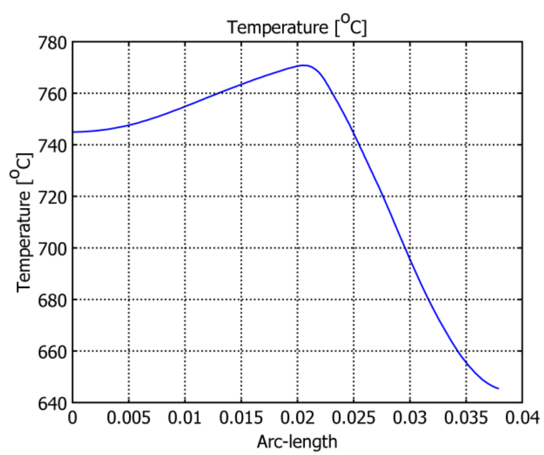
Temperature distribution of the cup:



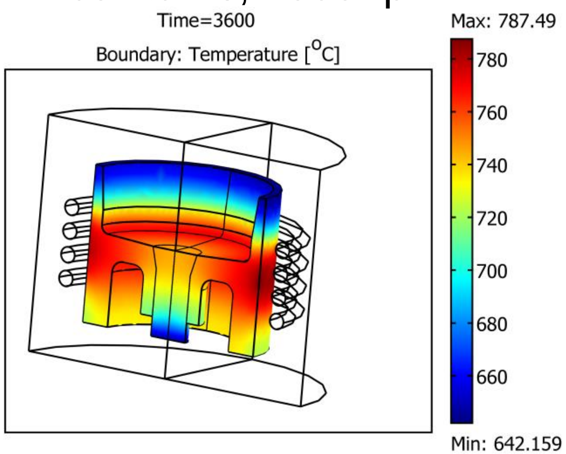


3 coil turns, 4000 rpm





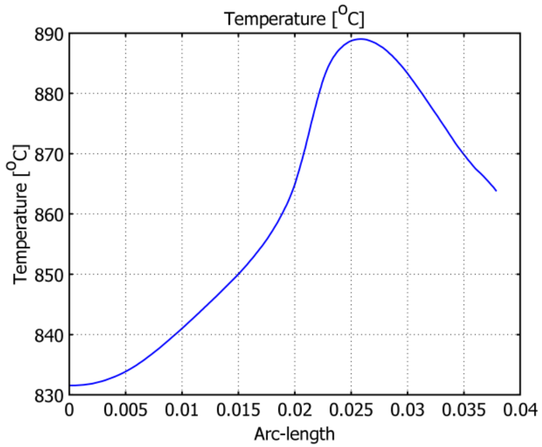
4 coil turns, 4000 rpm

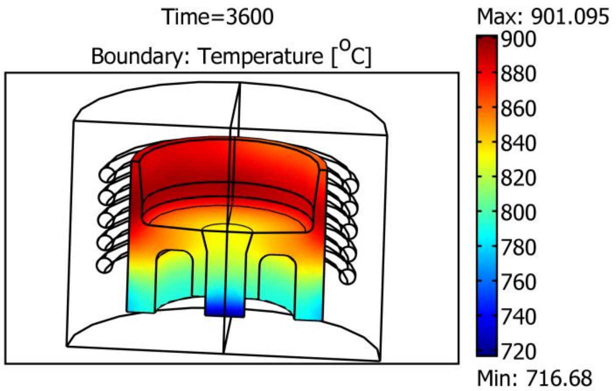


Simulation of Induction Heating

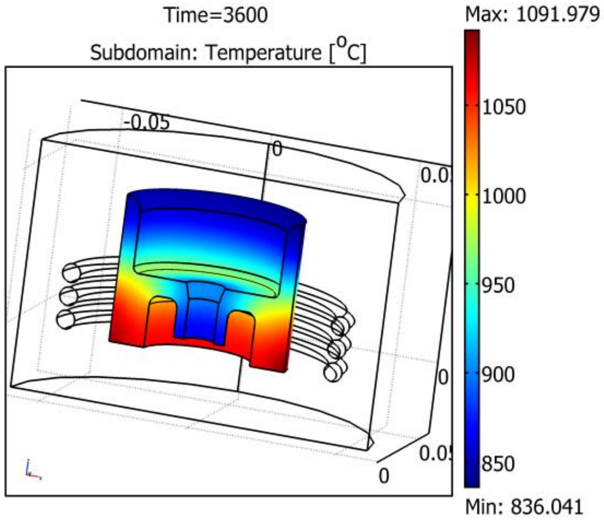
Temperature distribution of the cup:

5 coil turns, 4000 rpm

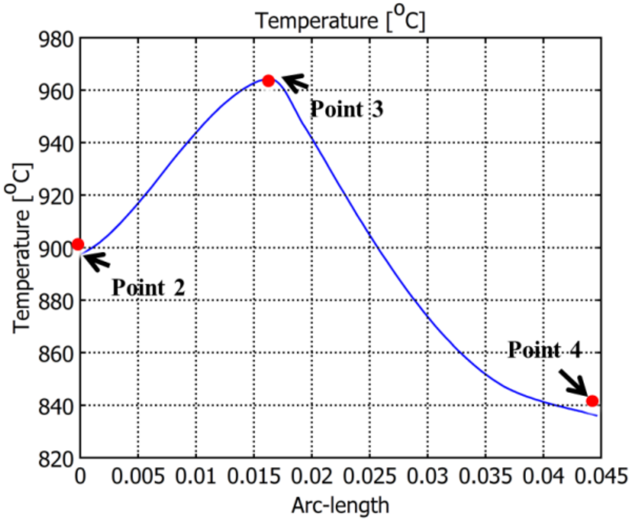




Experimental Verification



Sinus 8 (Himmelwerk GmbH, Germany) with 8 kW power and with frequency interval of 0.2-0.6 MHz.



Conclusion

- Simulation of the heated cup by means of burner flames;
- Evaluation of the energy balance on the rotating cup;
- Determination of the heat transfer coeffcients including the rotational effects;
- Transfer of these heat transfer coefficients into the induction heating;
- Modeling of the induction heating for different number of turns and position of the coils;
- Comparison between flame heating and induction heating.

→more homogenous temperatures can be achieved with induction heating; Difference between middle point and edge of the cup: 174° C (flame), 49° C (induction); Difference between edge and lip of the cup: 90° C (flame), 13° C (indcution) (4 000 rpm).

Thank you for your attention!

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