# Multiphysical Simulation of an Induction Sealing Process for Cups with Laminated Aluminum Foil

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**Introduction**: After filling of thermoformed cups, e.g. for yogurt, they are sealed with laminated aluminum foils. By today's standards the sealing of the laminated aluminum foil with the cup is primarily realized by contact heat with a hot stamp [1]. In this work an alternative sealing method based on induction heating is performed. The reasons for applying this alternative are the advantages shown in Table 1.

**Table 1.** Comparison of contact heat to induction heating

| | energy efficiency | precision | estimated rate of errors | | | contactless | cold sealing tool |
|---|---|---|---|---|---|---|---|
| | | | inappropriate sealing | over-heating | color detachment | | |
| **Contact heat** | rather low | rather low | rather high | rather high | rather high | no | no |
| **Induction heating** | rather high | rather high | rather low | rather low | rather low | yes | yes (with cooling) |

**Figure 1.** Photo of the real cup as template for the geometry of the simulation (without foil)

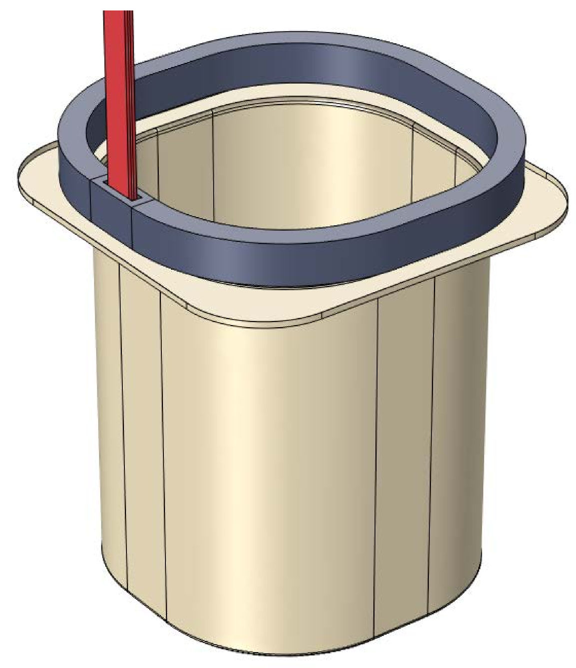

**Figure 2.** Geometry of the simulation with cup, induction coil and flux concentrator cap

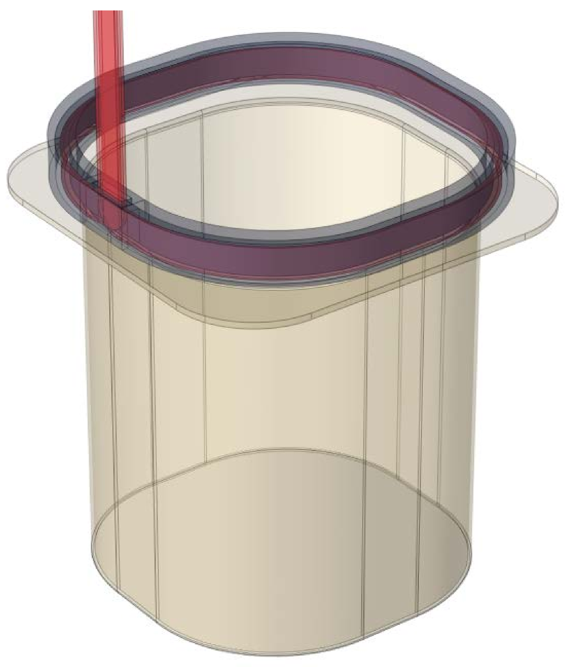

**Figure 3.** Geometry of Figure 2 in transparent rendering to see the covered coil

The motivation to use COMSOL Multiphysics® for simulating the induction sealing process for the cups' geometry (Fig. 1-3) was to verify the feasibility of substituting the common process and to derive optimization potentials.

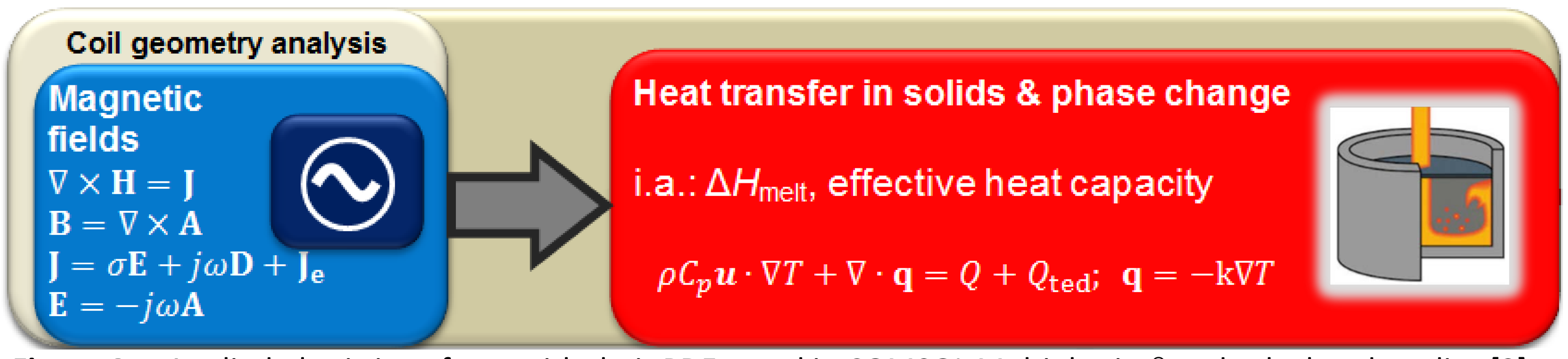


**Figure 4.** Applied physic interfaces with their PDEs used in COMSOL Multiphysics® and calculated studies [2].

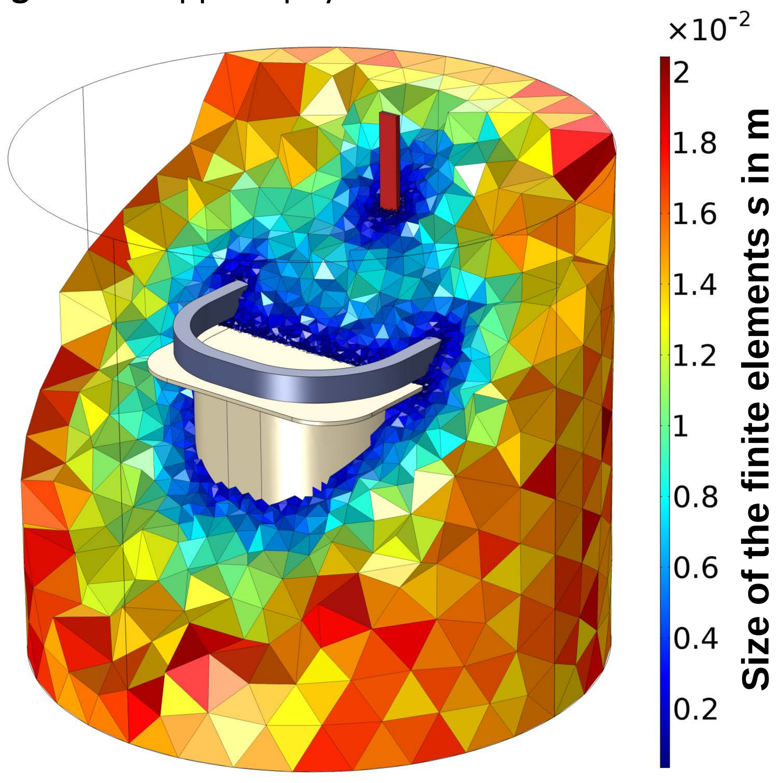


**Figure 5.** Cup, induction coil and flux concentrator cap plotted as in Figure 1-3, part of the mesh of the surrounding air illustrated as function of the mesh size

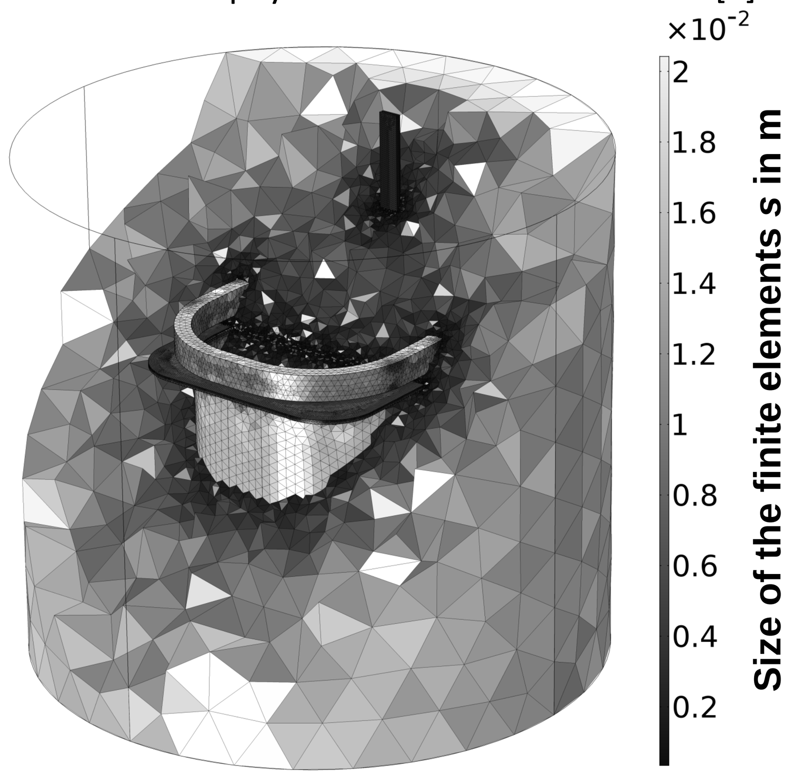


**Figure 6.** Illustration of the mesh also for the cup, the coil and the flux concentrator cap (scale only refering to the air domain)

**Computational Methods**: The applied studies are shown in Fig.4. The primarily meshed thin aluminum foil was modeled as boundary heat source and its coating with thin layers. Pictures of the mesh are shown in Fig.5-6. For the almost 0.9 Mio. elements an iterative solver was used. First studies with version 5.1 did only work with a mesh coarsening factor of 1.7. Later studies done with version 5.3 did work with a mesh coarsening factor of 2 as default value of the solver configuration. This reduced the demand of RAM.

**Results**: The temperature distribution is shown in Fig.7-8. The heated up region has almost the desired annular shape.

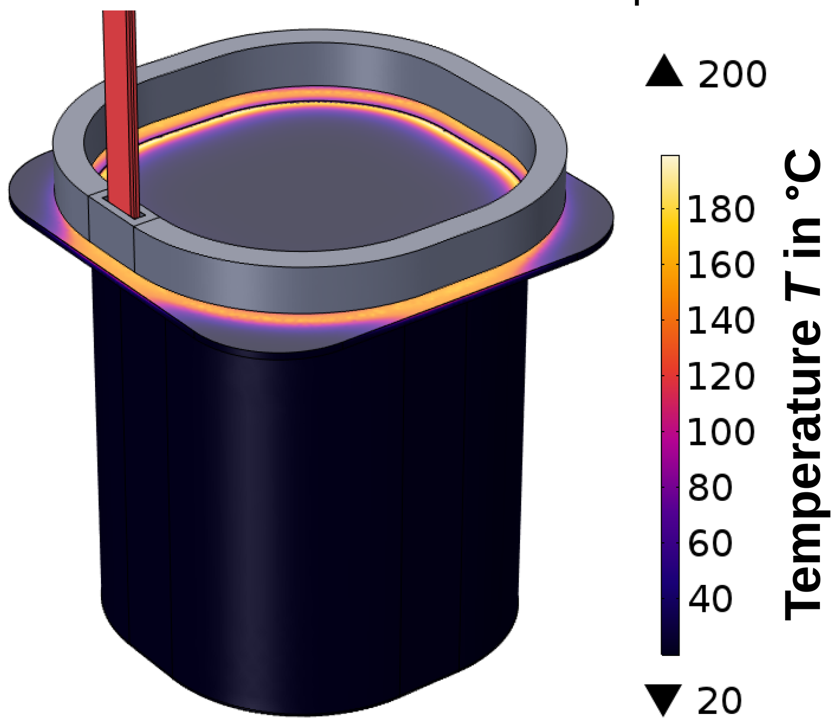


**Figure 7.** Temperature field for $\Delta t$ = 300 ms, $I_{coil}$ = 100 A, $f$ = 250 kHz

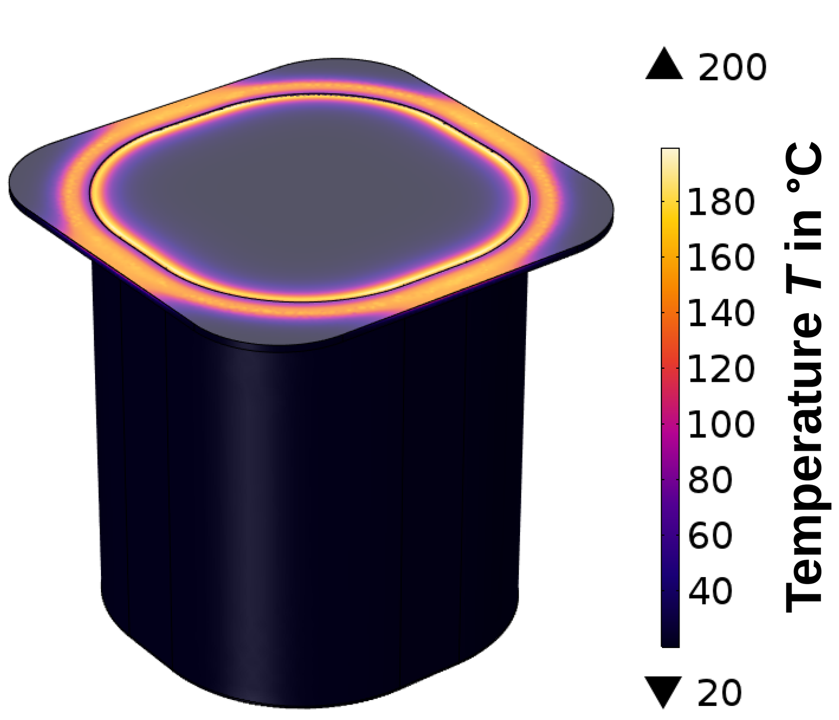


**Figure 8.** Illustration as in Figure 7 without displaying the coil and the flux concentrator cap

Besides the temperature field the regions of melting are of major interest for the sealing process. The phase change was modeled with the phase change subinterface parametrizising this with a latent heat of melting of $\Delta H_{PE}$ = 293 kJ/kg in an interval of 130-145 °C.

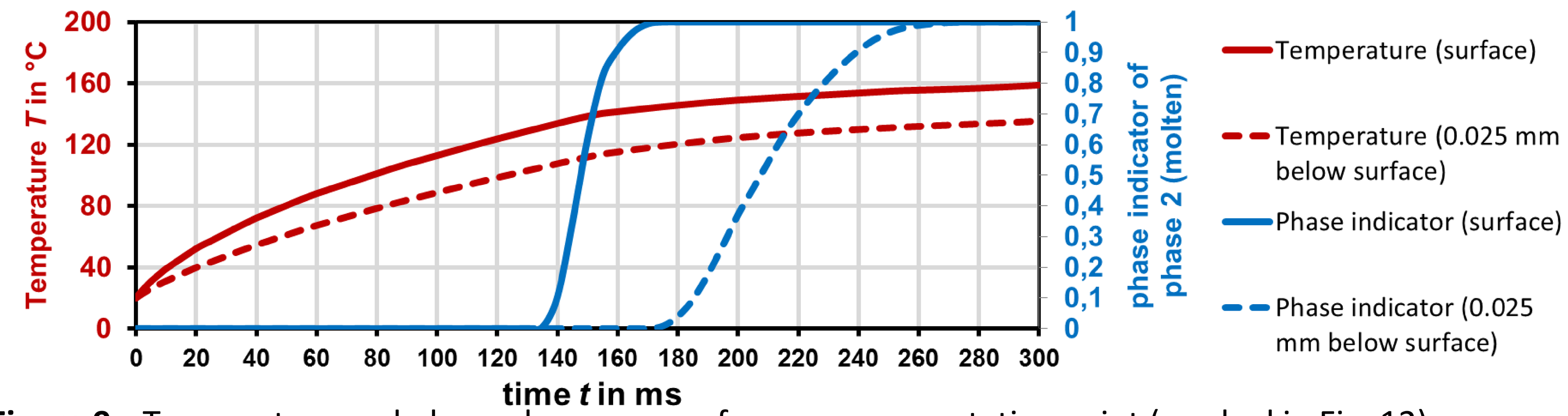


**Figure 9.** Temperature and phase change curve for one representative point (marked in Fig. 12) on the surface and for a second point 0.025 mm vertically beneath this point

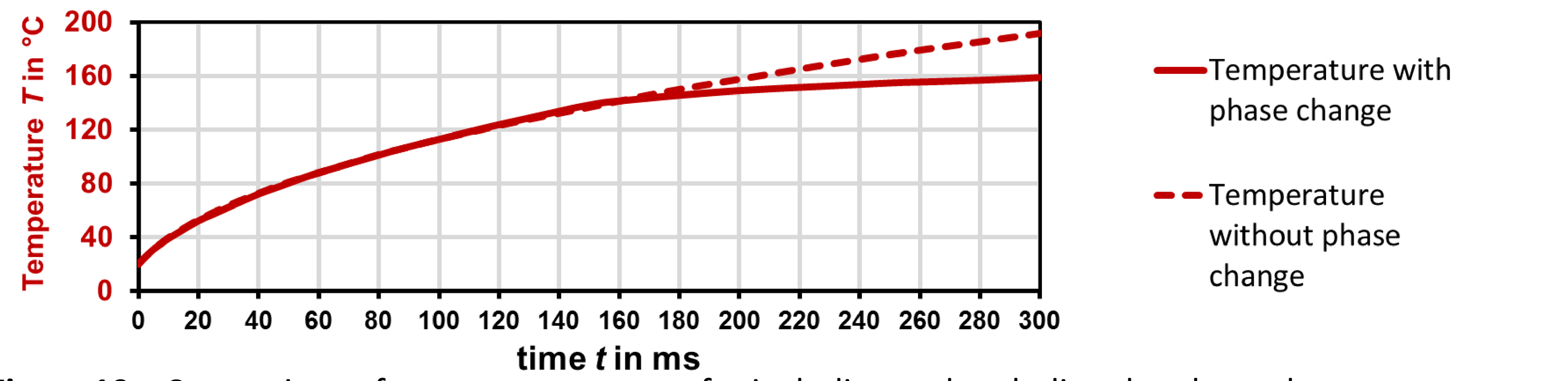


**Figure 10.** Comparison of temperature curves for including and excluding the phase change

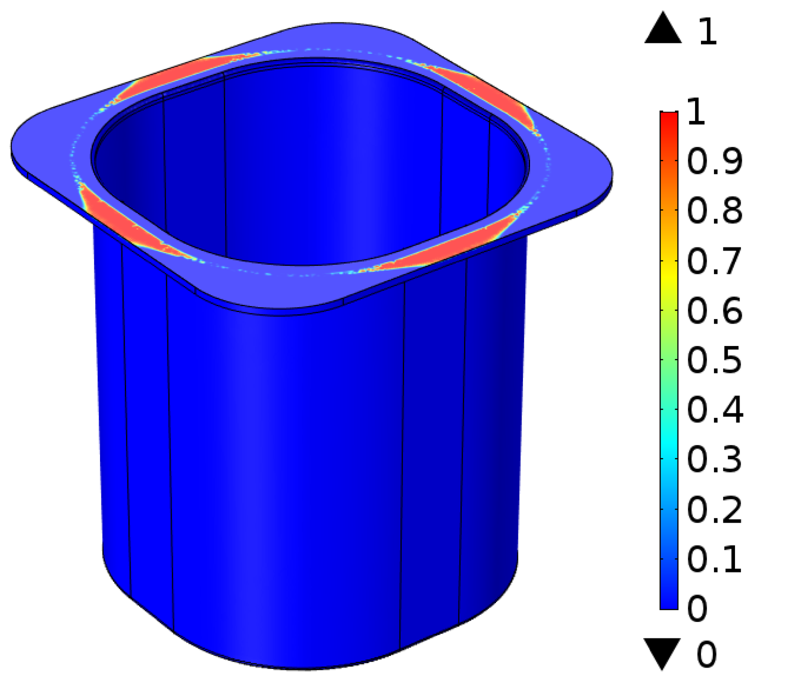

**Figure 11.** Phase change for $\Delta t$ = 225 ms, $I_{coil}$ = 100 A, $f$ = 250 kHz

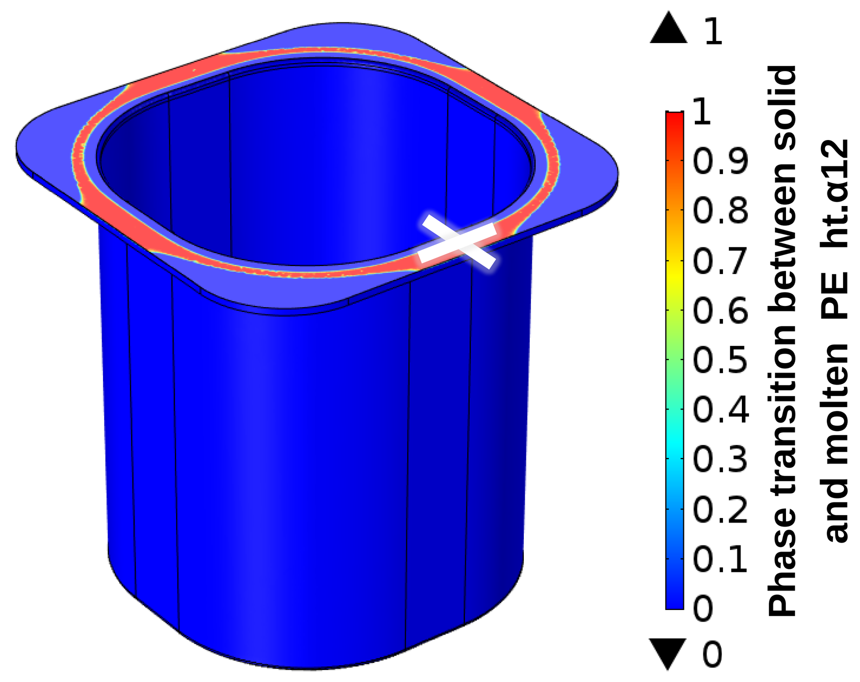


**Figure 12.** Phase change for $\Delta t$ = 300 ms, $I_{coil}$ = 100 A, $f$ = 250 kHz

Fig. 11 shows that melting occurs earlier in more narrow regions of the cup. After a time of $t$ = 300 ms (Fig. 12) the whole annular region is molten. For a representative point (marked in Fig. 12 with two white lines) the temperature and phase change curves are displayed in Fig. 9. Below the surface the heat flux is lower and melting occurs in a larger interval of time. Temperature curves of in- and excluding the phase change (in pre-studies) are compared in Fig. 10.

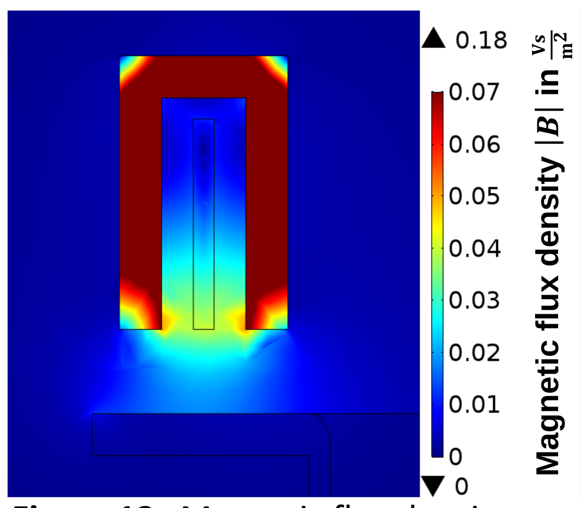


**Figure 13.** Magnetic flux density around the coil

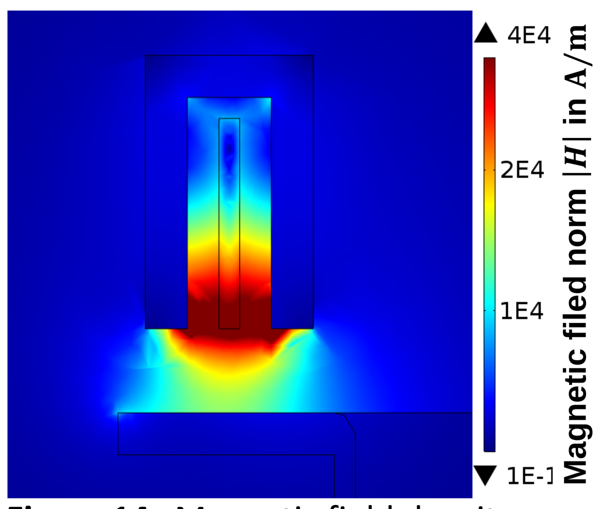


**Figure 14.** Magnetic field density around the coil

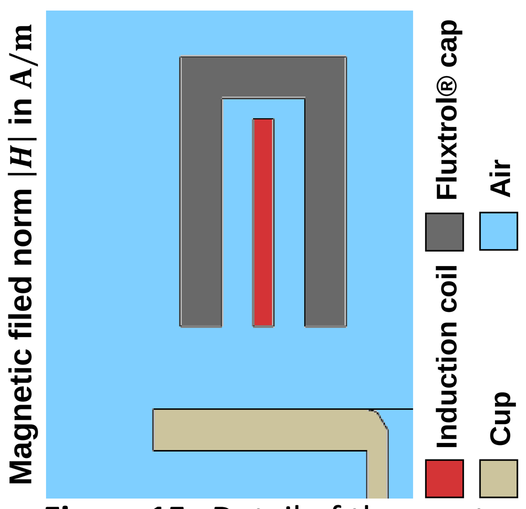


**Figure 15.** Detail of the most relevant part of the vertical cross section

In Fig. 13-15 the purpose of applying a flux concentrator can be seen. The flux concentrator has a shielding effect to the sides and to the top and it concentrates the magnetic field to the desired direction, i.e. to the foil.

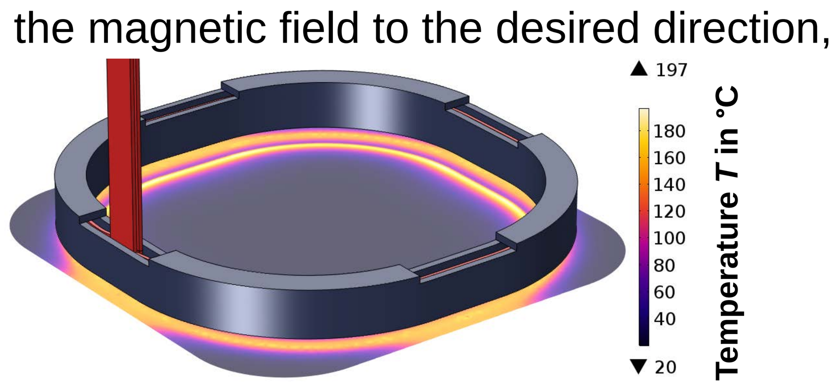


**Figure 16.** Temperature field for adapted flux conc.

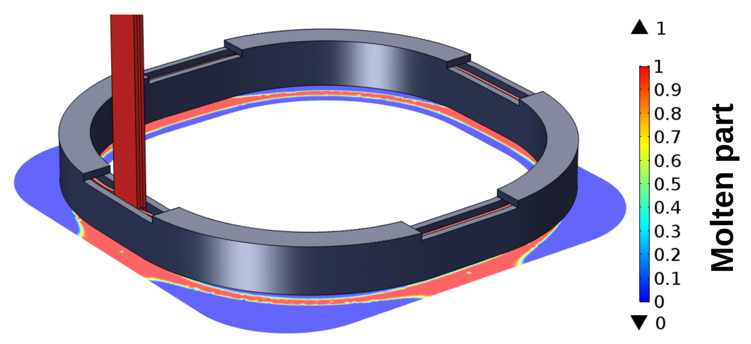


**Figure 17.** Phase transition for adapted flux conc.

In Fig. 16-17 an improved setup is shown. Above the regions of earlier melting, the top part of the flux concentrator is excluded. The effect is small, but there is to mention, that pressing the encapsulated coil (casing not shown in simulation) on the foil and cup has a decisive function for the strength of the sealing weld. Another option of improvement is to increase the distance of the coil in these regions.
The inductance of the coil is calculated (Global Evaluation) to $L_1$ = 0.222 µH and to $L_2$ = 0.205 µH (adapted variant, Fig. 16-17). This means that the surrounding ambience influences the inductance of the coil. Gaining values for the inductance of coils could alternatively only be done with expensive measurement devices. Knowing the inductance of a coil is important for an appropriate dimensioning of the connected oscillating circuit.

**Conclusions**:

The simulations show the potential of an appropriate working induction heating system for the shown geometry. The next step will be to build a functional demonstrator (FuD) for another, 2D-axisymmetric cup (see Fig. 18).

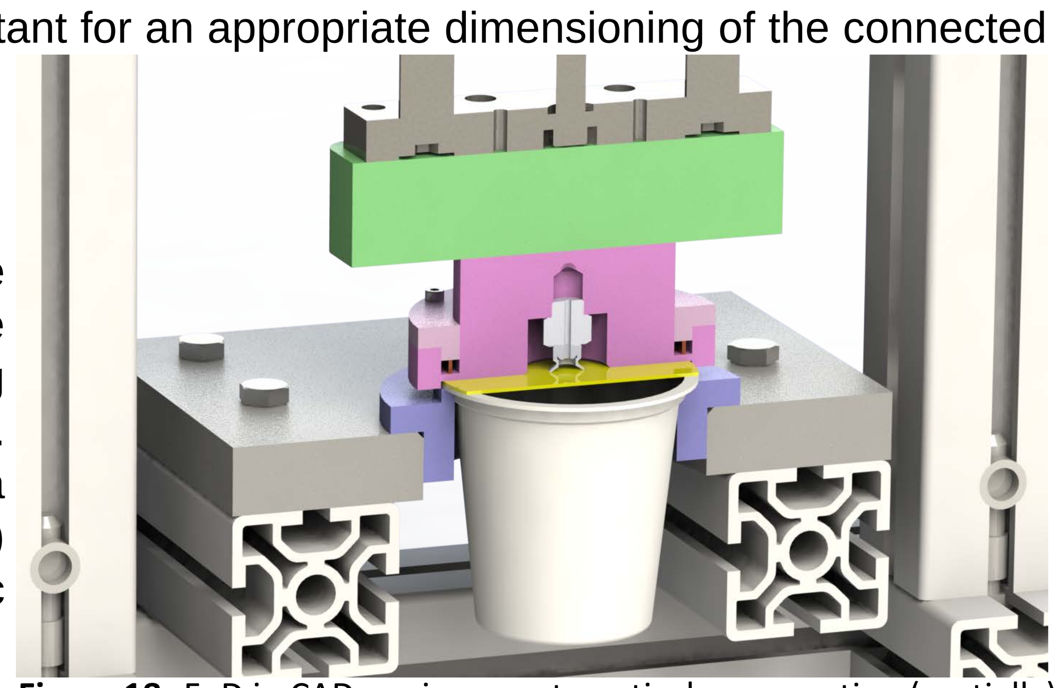

**Figure 18.** FuD in CAD-environment, vertical cross section (partially)

**References**:

1. Kühn O., Quack H., „Apparatus for sealing a covering film on filled containers, particularly thermoplastic cups, in a packaging machine“, EP 0786405 A1, publishing date: 30th July 1997
2. http://www.weerulin.de/produkte/power-drumr/spritzschutz/ (source for picture)