Thermal Cracking of Lignite Briquettes for Gasification with a 10 kW Microwave Applicator

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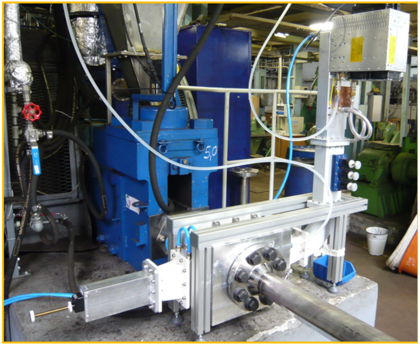
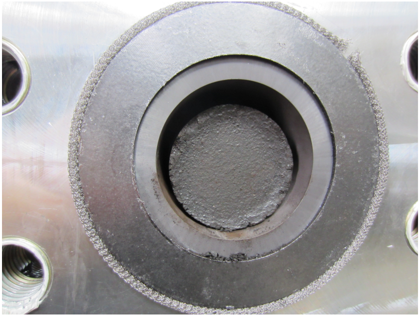
- Installation set up and Microwave Applicator
- Electromagnetic, thermo fluid and mechanical model
- Materials choices
- Experimental tests
- Conclusion

Set up

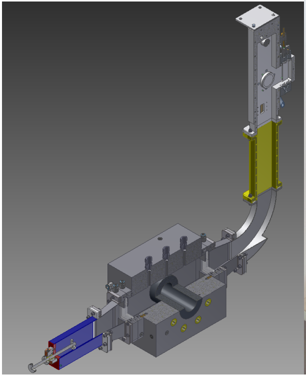
- Briquetting press machine: a reliable self sealing system to transfer material at high pressure (Technical University, Freiberg)
- applicator connected between a briquette press machine and a gasifier





Microwave applicator

- volumetric heating and thermal cracking of cylindrical lignite briquettes
- design and built a EM matched and high pressure applicator



Model summary

$$\frac{1}{\mu_r}\nabla \times (\nabla \times \boldsymbol{E}) - k_0^2 \epsilon_{rc} \boldsymbol{E} = 0 \quad \textbf{(EM)}$$

$$k_0^2 = \omega \epsilon_0 \mu_0$$

$$\epsilon_{rc} = \epsilon_r{}' - j\epsilon_r^{''}$$

$$q = \frac{1}{2}\omega \epsilon_0 \epsilon_r^{''} \boldsymbol{E}^2$$

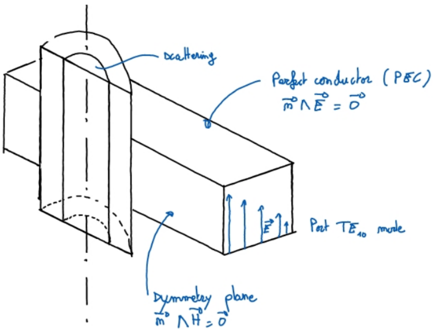
$$\rho c \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + q \quad \textbf{(THER)}$$

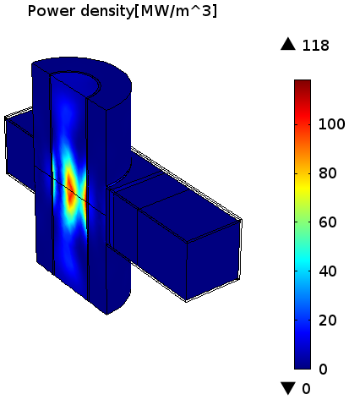
$$\cancel{\rho \ddot{\mathbf{u}}(\mathbf{x}, t)} - \nabla \cdot \boldsymbol{\sigma}(\mathbf{x}, t) - \cancel{\boldsymbol{\kappa}(\mathbf{x}, t)} = 0 \quad \textbf{(MEC)}$$

$$\boldsymbol{\sigma} = \frac{E}{1+\nu}\boldsymbol{\epsilon} + \frac{E\nu}{(1+\nu)(1-2\nu)} tr(\boldsymbol{\epsilon})\mathbf{I} - \alpha \frac{E}{1-2\nu} \Delta T \mathbf{I}$$

EM model

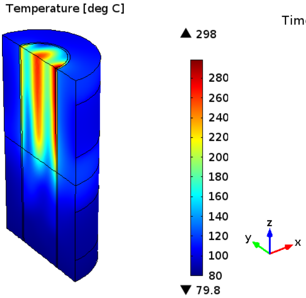
- rectangular wave guide channel crosses a ceramic tube

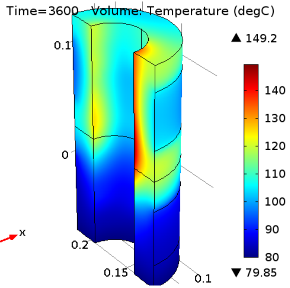




Thermal and fluid model

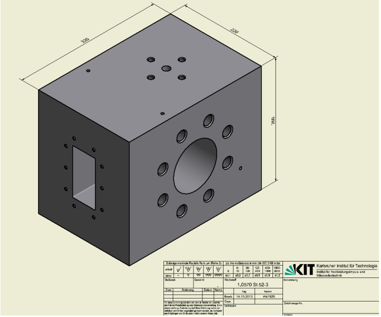
- heat equation in the solid domain and the Navier stokes equation in the fluid domain.
- moving briquettes into the channel, transport term is used in the heat equation (Translational motion at constant velocity)
- 200 to 300 $^\circ$ C, inside the lignite material (overestimated, no phase change is included)

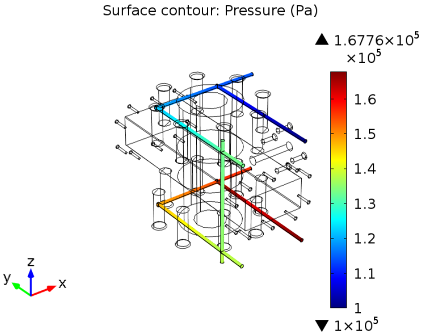




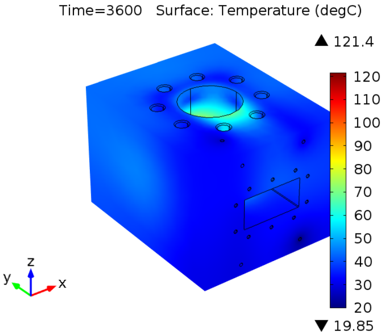
Geometry, Metal Bloc

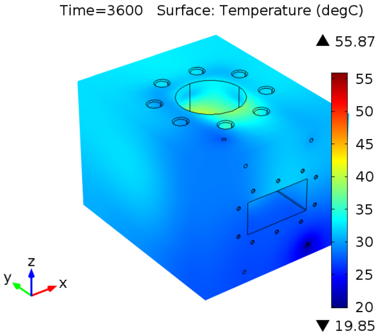
$32 \times 22 \times 26\ cm$





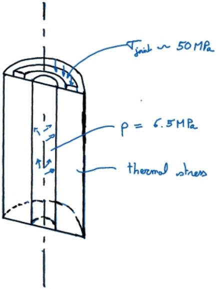
Temperature, stainless steel and Aluminium, $Q = 4l/min$

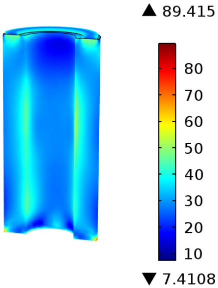


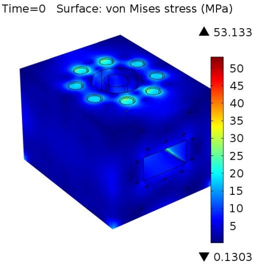


Mechanical model

- Stress inside the ceramic, 2.5 cm thick wall (thermal stress, inner pressure and gasket pressure)
- Constitutive law: linear elastic model
- Loads: Inner pressure 6.5 MPa, Gasket pressure $\simeq$ 50 MPa, screws: $16 \times M22$ per flange ($30 - 60$ kN per screw!), thermal stress due to temperature gradient



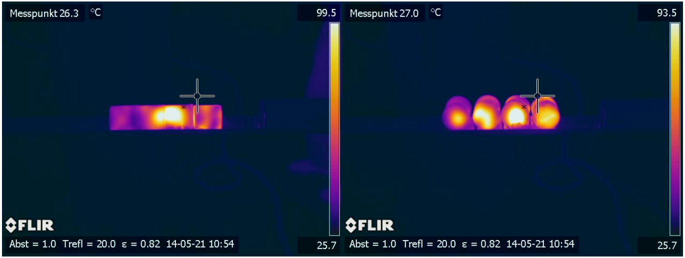




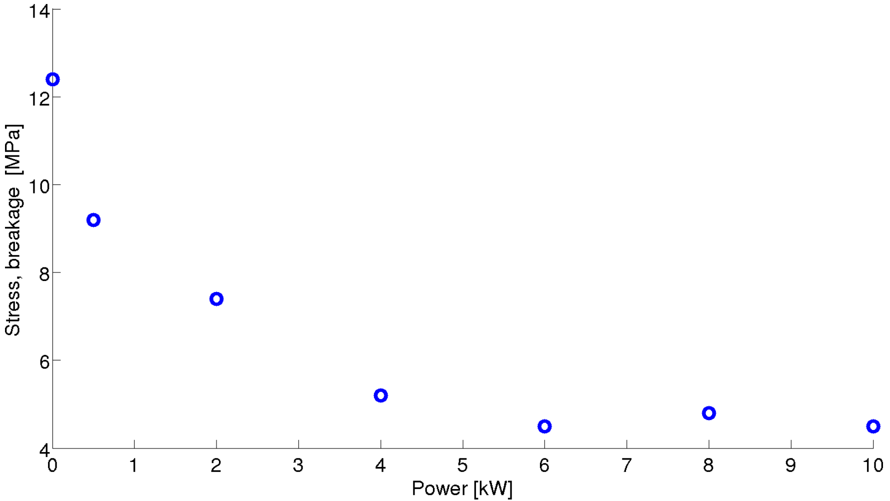
Materials choice

- Ceramic tube: silicium Nitride Si_3N_4 Very high mechanical strength (Tensile strength $\simeq$ 500 MPa, Compressive strength $>$ 2000MPa). And very low dielectric loss ($tan\,\delta < 4 \times 10^{-3}$).
- Metal bloc: high strength aluminium (Alumec 100 from Alcoa). Tensile strength $\simeq$ 400 MPa and very good electrical and thermal conductivity (efficient cooling circuit).

Experimental results



Stress versus power



Conclusions

- EM: Good matching, less then 2% reflected power with a manual tuner
- Ther: lignite very good MW absorber
- Ther: Importance of the cooling to maintain a constant temperature in the aluminium bloc
- Mech: Acceptable stress level for the ceramic
- Mech: stress in the aluminium bloc driven by thermal stress and screws
- Materials: Si_3N_4 combines low dielectric loss and high mechanical strength
- Simulations : Multiphysics simulation quite useful for the design of this applicator.

- Thank you for your attention
- Questions