Construction and evaluation of numerical model for heat transfer in a ladle during pre-heating and drying

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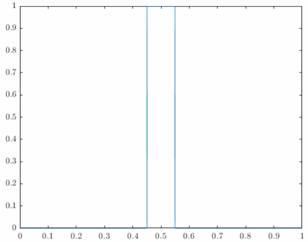
2023-05-16

Background

- Heat transfer is key to understanding many processes in engineering
- Heat transfer is governed by PDEs, in particular the diffusion equation

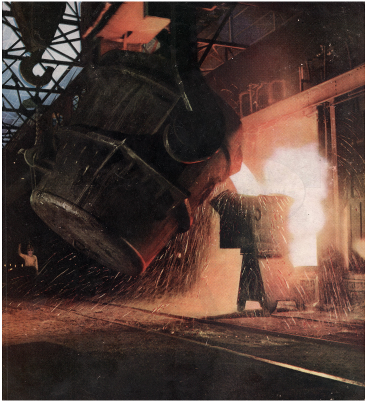
$$\frac{\partial(c_p \rho T)}{\partial t} = \nabla \cdot (k \nabla T)$$

- For complicated geometries and boundary conditions analytic solutions are not known, instead numerical methods are needed



Background

- The refractory lining on the inside of ladles gets worn down
- Thus the lining needs to be replaced
- In order to heat the ladle and dry the fresh brick and mortar a burner is used



Aim and purpose

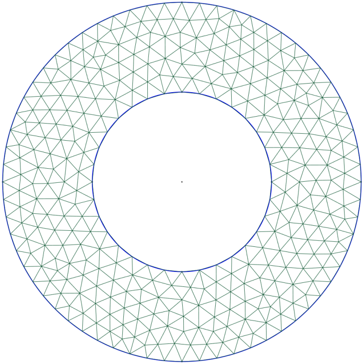
1. Write code in Julia that can solve the diffusion equation in an arbitrary 3D-geometry subject to Dirichlet, Neumann, Robin, and some kinds of non-linear boundary conditions
2. Construct and evaluate a mathematical model to describe the heating process of a ladle
3. Simulate the model using previously mentioned code

Method

The Finite Volume Method

- The first step in any numerical method for differential equations is to discretise the domain
- In FVM the domain is discretised into a finite number of volumes
- FVM is based on Gauss's divergence theorem

$$\int_{V_1} \nabla \cdot (k \nabla T) dV = \oint_{\partial V_1} k \nabla T \cdot d\overline{S}$$



Method

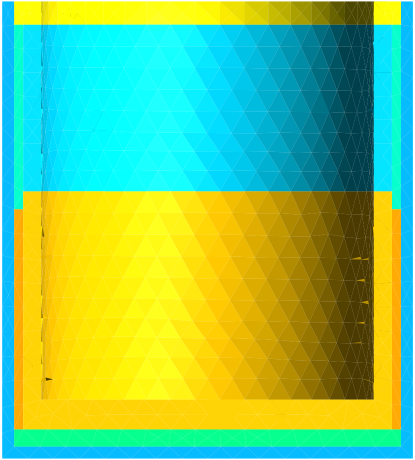
Mathematical model

- The model is described by the heat equation and on the inside a Neumann-condition

$$-k\nabla T \cdot \overline{n} = q(t)$$

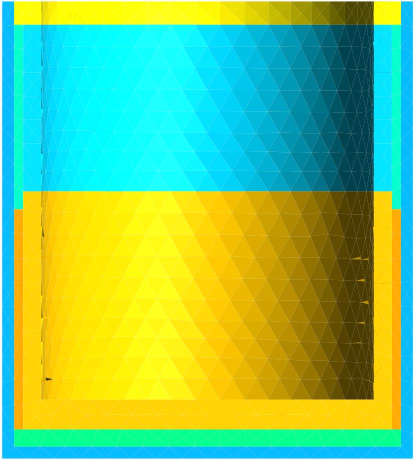
- and on the outside a combined radiation-convection condition

$$-k\nabla T \cdot \overline{n} = h(T - T_\infty) + \sigma\varepsilon(T^4 - T_\infty^4)$$



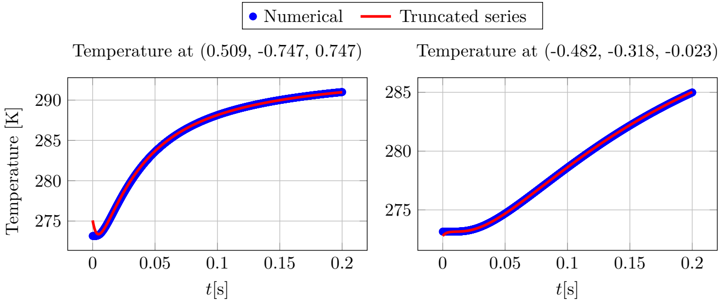
Method

- The ladle being studied is one from Ovako's site in Hofors
- During the heating process measurements were taken
  - Inside the bottom of the ladle
  - On the outer wall
- Supporting the measured data some photos were taken with a thermal imaging camera



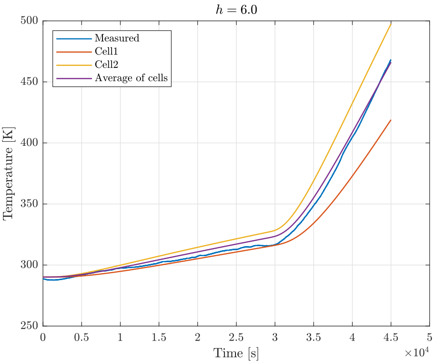
Results

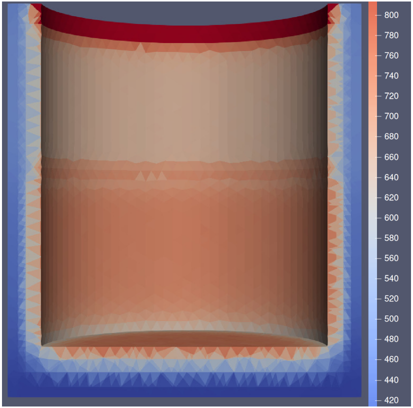
- First of all the computational accuracy of the code needed to be validated
- In order to do this simple cases where analytic solutions are known were studied
- Good agreement between numeric and analytic solutions was found



Results

The mathematical model was found to agree fairly well with measured temperatures





Conclusions

- The code can accurately solve the diffusion equation
- The mathematical model describes the heat transfer in ladles adequately well
- This means that the code can be used to evaluate different heating regimens without physical experiments
- Fewer physical experiments saves both resources and manpower