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Thermal Natural Convection Simulation with COMSOL Multiphysics in comparison with measurements

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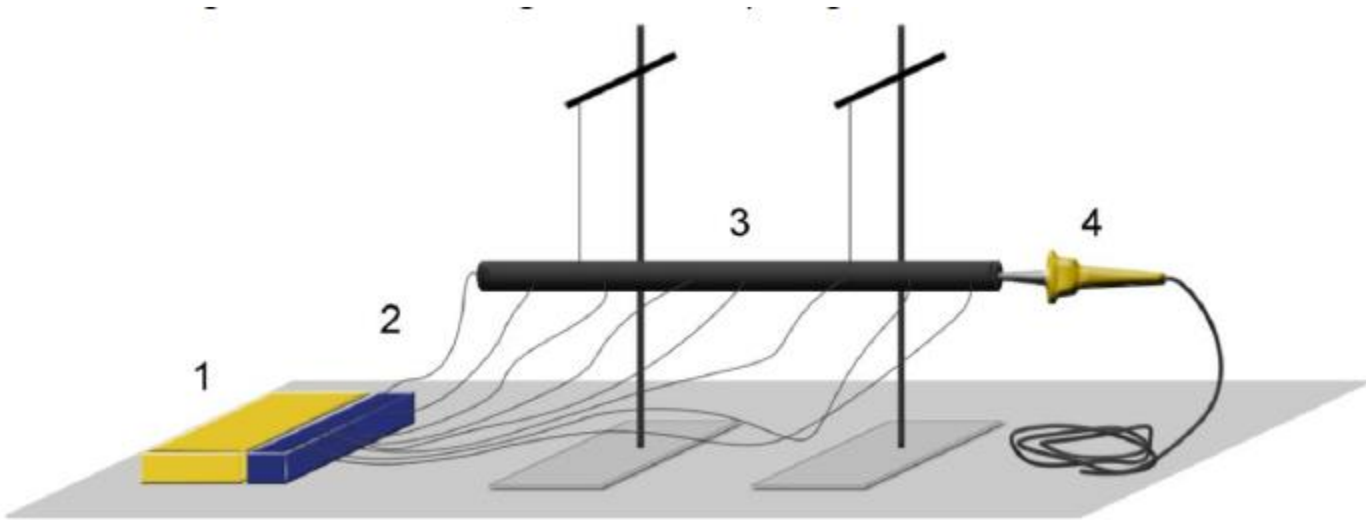
COMSOL CONFERENCE
2014 CAMBRIDGE

Fontys University of Applied Physics

- Every year 80 students learn COMSOL
- In second year students start to work with COMSOL
- In year 4, more complicated simulations are a part of the educational program
- A few examples:
  - Windtunnel simulations (turbulent)
  - Pipeflow (laminar, turbulent)
  - Heat exchanger
  - Natural convection

Horizontal rod setup



Setup of experiment.

1. Datalogger
2. Input data from thermo couples
3. Brass rod (Cu 70% Zn 30%)
4. Heater

Exercise

- Setup an appropriate COMSOL model.
- Prepare the measurements, take data.
- Which physics is involved?
- Natural convection?
- Radiation?
- Conduction?
- Accuracy in the end , 4%?

Heat loss mechanisms

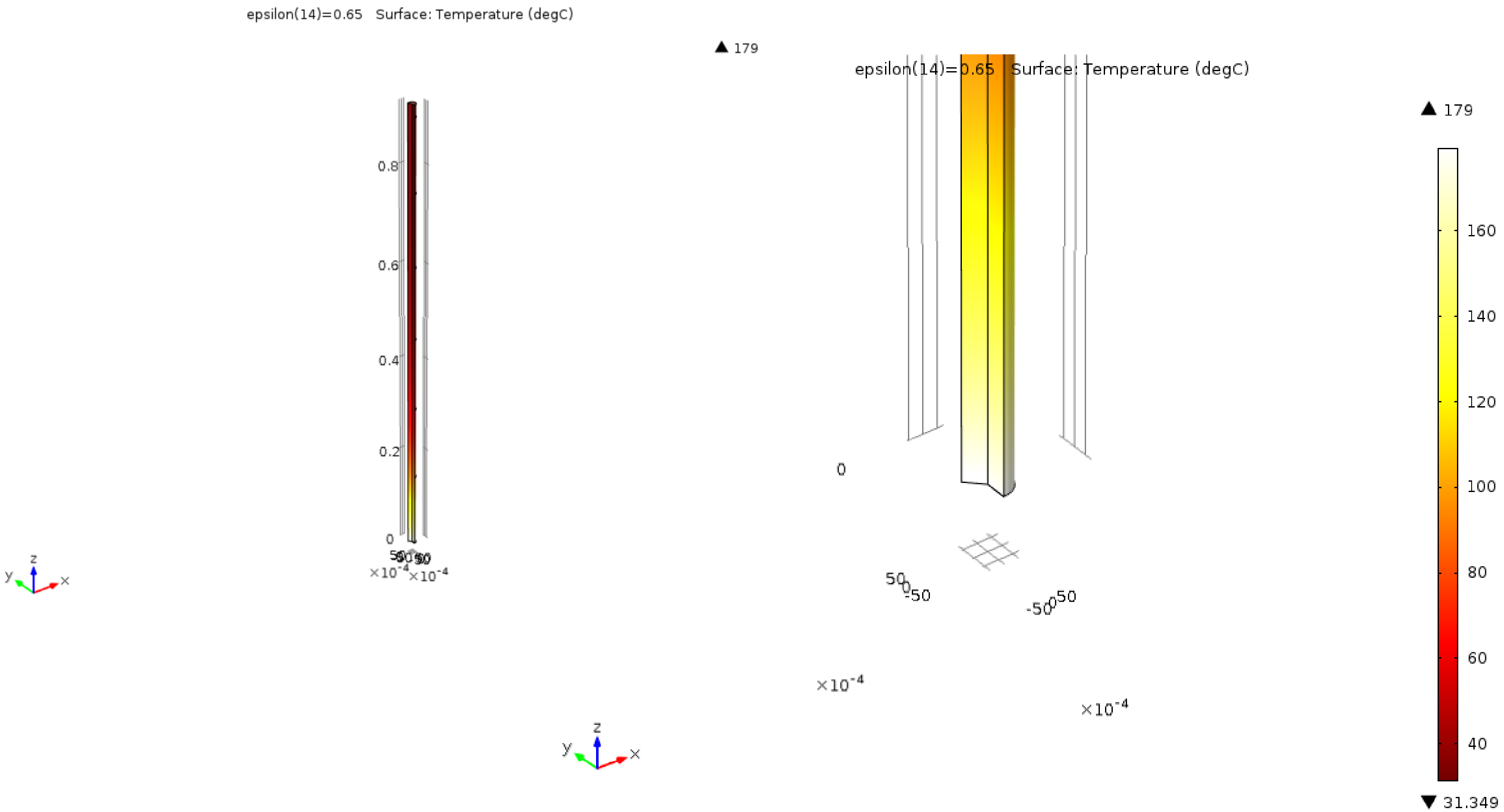
1. Conduction
   - Brass heat conductivity changes with tempearture.
2. Convection
   - Transfer coefficient depends on temperature
3. Radiation
   - Brass, if oxidized shows an epsilon of about 0.5-0.6

COMSOL Multiphysics

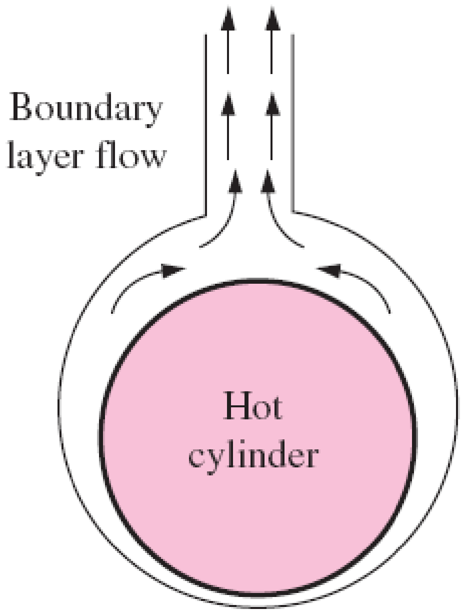
- Rod is simulated in 2D axisymmetric mode
  – Dimensions are implemented, easy
  – Stationary solver, easy and fast.(few seconds)

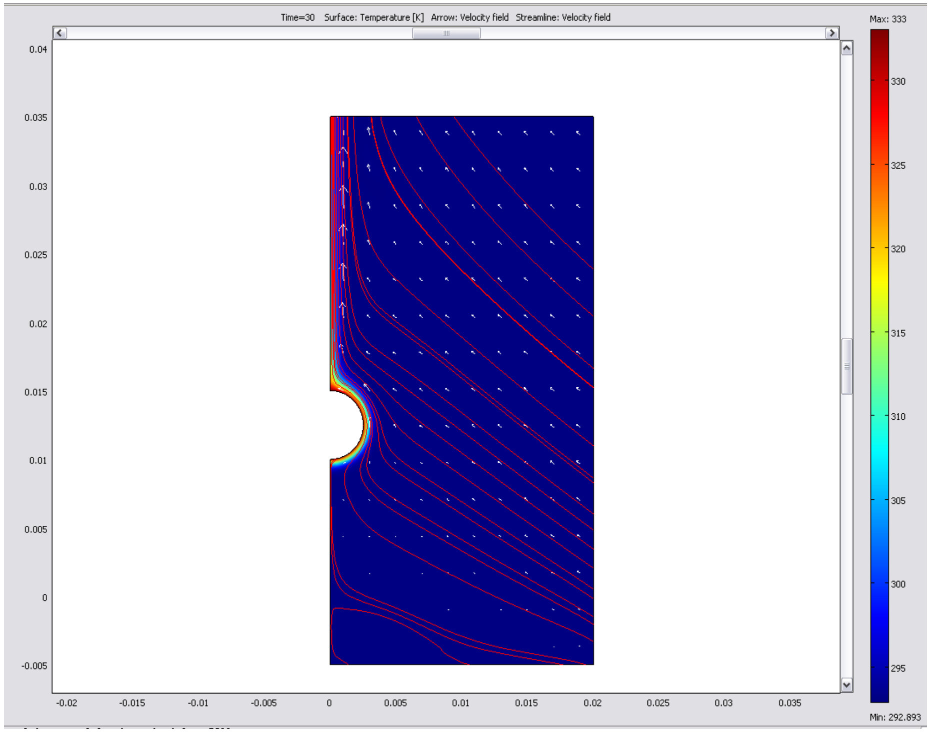
- Are there any problems for students?
  – **YES**.
  – Realise that heat transfer is not constant over rod.
  – Conductivity rod changes with temperature
  – Estimate the emissivity of the rod material.
  – You need patience to do the measurements without disturbing the natural convection.

Overview of simulation



Convection around rod





Laminar flow model on the right.

The heat transfer coefficient is

The heat transfer coefficient is then:

$$h = \frac{Nu\, k}{D} \ \ [\mathrm{W/m^2\ K}]$$

Nusselt is Dimensionless convection heat transfer coefficient defined as

Nusselt number for rod

Nusselt is Dimensionless convection heat transfer coefficient

$$Nu = \left\{0.6 + \frac{0.387Ra^{1/6}}{\left[1 + \left(0.559/_{Pr}\right)^{9/16}\right]^{8/27}}\right\}^2$$

Thermal-Fluid Sciences, Cengel, 4th edition.

In which Ra is the Rayleigh number:

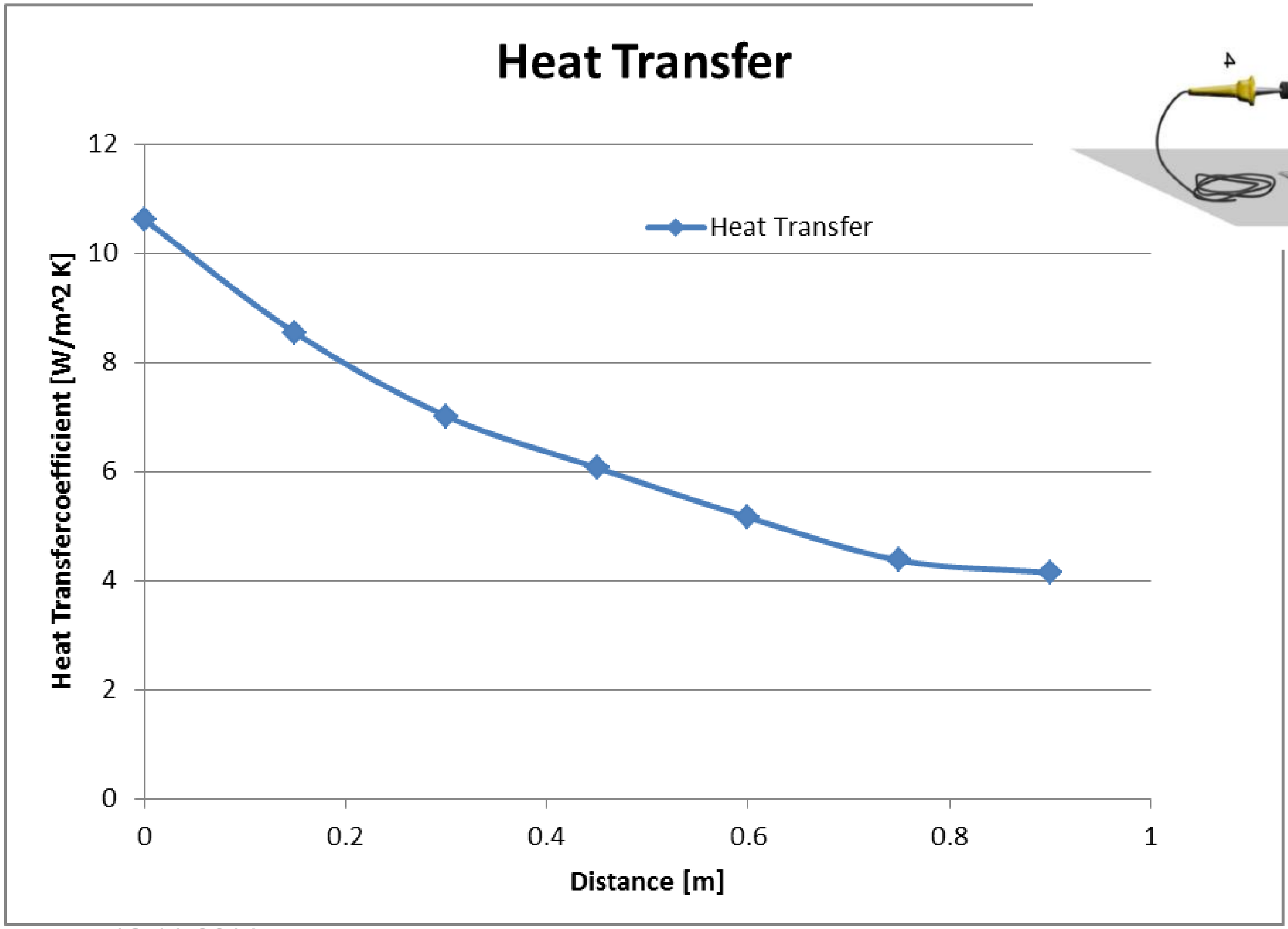
$$Ra = Gr\ Pr = \frac{g\beta(T - T_\infty)D^3}{\vartheta^2}.Pr$$

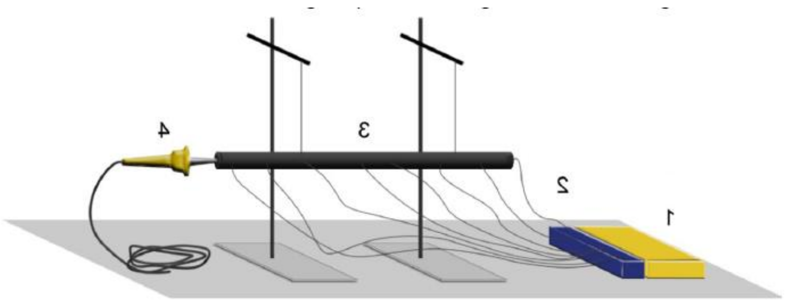
Gr is the Grashof number, $g=9.81[m/s^2]$, T temperature, T_{00} room temperature, D diameter rod, ϑ the viscosity and $\beta = 1/T_{film}$

At last the $T_{film} = \frac{T_{rod}+T_{room}}{2}$, al parameters should be taken at film temperature.

Heat Transfer Coefficient

$$h = \frac{Nu\, k}{D} \ [\mathrm{W/m^2\ K}]$$





Heat transfer is calculated in MathCAd.

In left graph the heat transfer is depicted taking into account the temperature at the measuring points.

Radiation losses

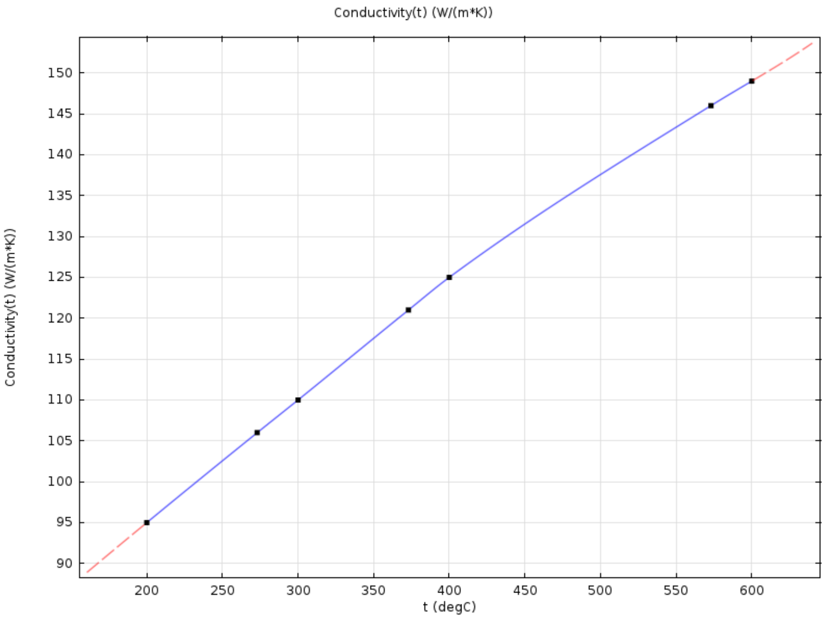
- Radiation law of Stefan-Boltzmann

$$P = A\sigma T^4$$

- Is used in COMSOL Boundary conditions.

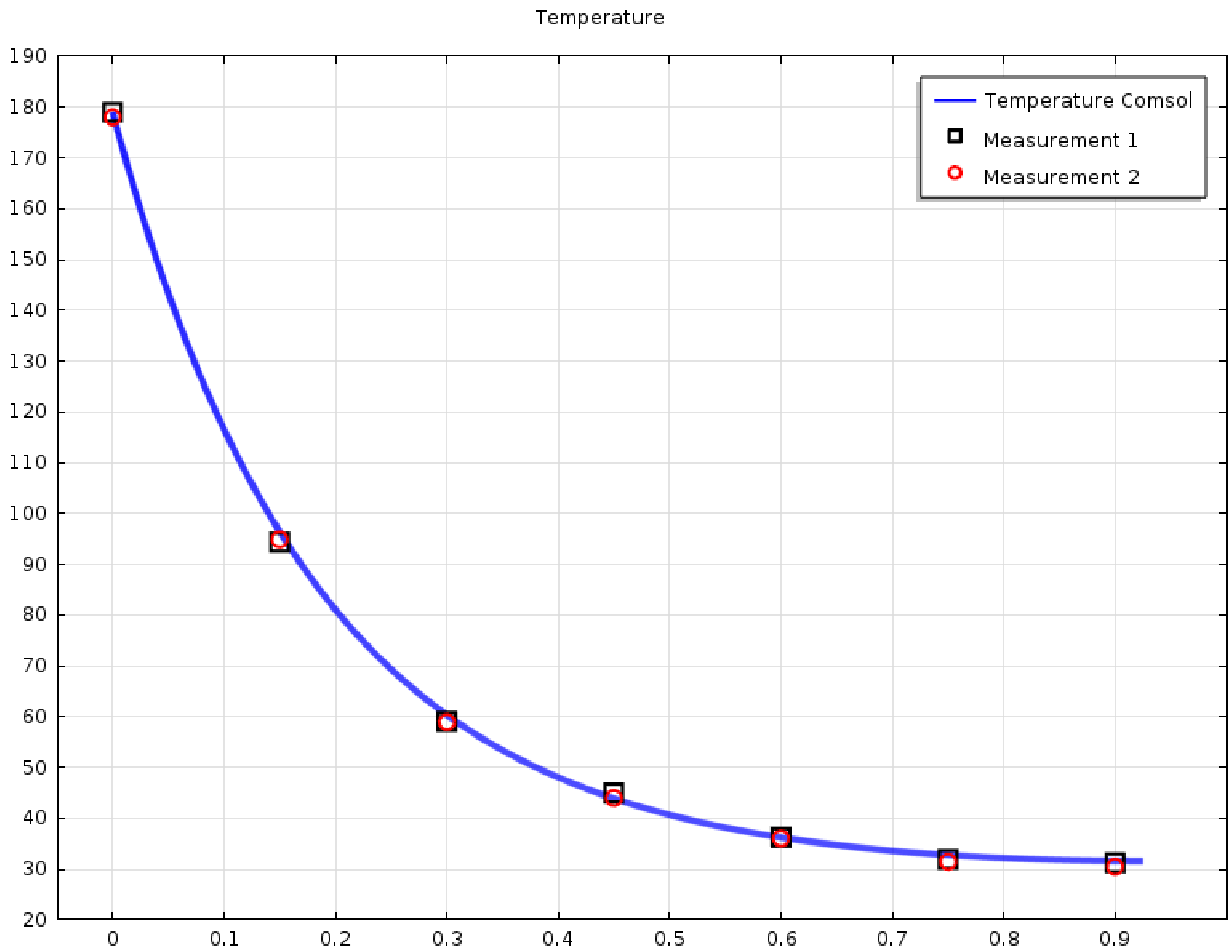
Heat conductivity

- This conductivity depends on the temperature of the brass material.
- This is implemented in Comsol

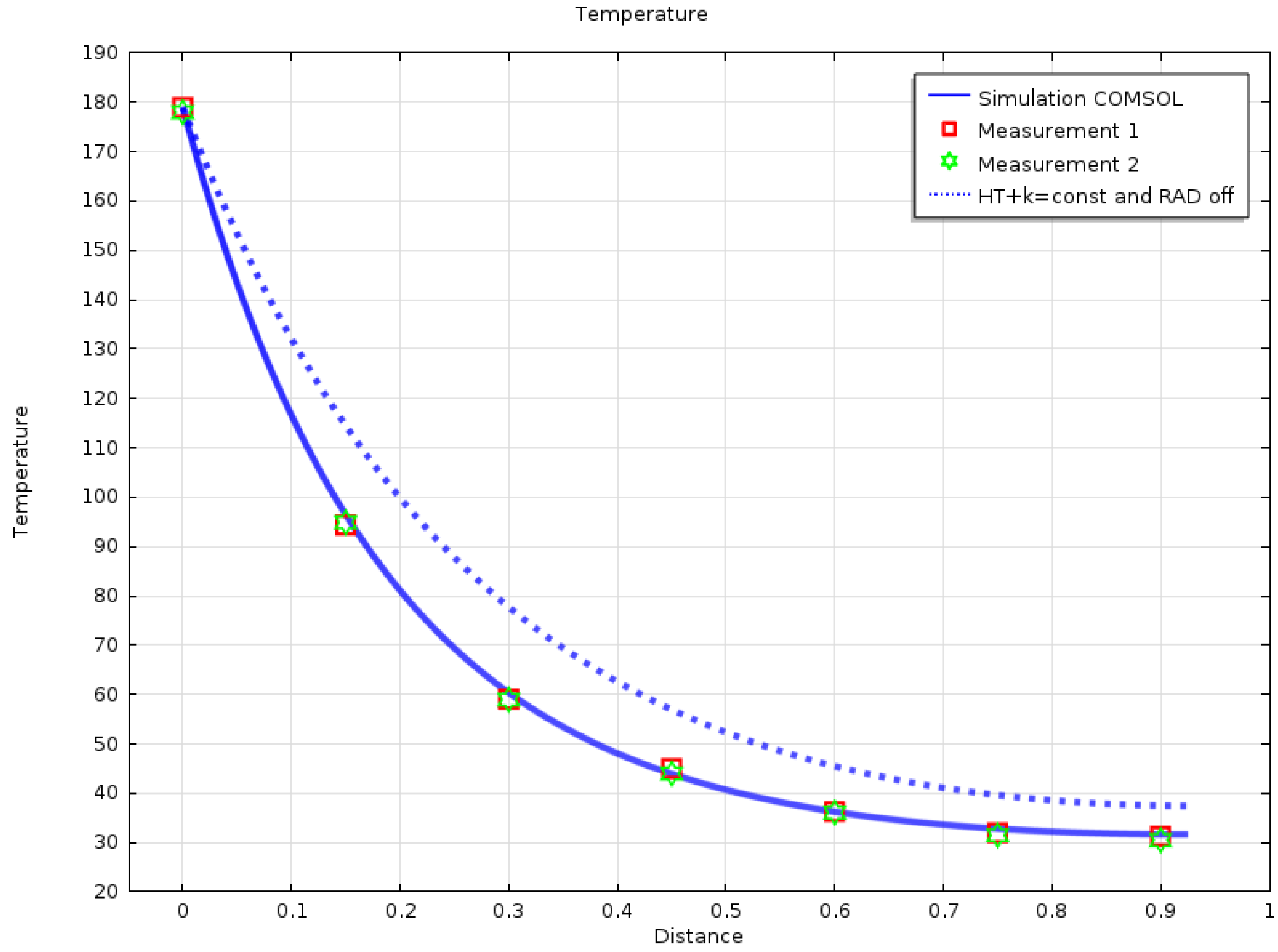


- Taking the λ[W/mK], h[W/m^{2}K] and ε[1], results in:

Simulations and measurement



Heat tranfer and conduction constant Radiation off

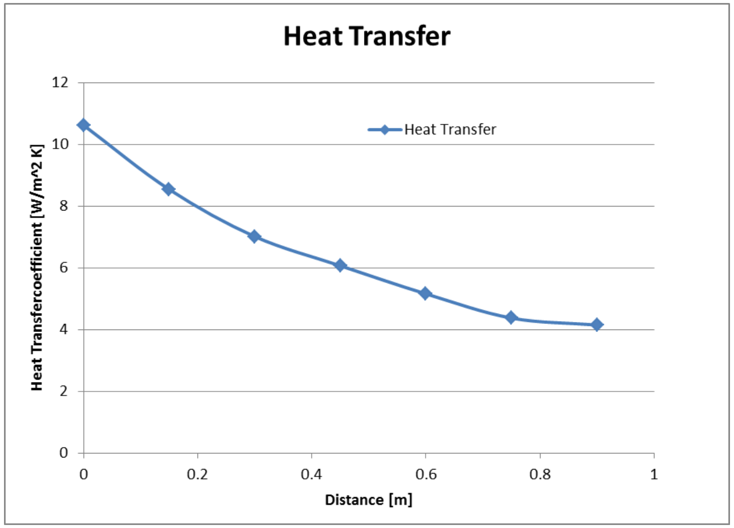


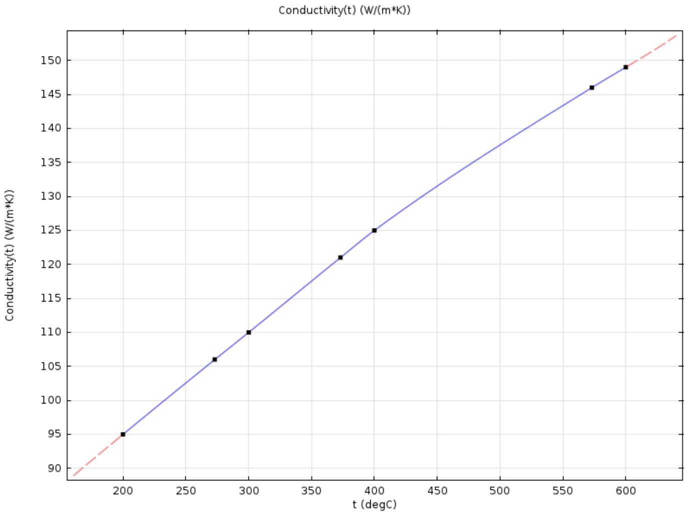
Some comments on the measurements

- The rod is heated and it takes approx. 1 ½ hour to stabilize the temperature.
- During this time the experiment should stay in a room without any extra movement of air. Such as people passing by the experimental setup.
- The temperature is logged with thermo couples.
- Deviation measurements/simulation < 4%

Summary of the physics involved

- The convection is dependent on the surface temperature of the rod.
- The epsilon is approx 0.6-0.65, fits well with literature of oxidized brass.
- The heat conductivity of the brass varies with temperature





Conclusion

- This simulations seems to be simple.
  - The included physics is always a battle for students.
  - Is heat transfer changing? And also the conductivity changes!
  - Finally the accuracy is very high!
- Multiphysics can be simulated accurately, if one understand the underlying physics!