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Using Temperature Signals to Estimate Geometry Parameters in Fractured Geothermal Reservoirs

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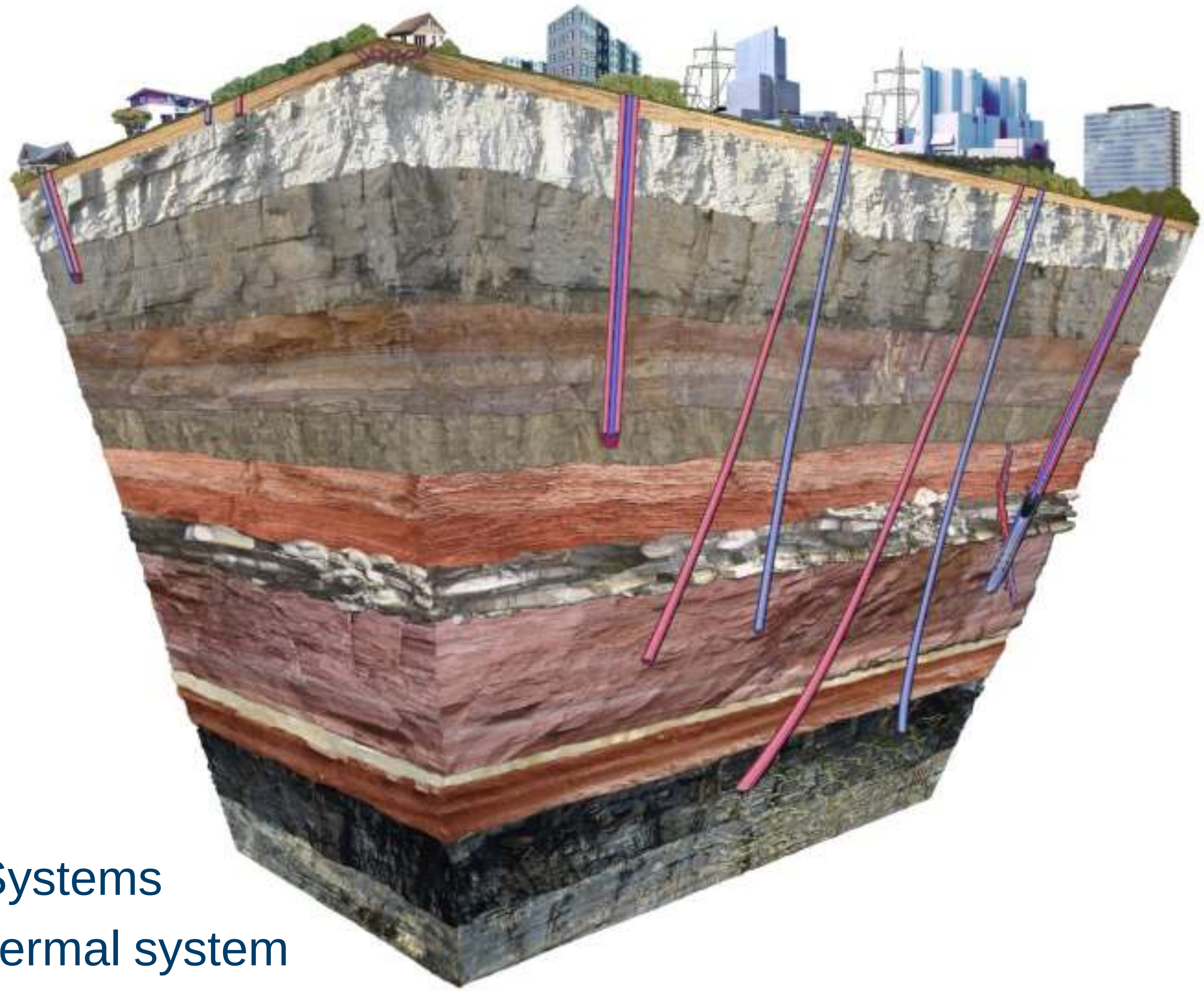
Objective



Deep Geothermal Systems
- Enhanced geothermal system
- Naturally fractured reservoirs


http://water.usgs.gov/nawqa/pubs/carbonate/design.html

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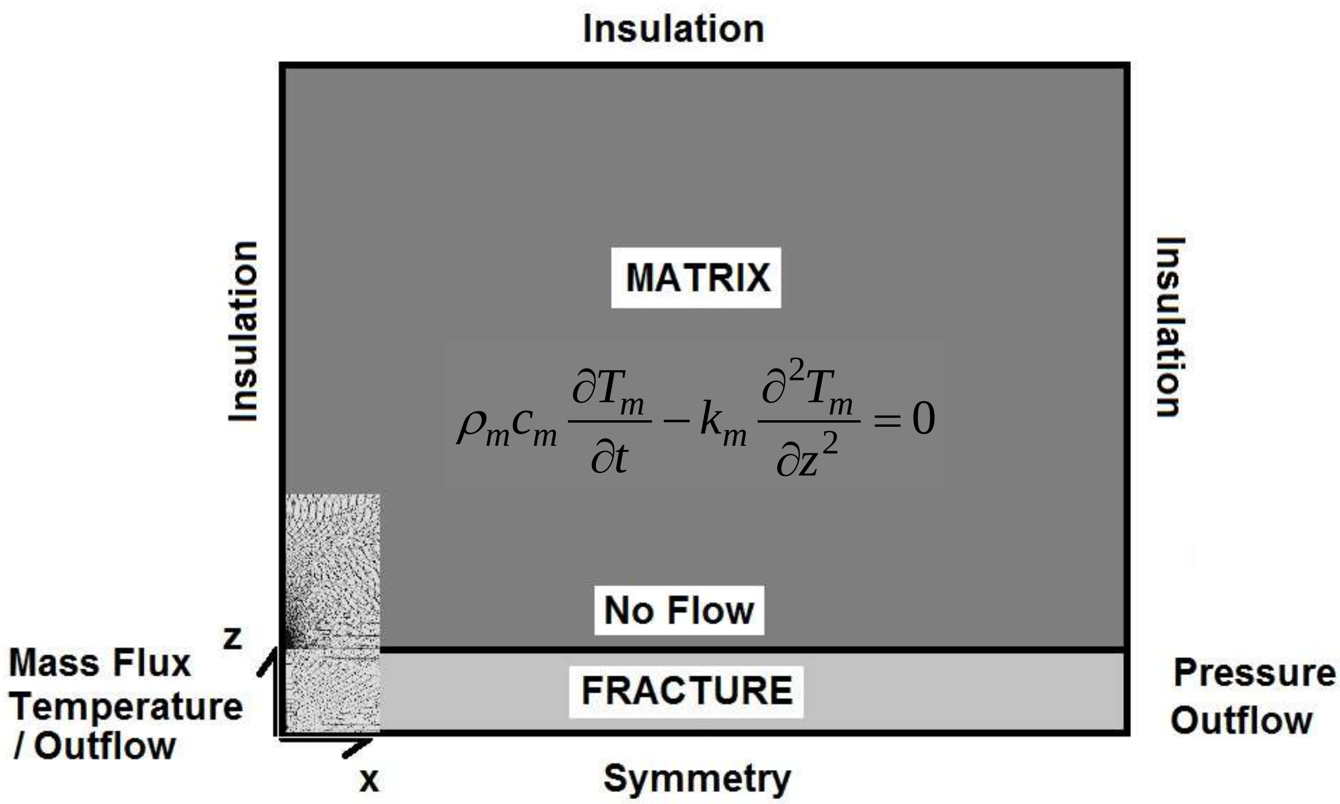
http://www.lkm.rub.de/mitarbeiter/vinci/borehole.bmp


http://public.bakerhughes.com/shalegas/fracturing.html

Idealized single fracture system



$$\rho_f c_f \frac{\partial T}{\partial t} \pm \rho_w c_w \phi u \frac{\partial T}{\partial x} - \frac{k_m}{b} \frac{\partial T_m}{\partial z} \Big]_{z=0} = 0$$

Analytical Solution

$$T_D = \int_0^{\min(1,\frac{t_n}{\lambda})} \left(\frac{\lambda^2 \sqrt{\alpha}\,\omega}{2(t_n - \lambda\omega)} + \lambda\sqrt{\alpha} \right) \frac{\exp\left(- \frac{\lambda^2 \alpha \omega^2}{4(t_n - \lambda\omega)} \right)}{\sqrt{\pi (t_n - \lambda\omega)}}\, erfc\left(\frac{\sqrt{\alpha}\,\omega}{2\sqrt{(1-\omega)}} \right) d\omega + \int_0^1 \int_0^{\min\left(1-\eta, \frac{t_n+\eta}{\lambda}\right)} \left(\frac{\lambda^2 \alpha\omega}{t_n + \eta - \lambda\omega} - \frac{\lambda\alpha\omega}{1-\eta-\omega} \right) \frac{\exp\left(\frac{-\alpha\omega^2}{4(1-\eta-\omega)} \right)}{\sqrt{\pi(1-\eta-\omega)}} \frac{\exp\left(\frac{-\lambda^2\alpha\omega^2}{4(t_n+\eta-\lambda\omega)} \right)}{2\sqrt{\pi(t_n+\eta-\lambda\omega)}}\, d\omega\, d\eta$$

$$\alpha = \frac{\rho_R c_R k}{(\rho c)^2} \frac{t_i}{b^2}$$

Implementation in Comsol 1

- Model setup
  - Boundaries are assumptions
  - Alpha dependend adjustment of model domain
  - Boundary mesh at the inlet and the fracture/matrix interface

- Numerical bottleneck
  - Step input of the Temperature
  - High resolution in space and time

- Cell peclet number

$$Pe_{cell} = \frac{\Delta l}{\alpha}$$

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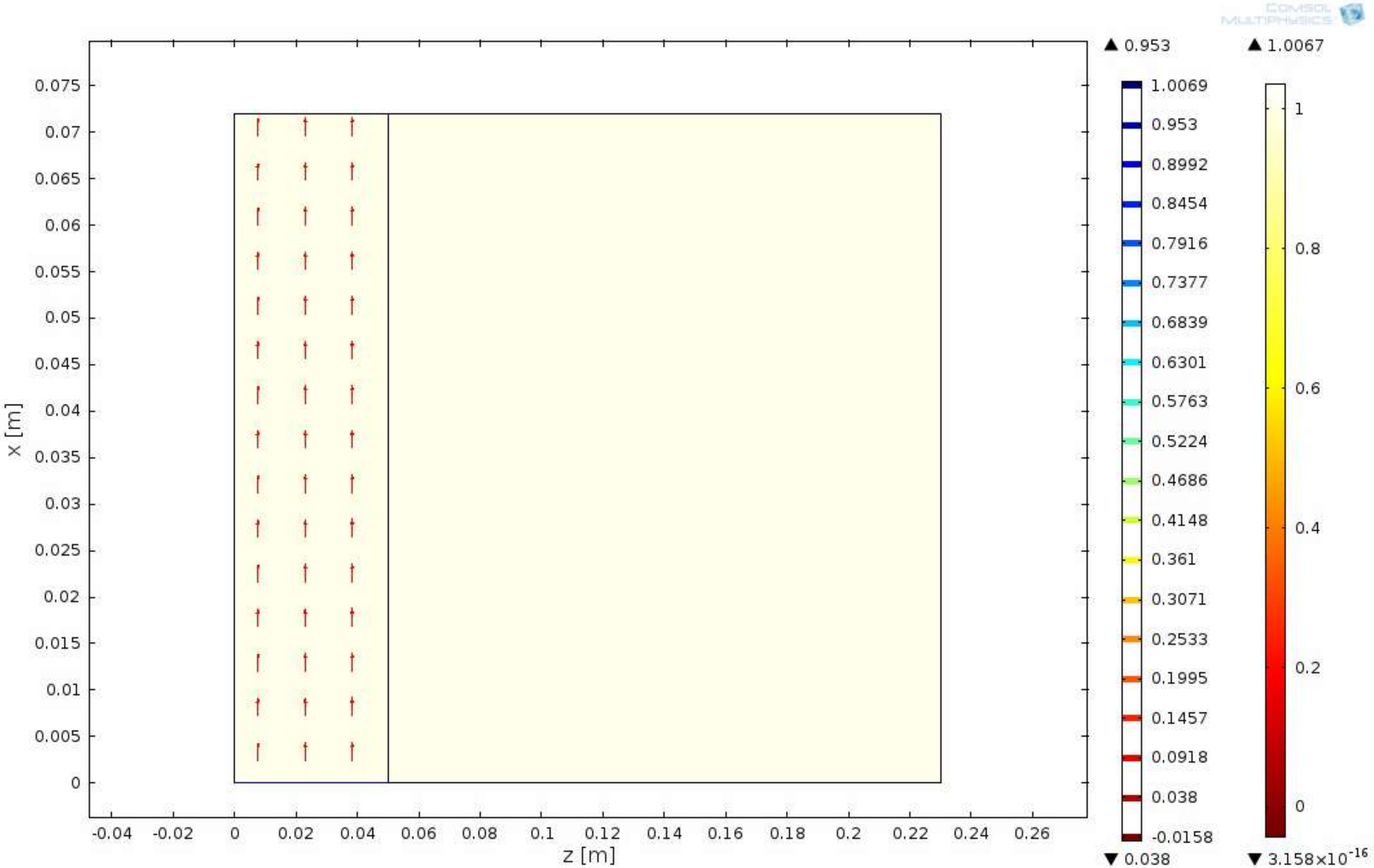
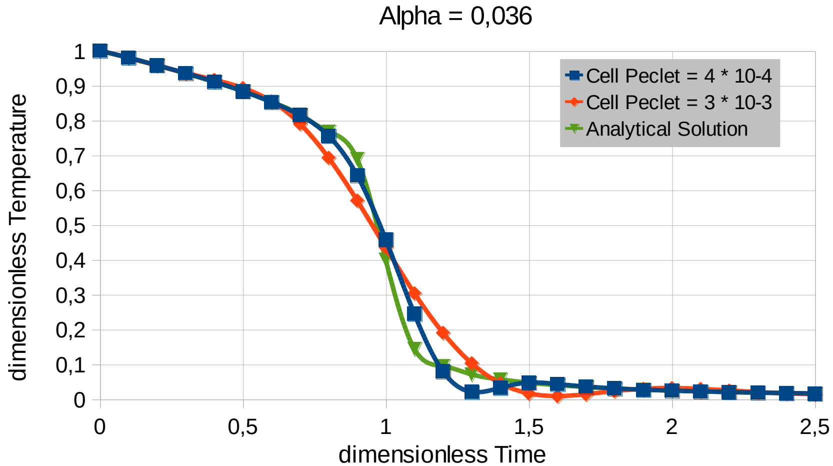
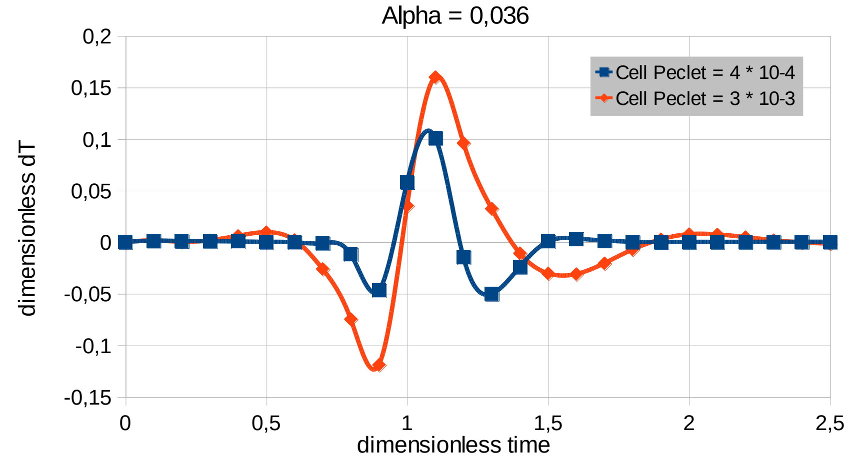
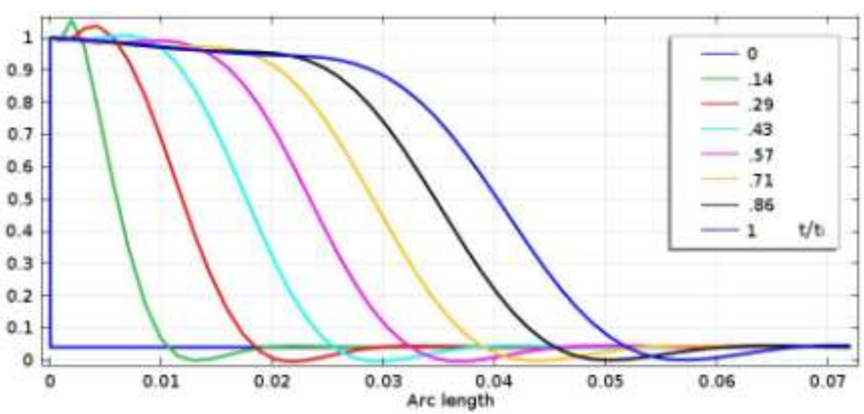
Implementation in Comsol 2

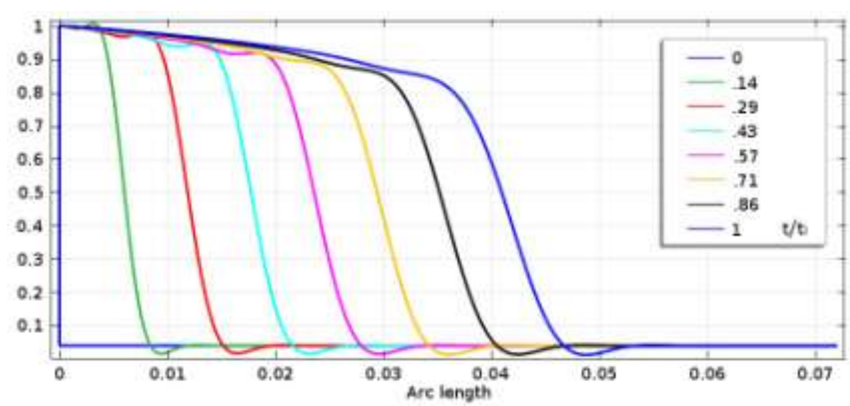


Results 1


Alpha = 0,036
dimensionless Temperature
dimensionless Time
Cell Peclet = 4 * 10-4
Cell Peclet = 3 * 10-3
Analytical Solution


Alpha = 0,036
dimensionless dT
dimensionless time
Cell Peclet = 4 * 10-4
Cell Peclet = 3 * 10-3


Arc length
0
.14
.29
.43
.57
.71
.86
1
t/t₀


Arc length
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.14
.29
.43
.57
.71
.86
1
t/t₀

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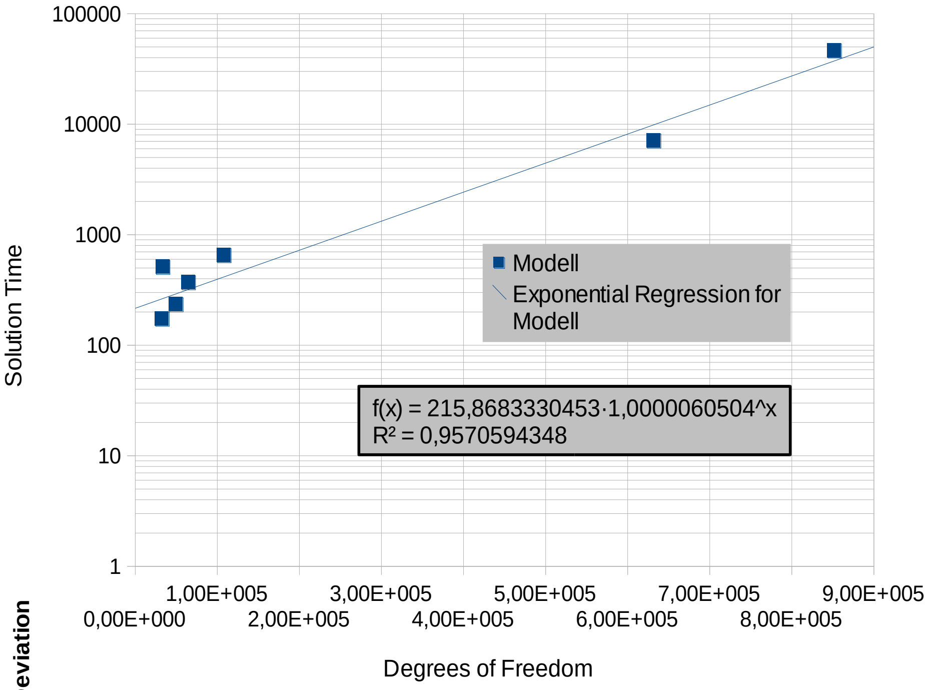
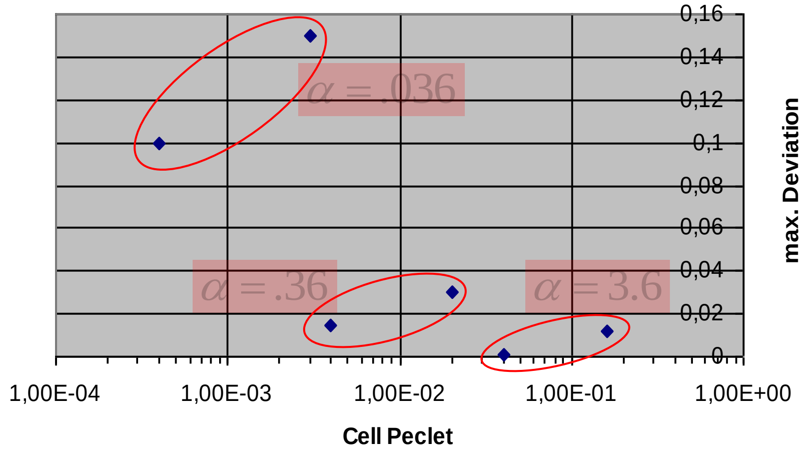
Results 2

- Exponential increase of computational time with DOF
- Deviation increase with deacreasing alpha





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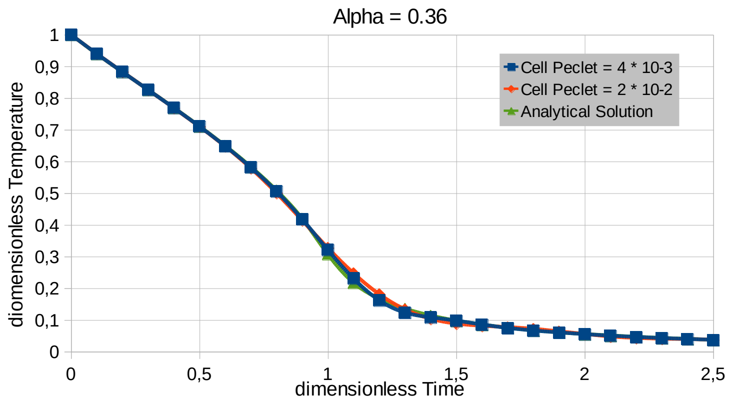
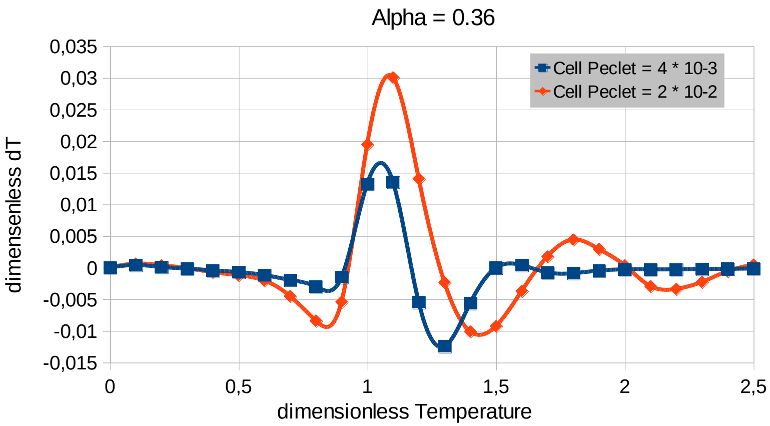
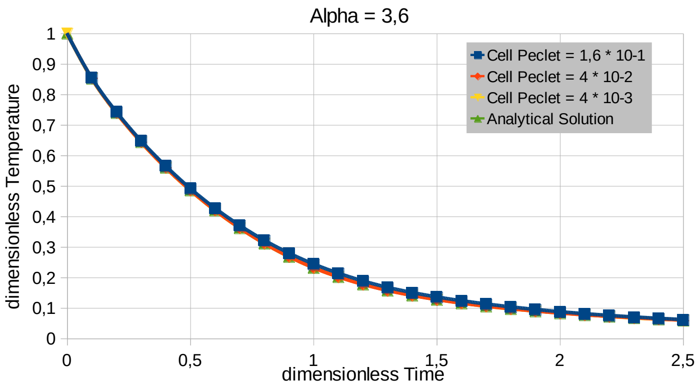
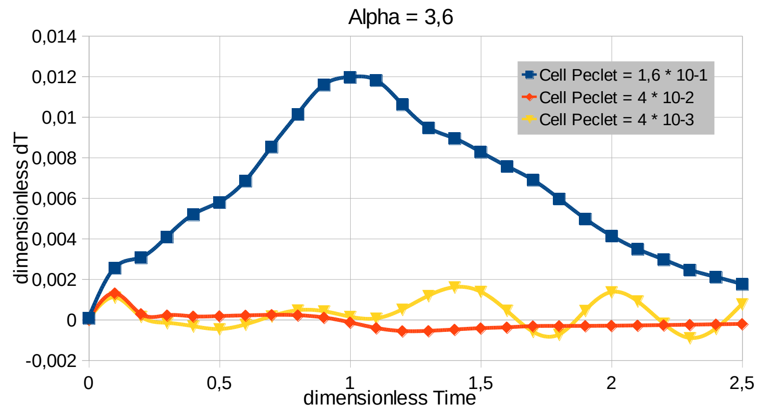
Results 3

$$\alpha \propto t_i$$





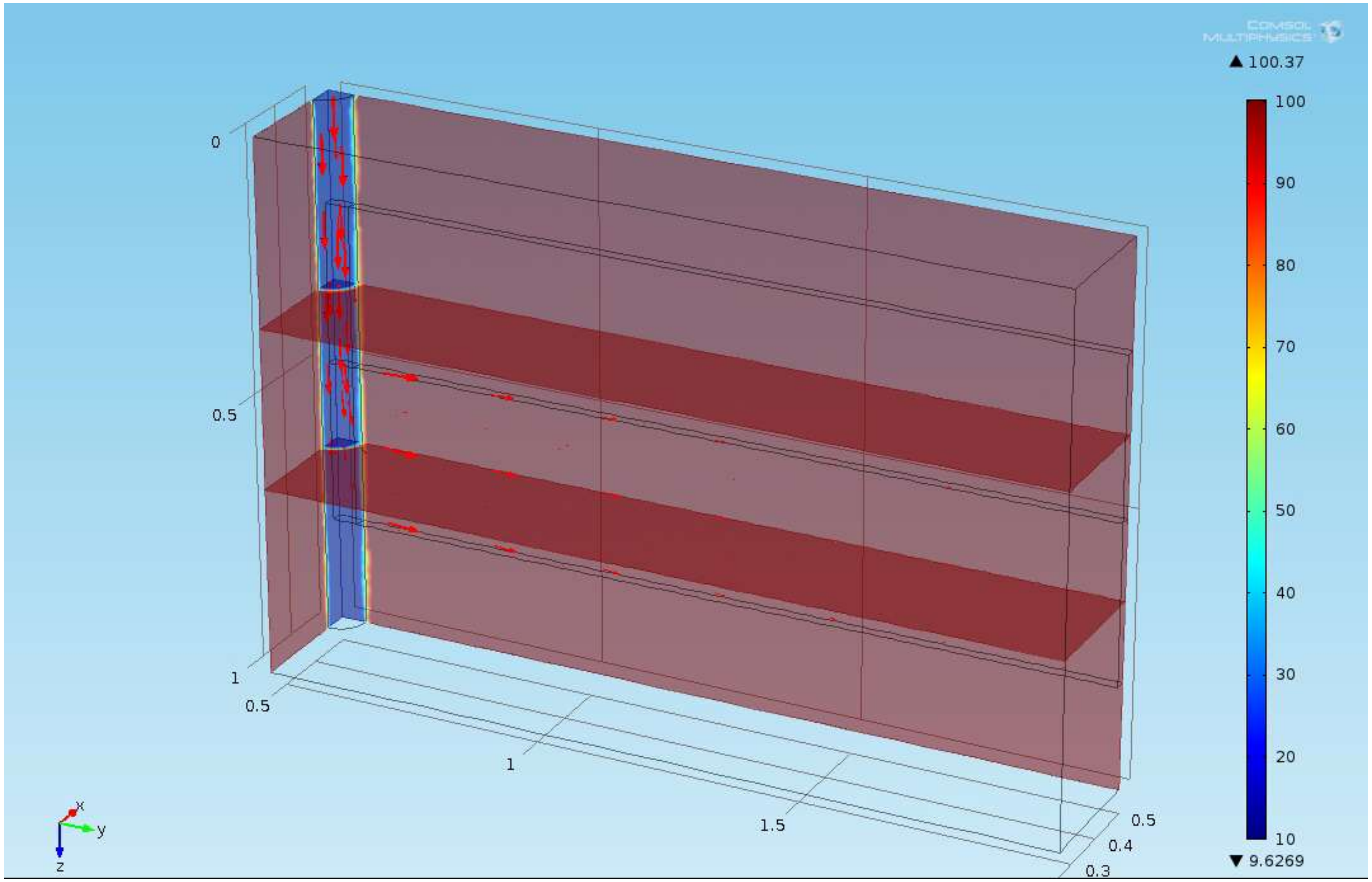




Conclusions

- Dependency error vs. cell peclet vs. alpha
- Data around the front is most heavily biased
- Computational power limits the resolution of the advancing temperature front

Outlook


COMSOL MULTIPHYSICS
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60
50
40
30
20
10
▼ 9.6269
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1
0.5
1
1.5
0.5
0.4
0.3
x
y
z

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Thank you for your attention!

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