Comparison of Borehole Heat Exchangers (BHEs): State of the Art vs. Novel Design Approaches

Phillip Oberdorfer
Georg-August-University Göttingen

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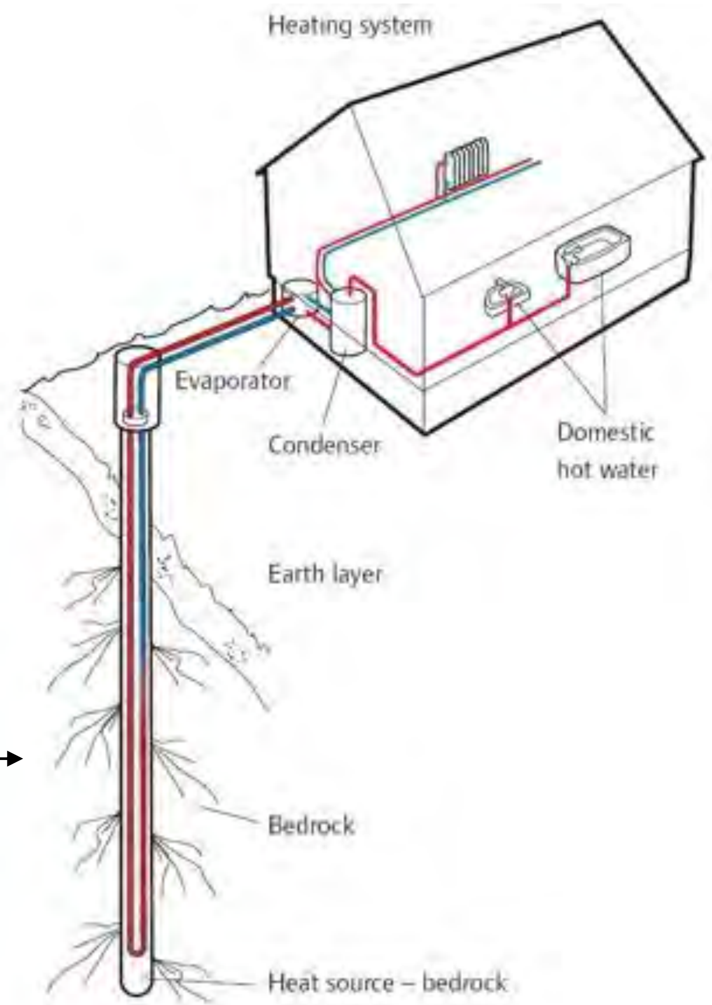
Geothermal Heat Production in Low Depth

- Sustainable power source
- Heat is used for direct application

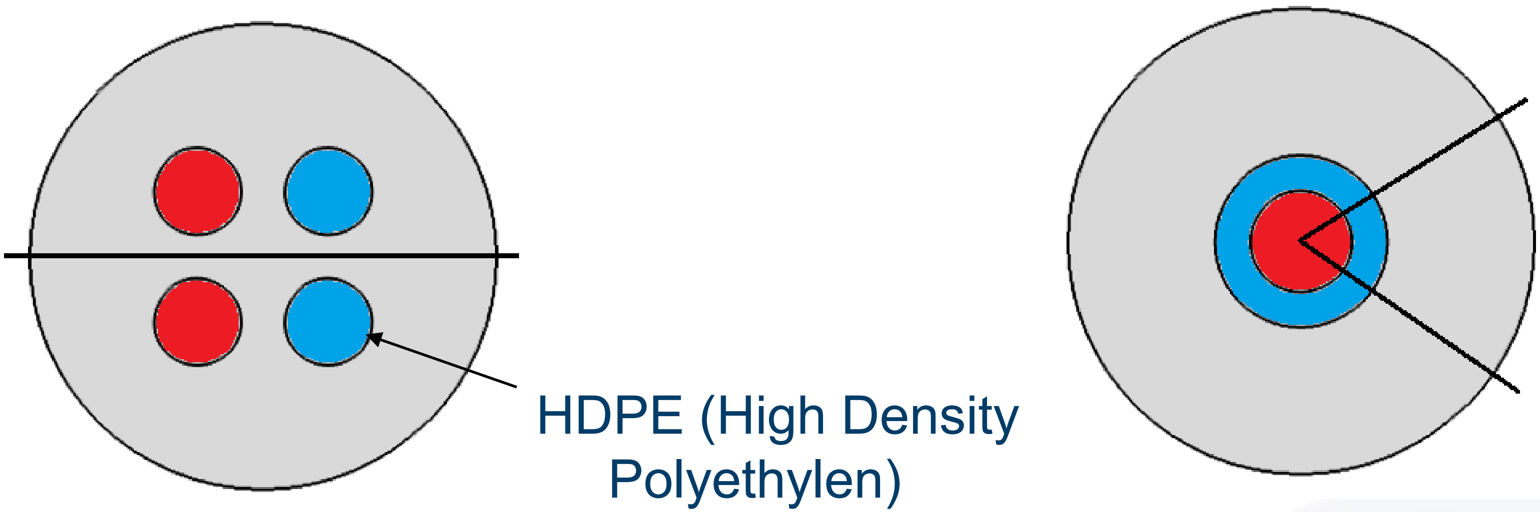
- Subsurface temperature distribution: 10m depth → 10°C
- Geothermal gradient ≈ 0.03°C/m
- Depth: ≈100m

- Ground-coupled heat exchange done by borehole heat exchangers (BHEs)
- Efficiency of heat exchange depends on ambient parameters and BHE-design



from: http://www.uponor.co.uk

Types of BHEs: Common Designs



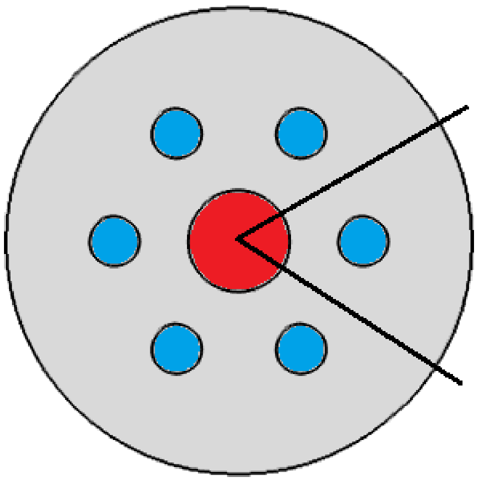
Double U-Pipe

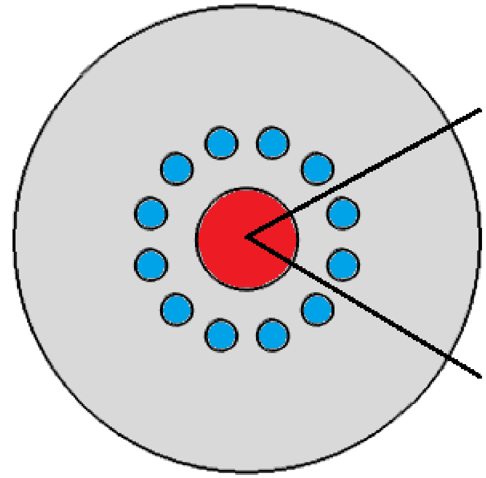
- most common design
- two downward pipes leading in two upward pipes

Coaxial Pipe

- centered downward pipe
- embedded in the upward pipe

Types of BHEs: Novel Designs





Terra$_6$ Pipe (Terra Umweltsonde)

- Centered downward pipe (isolated)
- Surrounded by six upward pipes

Terra$_{12}$ Pipe

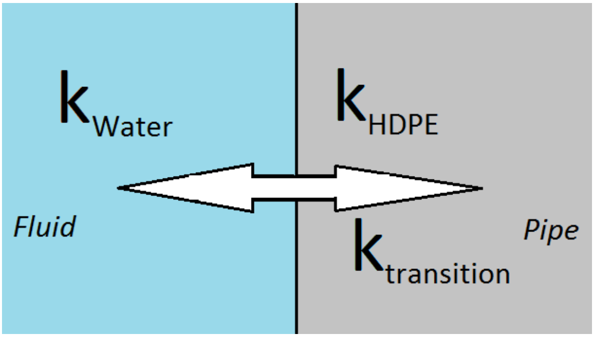
- Centered downward pipe (isolated)
- Surrounded by twelve upward pipes

Heat Transfer in BHEs

- Thickness-Length-Ratio: ≈1/1000

→ Flow in Pipe incomputable

- Solution: Calculate heat exchange between pipe and fluid manually



- Effective conductivity:

$$k_{1,eff}^{-1} = k_{HDPE}^{-1} + k_{transition}^{-1} = \frac{1}{h \cdot r_i \cdot \log\left(\frac{r_o}{r_i}\right)} + \frac{1}{k_{HDPE}}$$

- Convection coefficient:

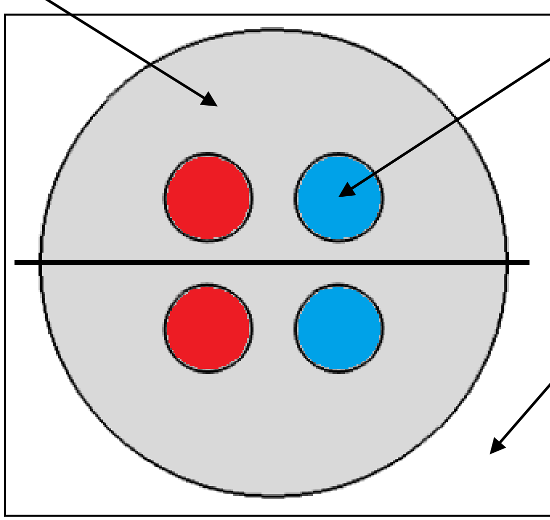
$$h = \frac{Nu \cdot k_w}{r_i}$$

- Churchill-Bernstein-Correlation:

$$Nu = 0.3 + \frac{0.62\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}}{\left(1 + (0.4/\mathrm{Pr})^{2/3}\right)^{1/4}} + \left(1 + \left(\frac{\mathrm{Re}}{28200}\right)^{5/8}\right)^{4/5}$$

Parameters

Properties of Grout		
Therm. Conductivity	k_{grout}	$2\,[W/(m\cdot K)]$
Density	ρ_{grout}	$1680\,[kg/m^3]$
Spec. Heat Capacity	$c_{p,grout}$	$730[J/(kg\cdot K)]$

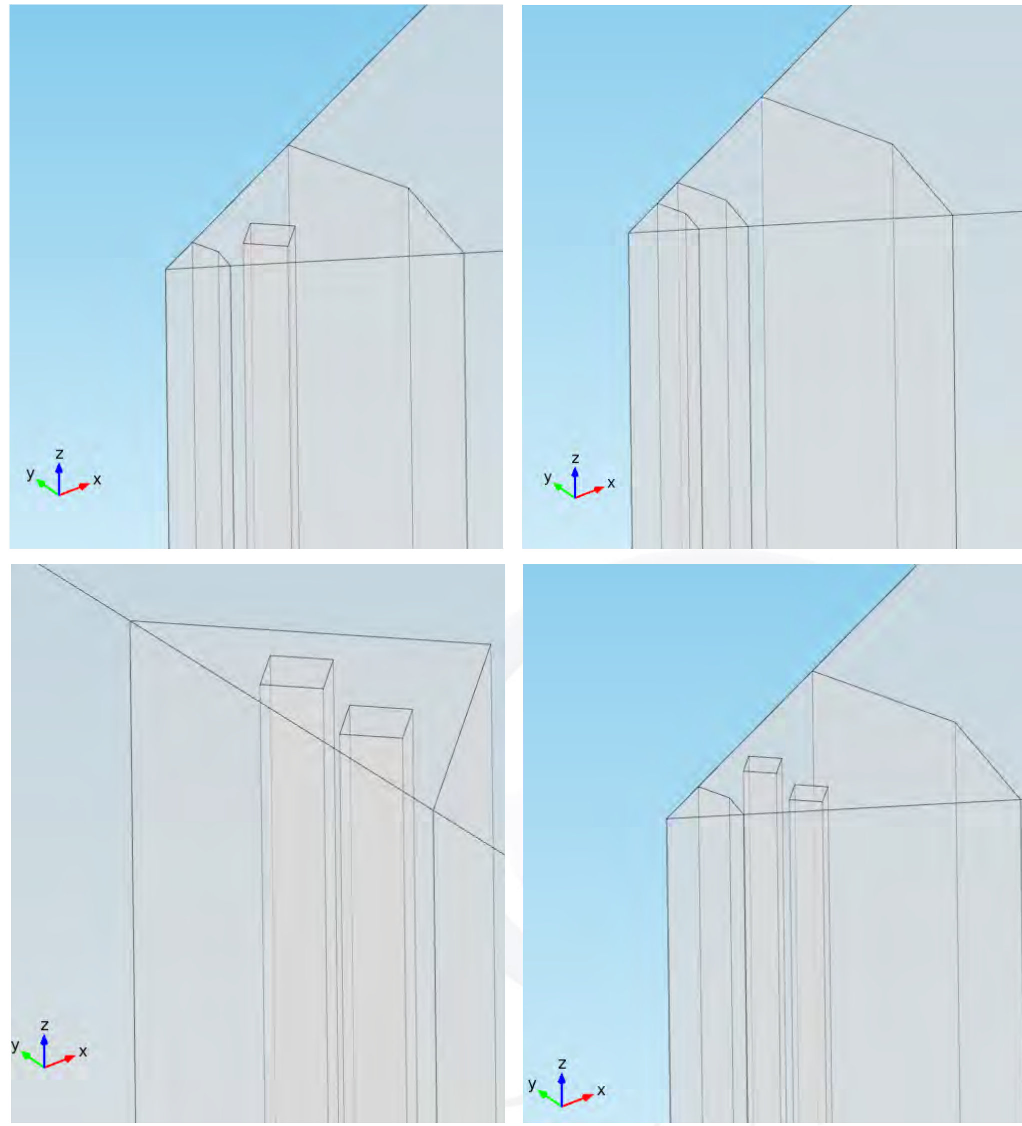


Properties of HDPE-BHEs		
Double U	type	$32x2.9\,[mm]$
Coaxial (out)		$63x3.8\,[mm]$
$Terra_6$ (out)		$20x2\,[mm]$
$Terra_{12}$ (out)		$14x2\,[mm]$
$Terra_{6,12}$, Coaxial (in)		$40x3.7\,[mm]$
Pipe length	l	$70\,[m]$
Therm. Conductivity	k_{HDPE}	$0.4[W/(m\cdot K)]$
Therm. Cond. Isolated Pipe	k_{iso}	$0.04\,[W/(m\cdot K)]$

Properties of Ground		
Volume fraction	θ_s	0.75
Eff. thermal conductivity	$k_{2,eff}$	$2\,[W/(m\cdot K)]$
Eff. Density	ρ_{eff}	$2000[kg/m^3]$
Eff. Spec. Heat Capacity	$c_{p,eff}$	$1000[J/(kg\cdot K]$

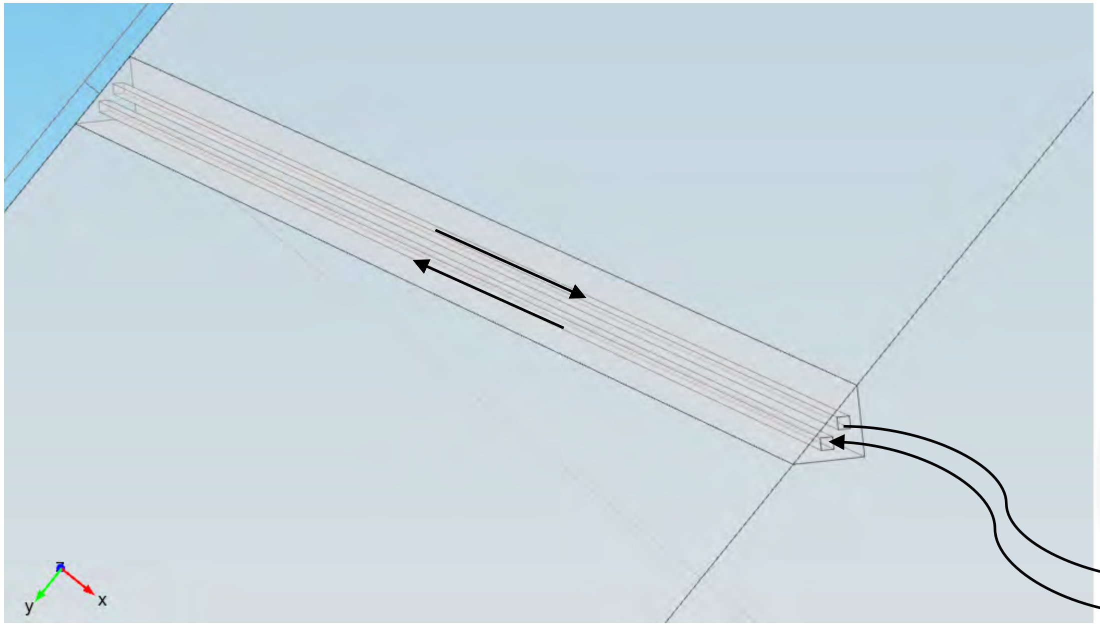
Model Set-Up in COMSOL Multiphysics®

- 3D-transient models
- Geometry: Use of symmetry planes
- Physical Modes: Heat transfer in fluids, solids and porous media
- BC: Geothermal Gradient, T_{in}=0°C
- Mesh: Manually meshed using free triangles on top and sweeping method to bottom



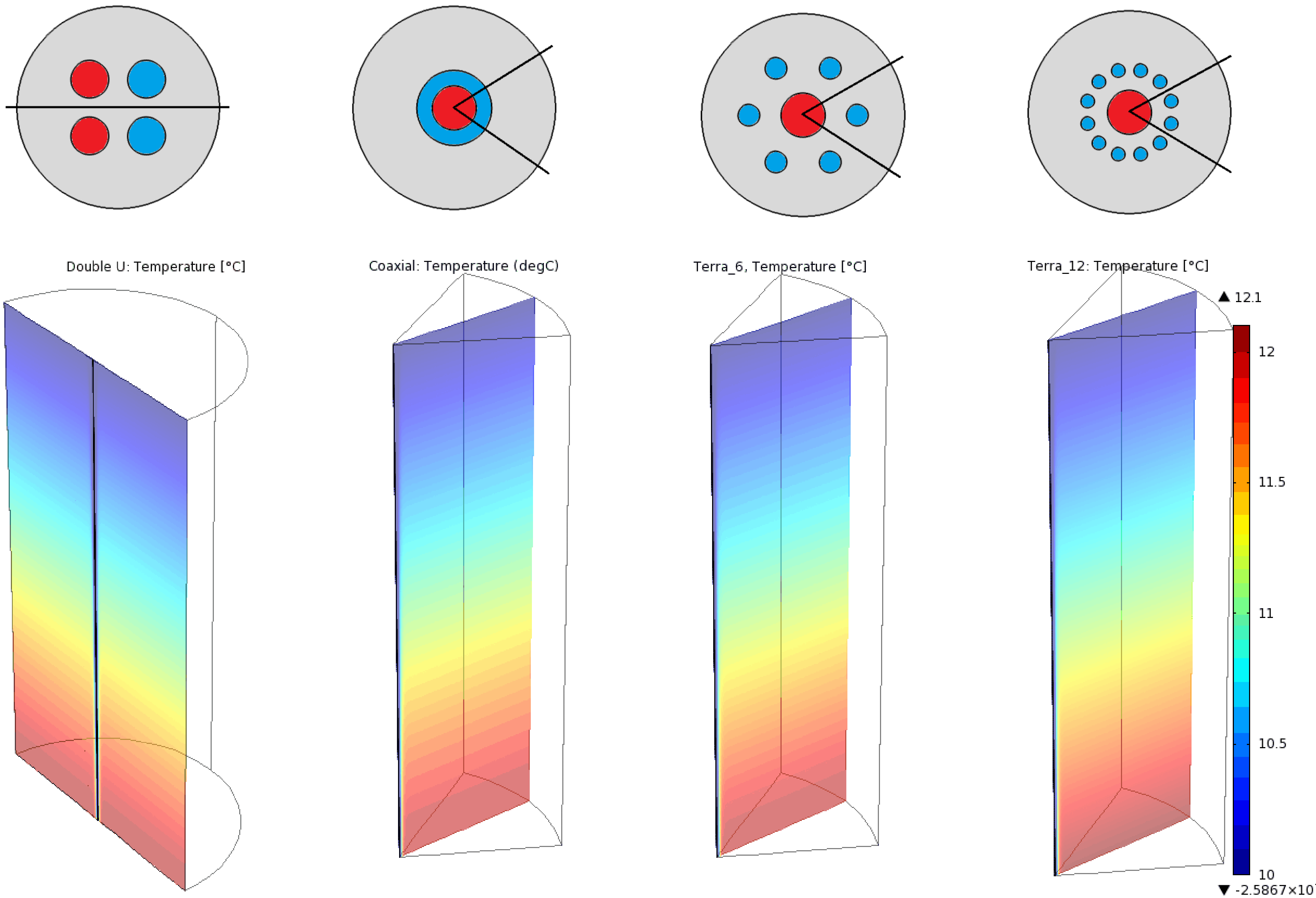
Model Set-Up in COMSOL Multiphysics®

- Reversal point: End of Geometry, temperature outflow
- Mean outflow temperature is measured and set as BC for reinjection

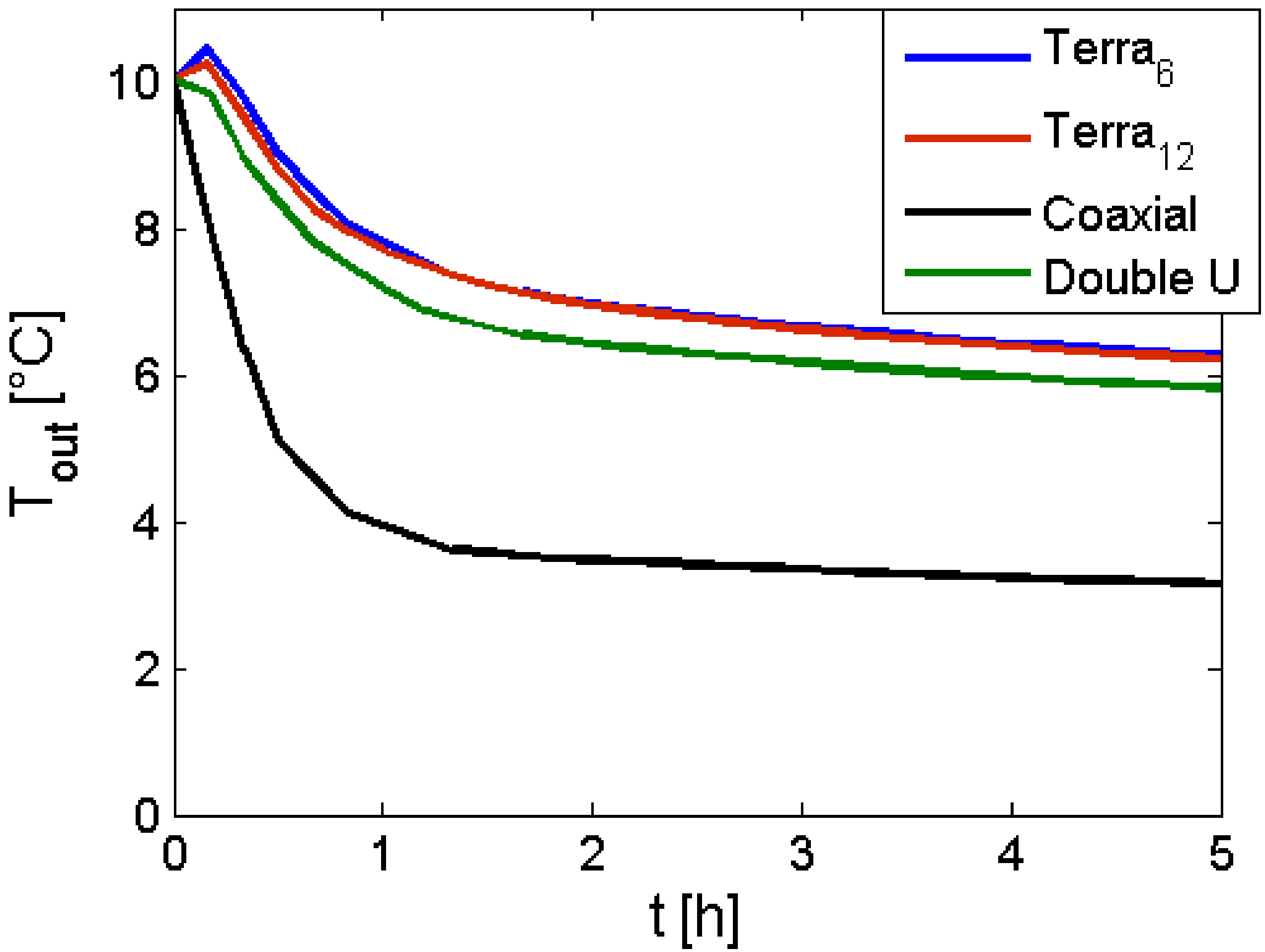


$$\overline{T}_{in} \equiv \overline{T}_{out}$$

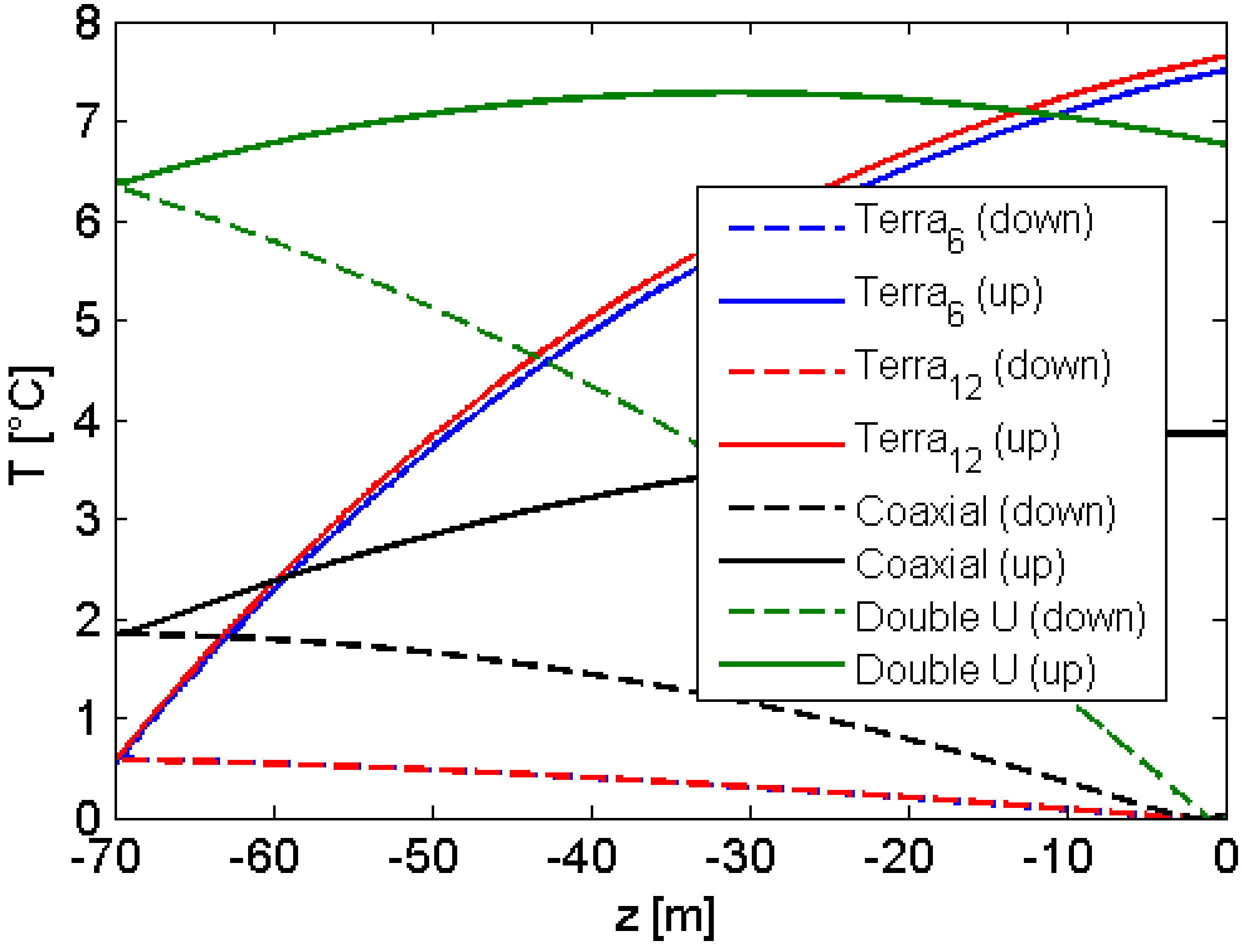
Results


Double U: Temperature [°C]
Coaxial: Temperature (degC)
Terra_6, Temperature [°C]
Terra_12: Temperature [°C]
▲ 12.1
12
11.5
11
10.5
10
▼ -2.5867×10^-3

Results: Outflow Temperature

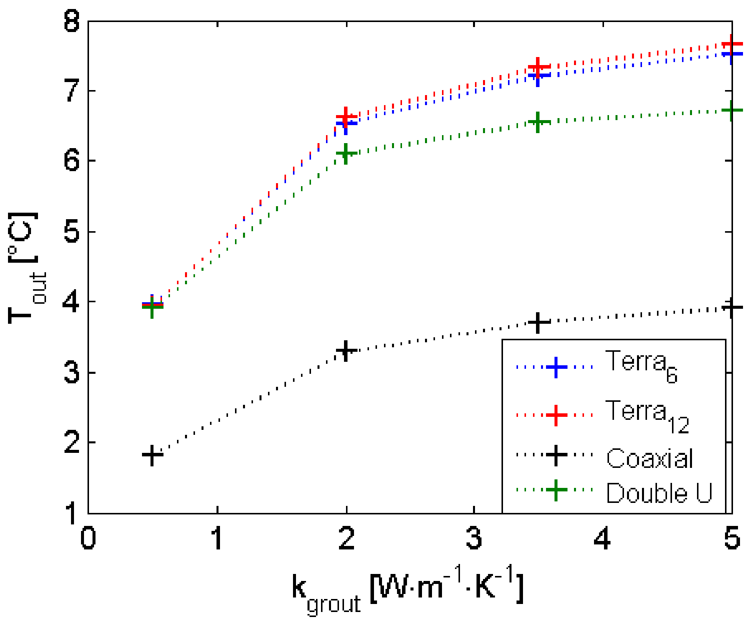


Results: Inner Heat Distribution

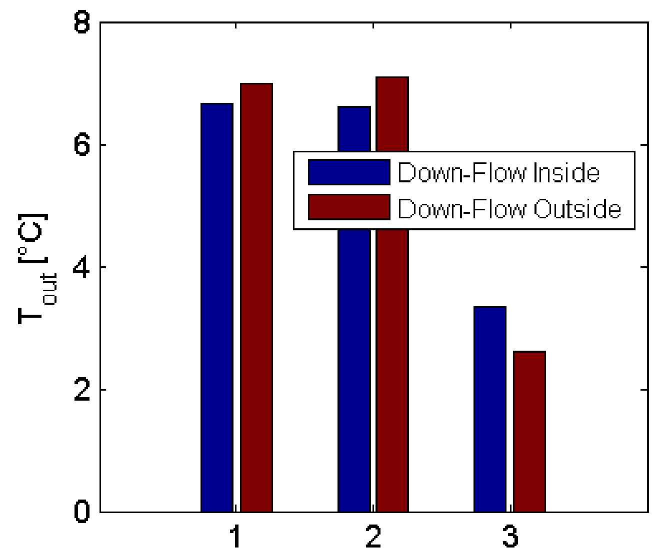


Results: Thermal Conductivity of Grout and Influence of Flow Direction

Influence of Th. Cond. Of Grout



Influence of Flow Direction



1: Terra$_6$, 2: Terra$_{12}$, 3: Coaxial

Conclusions and Lookout

- COMSOL Multiphysics works on long and thin geometries
- The comparison of different BHEs shows: There can be improvements achieved by design change and flow direction changes

- Further working indented: Adding porous media flow for more realistic models could change long-time behavior
- Field data verification of the models within our Project (GeoSolarWP)
- Use models for BHE field simulation

Thank you for your attention!

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