Flow123d tutorial 5 – “Heat transport”

Contents

1 Description

The task is inspired by the hot-dry-rock method of geothermal heat exchanger. The exchanger should be in progress for 30 years and give the power of 25 MW.

The user will learn how to:

- Set up heat transfer model;
- Use transition parameters at interfaces;
- Specify linear algebra solver.

2 Input

2.1 Geometry

We consider a two-dimensional model 5000 × 5000 m with two vertical wells at the distance of 3000 m. The wells are 4300 m deep with the diameter approx. 11 cm (Figure 1). In order to better capture the 3D nature of the problem, we set `cross_section` (width) of the rock region to 100 m (the value was gained from calibration), and the cross section of the wells to 0.04 m^2.

Parameter	Value
Model width	5000 m
Model depth	5000 m
Depth of heat exchanger	4100 – 4300 m
Distance of wells	3000 m

Parameter	Value
Depth of wells	4200 m
Model cross section	100 m
Well cross section	0.04 m^2

Table 1: Geometrical parameters.

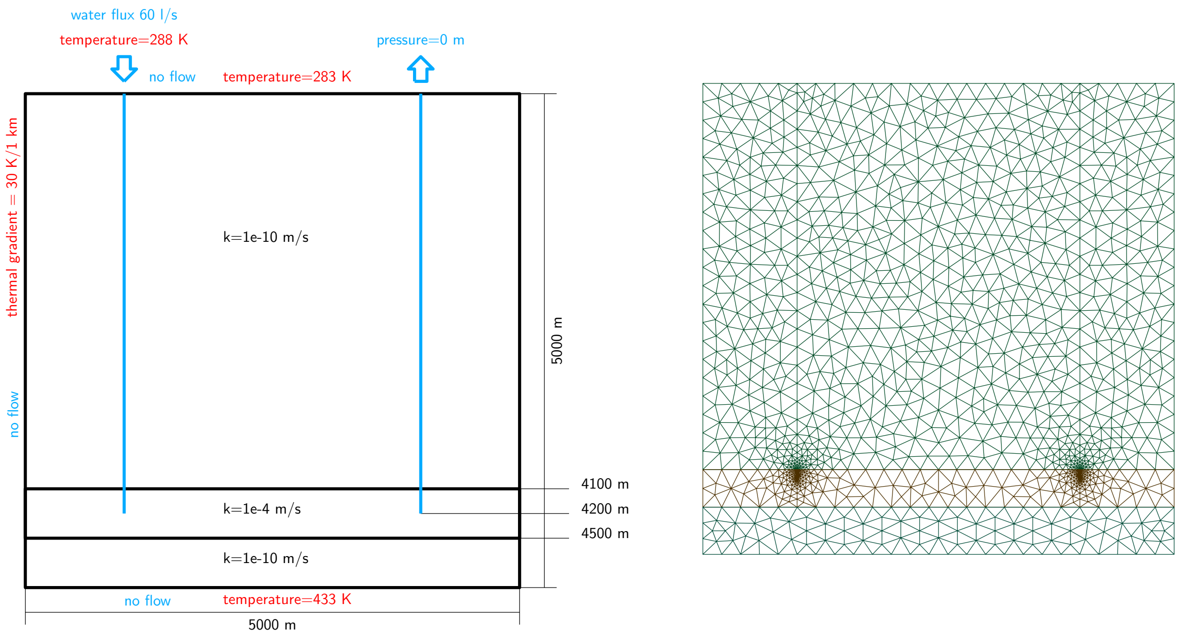

Figure 1: Geometry, boundary conditions and computational mesh.

2.2 Hydraulic model

The hydraulic conductivity was set to 1×10^{-10} m/s for the rock and to 1×10^{-4} m/s for the exchanger zone.

```
- region: rock
  cross_section: 100
  conductivity: 1.0e-10
- region: exchanger
  conductivity: 1e-4
```

The flow in the wells is modelled using the Darcy equation with a high hydraulic conductivity (10 m/s). The transition coefficient `sigma` [–], determines the rate of exchange between 2D rock and 1D wells. Its default value 1 is kept at the lower well ends, elsewhere the wells are isolated and hence we set `sigma` to zero.

```
- region: wells
  conductivity: 10.0
  cross_section: 0.04
```

```
    sigma: 0
  - region: wells_deep
    sigma: 1
```

On the injection well (".well1_surface"), we prescribe the flux 60 l/s, i.e. the flux velocity is 1.5 m/s. On the production well (".well2_surface") we prescribe zero pressure.

```
  - region: .well1_surface
    bc_type: total_flux
    bc_flux: 1.5
  - region: .well2_surface
    bc_type: dirichlet
    bc_pressure: 0
```

We assume that the system does not have contact with its surrounding because of high depth and intact granite massive. Hence no flow boundary conditions are given on the sides, on the bottom and on the surface.

For the solution of the flow problem we choose the LU decomposition as the linear algebra solver:

```
  nonlinear_solver:
    linear_solver: !Petsc
      options: -ksp_type preonly -pc_type lu
```

2.3 Heat transport model

The heat transport model (`Heat_AdvectionDiffusion_DG`) assumes that the fluid and solid phase are at thermal equilibrium. For the whole model (`- region:  ALL`) we prescribe the parameters for water and granite (density, thermal conductivity and capacity):

```
  heat_equation: !Heat_AdvectionDiffusion_DG
    balance:
      cumulative: true
    input_fields:
      - region: ALL
        fluid_density: 1000.0
        fluid_heat_capacity: 4000
        fluid_heat_conductivity: 0.5
        solid_density: 2700.0
        solid_heat_capacity: 790
        solid_heat_conductivity: 2.5
```

The temperature on the surface is set to 283 K (=10°C):

```
  - region: .surface
    bc_type: dirichlet
    bc_temperature: !FieldFormula
      value: 10+273.15
```

The injected water has temperature 15°C:

```
  - region: .well1_surface
    bc_type: dirichlet
    bc_temperature: !FieldFormula
      value: 15+273.15
```

The temperature on the bottom and sides as well as the initial temperature in the rock and the wells is then prescribed in agreement with typical geological gradient, approx. 1°C / 33 m:

```
    init_temperature: !FieldFormula
      value: 10-z/5000*150+273.15
```

The porosity was set to 1×10^{-5} for rock and 1×10^{-4} for exchanger. The transition coefficient of wells ("fracture_sigma") was set to 0 in rock surrounding and to 1 in deep surrounding:

```
  - region: wells
    init_temperature: !FieldFormula
      value: 15-z/5000*150+273.15
    porosity: 1.0e-05
    fracture_sigma: 0
  - region: wells_deep
    fracture_sigma: 1
```

3 Results

The evolution of power of the heat exchanger (difference of absolute energy flux on the surface of the two wells) is depicted in Figure 2. The result of water flow is depicted in Figure 3 and the temperature field of the whole massif after 30 years is depicted in Figure 4.

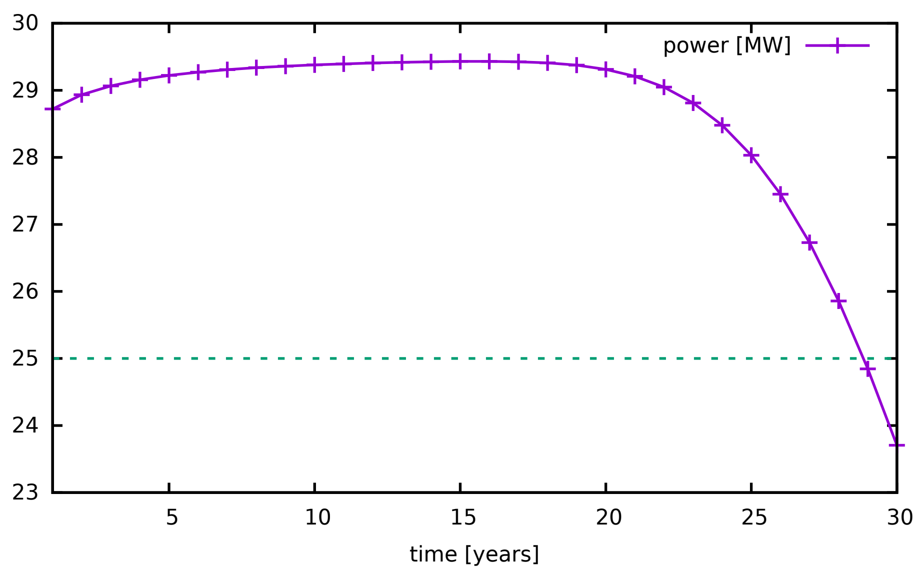

Figure 2: The power of heat exchanger system in 30 years.

```
flow123d_version: 1.8.9
problem: !Coupling_Sequential
```

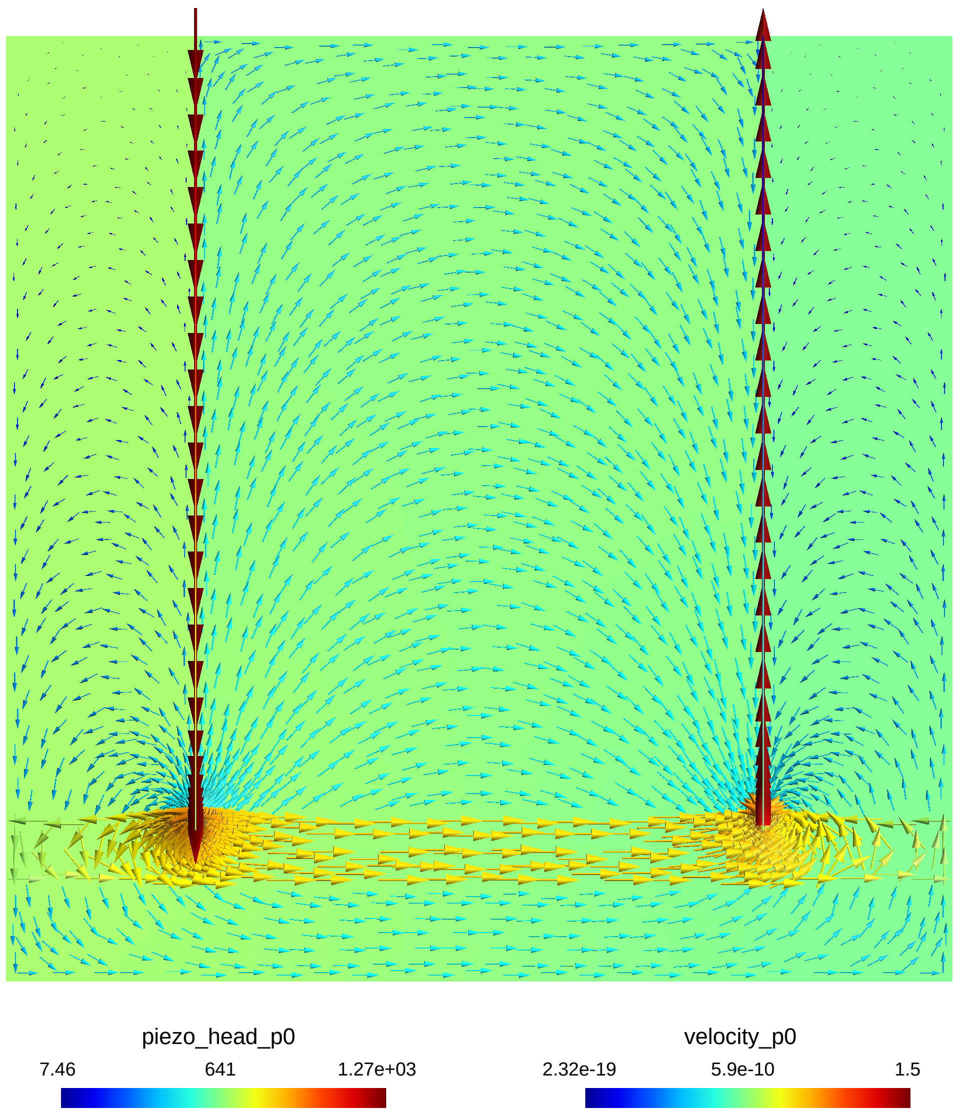

Figure 3: The flux field with piezometric head.

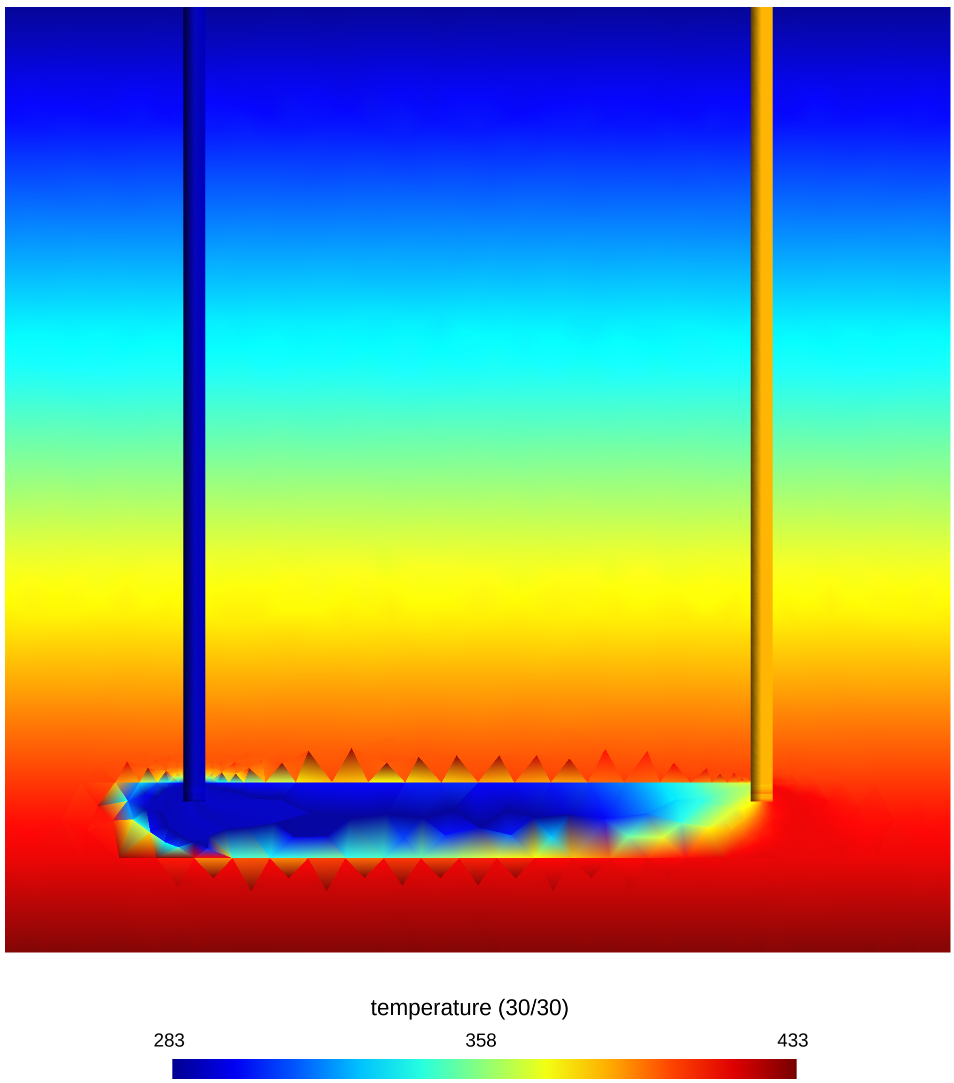

Figure 4: The temperature of exchanger after 30 years.

```
description: "Example 5 - Heat transport"
mesh:
  mesh_file: 05_mesh.msh
  regions:
    - !Union
      name: rock
      regions:
        - near_surface
        - exchanger
        - deep
    - !Union
      name: well1
      regions:
        - well1_surface
        - well1_middle
        - well1_deep
    - !Union
      name: well2
      regions:
        - well2_surface
        - well2_middle
        - well2_deep
    - !Union
      name: wells
      regions:
        - well1
        - well2
    - !Union
      name: wells_deep
      regions:
        - well1_deep
        - well2_deep
flow_equation: !Flow_Darcy_MH
  nonlinear_solver:
    linear_solver: !Petsc
      options: -ksp_type preonly -pc_type lu
  input_fields:
    - region: rock
      cross_section: 100
      conductivity: 1.0e-10
    - region: exchanger
      conductivity: 1e-4
    - region: wells
      conductivity: 10.0
      cross_section: 0.04
      sigma: 0
    - region: wells_deep
      sigma: 1
    - region: .well1_surface
      bc_type: total_flux
      bc_flux: 1.5
    - region: .well2_surface
      bc_type: dirichlet
      bc_pressure: 0
```

```
  balance: true
  output:
    output_stream:
      file: flow.msh
      format: !gmsh
        variant: ascii
    output_fields:
      - piezo_head_p0
      - velocity_p0
heat_equation: !Heat_AdvectionDiffusion_DG
  balance:
    cumulative: true
  input_fields:
    - region: ALL
      fluid_density: 1000.0
      fluid_heat_capacity: 4000
      fluid_heat_conductivity: 0.5
      solid_density: 2700.0
      solid_heat_capacity: 790
      solid_heat_conductivity: 2.5
    - region: rock
      init_temperature: !FieldFormula
        value: 10-z/5000*150+273.15
      porosity: 1.0e-05
    - region: exchanger
      porosity: 1.0e-05
    - region: wells
      init_temperature: !FieldFormula
        value: 15-z/5000*150+273.15
      porosity: 1.0e-05
      fracture_sigma: 0
    - region: wells_deep
      fracture_sigma: 1
    - region: .well1_surface
      bc_type: dirichlet
      bc_temperature: !FieldFormula
        value: 15+273.15
    - region: .deep
      bc_type: dirichlet
      bc_temperature: !FieldFormula
        value: 10-z/5000*150+273.15
    - region: .surface
      bc_type: dirichlet
      bc_temperature: !FieldFormula
        value: 10+273.15
    - region: .sides
      bc_type: dirichlet
      bc_temperature: !FieldFormula
        value: 10-z/5000*150+273.15
  output_stream:
    file: heat.msh
    format: !gmsh
      variant: ascii
    time_step: 31557600       # 1 yr
```

```
output_fields:
  - temperature
solver: !Petsc
  a_tol: 1.0e-14
  r_tol: 1.0e-14
time:
  end_time: 946728000       # 30 yr
```