Exercise 1

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Exercises

1. Heat transport
   - Heat diffusion with Dirichlet BC (Ex2.1)
   - Heat diffusion with Neumann BC (Ex2.2)

2. Heat transport + Groundwater flow
   - Heat advection in single fracture (Ex2.3)
   - Thermohaline flow (Ex2.4)

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Exercises
Session 1 – Heat Transport Processes

Heat Transport

- by conduction only
- by convection and conduction

For this session, you will need the following software:

OpenGeoSys

ogs.exe v.5.3.0
from ../software/ogs

Paraview

for result visualization
http://www.paraview.org/paraview/resources/software.php

A text Editor

e.g. Notepad++
http://notepad-plus-plus.org/download/v6.1.4.html

A Spreadsheet software

e.g. LibreOffice
http://www.libreoffice.org/download/

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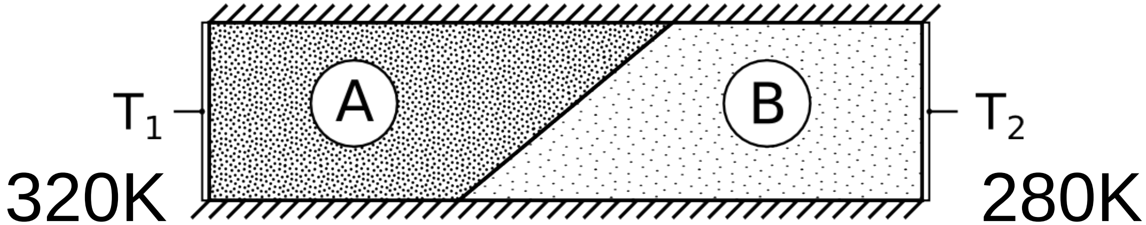
Exercises

Session 1 – Heat Transport Processes

Heat Transport Exercise 1



property	Copper Cu	Tin Sn
Thermal conductivity [W/m/K]	400	67

- Conduction of heat through a heterogeneous solid
- Thin stripes of two metals, soldered together
- Insulated at exposed edges
- Faces maintained at constant temp. T1 and T2

Input file description

1) Process definition - *.pcs file

```
#PROCESS
 $PCS_TYPE
  HEAT_TRANSPORT
 $BOUNDARY_CONDITION_OUTPUT
#STOP
```

Keyword begins a new block

Subkeyword defines the process

Optional; to check which nodes are assigned to boundary conditions

#STOP ends the reading process. Everything beyond this keyword will be ignored

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Input file description

1) Process definition - *.pcs file

Processes currently available (selection)

HEAT_TRANSPORT	T
LIQUID_FLOW	H
DEFORMATION	M
MASS_TRANSPORT	C
MULTIPHASE_FLOW	H^n
X_GLOBAL	
GROUNDWATER_FLOW	
RICHARDS_FLOW	
AIR_FLOW	
… and others	

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Input file description

2) Numerical characteristics - *.num file

```
#NUMERICS
 $PCS_TYPE
  HEAT_TRANSPORT
 $LINEAR_SOLVER
; mthd – er_mthd - er_tol - max_it - theta - precond - stor
  2       1      1.e-012   1000    0.5     100      4
#STOP
```

each process can have a different setup

Linear solver for constant material properties

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Input file description

3) Spatial discretization - *.msh file

```
#FEM_MSH
 $NODES
  751
0 0.127950587672957 .05  0.0
...
 $ELEMENTS
  1396
0 0 tri 0 1 21
...
#STOP
```

number of mesh nodes

node_ID | X | Y | Z

number of mesh elements

element_ID | mat_group | element_type | node[i]

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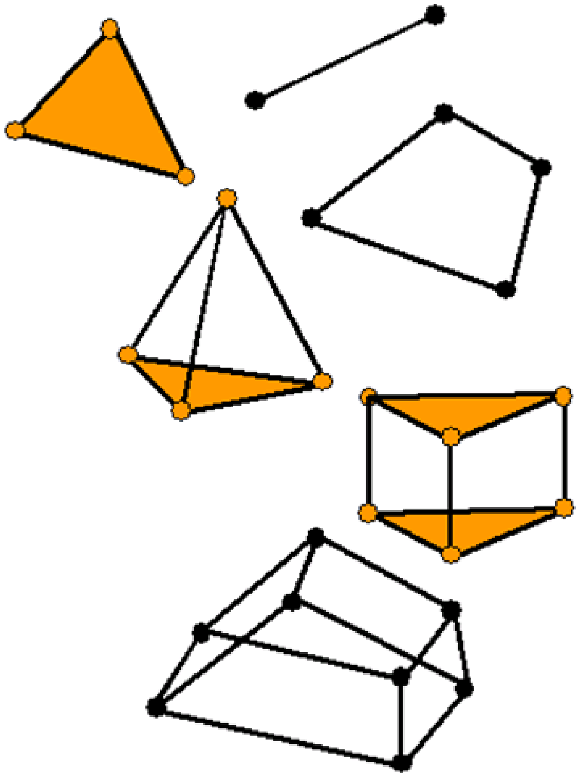
Input file description

3) Spatial discretization - *.msh file

Element types are:

1D Lines line
2D Triangles tri
2D Rectangles quad
3D Tetrahedra tet
3D Hexahedra hex



4) Geometry - *.gli file

```
#POINTS
0 0 0 0
1 0.07 0 0
2 0.13 0.05 0
3 0 0.05 0
#POLYLINE
 $NAME
  copper
 $POINTS
  0
  1
  2
  3
  0
#SURFACE
 $NAME
  copper
 $POLYLINES
  copper
 $TYPE
  0
```

Points, polylines and surfaces are assigned to the mesh to apply initial and boundary conditions

Polylines are defined by points

Surfaces are defined by polylines

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Input file description

5) Initial conditions - *.ic file

```
#INITIAL_CONDITION
 $PCS_TYPE
   HEAT_TRANSPORT
 $PRIMARY_VARIABLE
   TEMPERATURE1
 $GEO_TYPE
   DOMAIN
 $DIS_TYPE
   CONSTANT 300
#STOP
```

Initial conditions have to be defined for each process by its primary variable

GEO_TYPE refers to the model geometry

DIS_TYPE refers to distribution; an initial value can be defined as constant, linear gradient, or can be read from a datafile

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6) Boundary conditions - *.bc file

```
#BOUNDARY_CONDITION
 $PCS_TYPE
  HEAT_TRANSPORT
 $PRIMARY_VARIABLE
  TEMPERATURE1
 $GEO_TYPE
  POLYLINE left
 $DIS_TYPE
  CONSTANT 320
#BOUNDARY_CONDITION
 $PCS_TYPE
  HEAT_TRANSPORT
 $PRIMARY_VARIABLE
  TEMPERATURE1
 $GEO_TYPE
  POLYLINE right
 $DIS_TYPE
  CONSTANT 280
#STOP
```

Boundary conditions refer only to *Dirichlet*-boundary conditions. Similar to IC, they can defined for each process by its primary variable

Boundary conditions at different geometries are defined by additional blocks

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Input file description

7) Source terms - *.st file

#STOP

Source terms refer to *Neumann*-boundary conditions.

In this example, we don't have such boundary conditions.

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Input file description

8) Solid material definition - *.msp file

```
#SOLID_PROPERTIES
 $DENSITY
  1 8920.0
 CAPACITY
  1 385
 CONDUCTIVITY
  1 400.0
#STOP
```

a “’SOLID_PROPERTIES” – block have to be defined for every material (refers to mesh-file)

for (heat) CAPACITY and (thermal) CONDUCTIVITY, don’t begin a “$”

(this is the exception from the rule)

property	Copper Cu	Tin Sn
Density [kg/m^3]	8920	7265
Heat capacity [J/kg/K]	385	227
Thermal conductivity [W/m/K]	400	67

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9) Fluid material definition - *.mfp file

```
#FLUID_PROPERTIES
 $FLUID_TYPE
  LIQUID
 $DENSITY
  1 0.0
 $VISCOSITY
  1 0.0
 $SPECIFIC_HEAT_CAPACITY
  1 0.0
 $HEAT_CONDUCTIVITY
  1 0.0
#STOP
```

In this particular problem, we do not have any fluids. Anyway, since OGS was written for porous media transport pcs, a fluid have to be defined.

In multi-phase simulations, a #FLUID_PROPERTIES block has to be given for each fluid

If any fluid property is not defined in this file, OGS will use a default value (which refers to water at standard conditions in most cases.

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Input file description

10) Medium definition - *.mmp file

```
#MEDIUM_PROPERTIES
 $GEOMETRY_DIMENSION
  2
 $GEOMETRY_AREA
  1.0
 $POROSITY
  1 0.0
#STOP
```

Similar to *.msp, the medium for each material group have to be defined here

$GEOMETRY_DIMENSION refers to the spatial degree of freedom of the problem (1D,2D, or 3D)

$GEOMETRY_AREA defines the thickness (2D) or the Area (1D) of a mesh node. in 3D, this subkeyword has no effect.

Input file description

11) Temporal discretisation - *.tim file

```
#TIME_STEPPING
  $PCS_TYPE
    HEAT_TRANSPORT
  $TIME_STEPS
    100 1
  $TIME_START
    0.0
  $TIME_END
    1e99
#STOP
```

Each process can have its own temporal discretization

Number of Timesteps | Duration of a Timestep

Begin and Ending of the simulation has to be defined additionally. END can be just a very large value.

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Input file description

12) Output selection - *. out file

```
#OUTPUT
 $NOD_VALUES
  TEMPERATURE1
 $GEO_TYPE
  DOMAIN
 $DAT_TYPE
  PVD
$TIM_TYPE
  STEPS 1
#STOP
```

The desired output value can be indicated by its variable name.

$GEO_TYPE refers to the geometry, for wich the output shall be written:

DOMAIN - whole domain

POLYLINE - a profile

POINT - a breakthrough curve

$DAT_TYPE defines the output file format

$TIM_TYPE defines the output frequency

STEPS X - data output each X timesteps

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Input file description

12) Output selection - *. out file

available data types (selection)

TECPLOT
VTK
VTU
PVD
MATLAB

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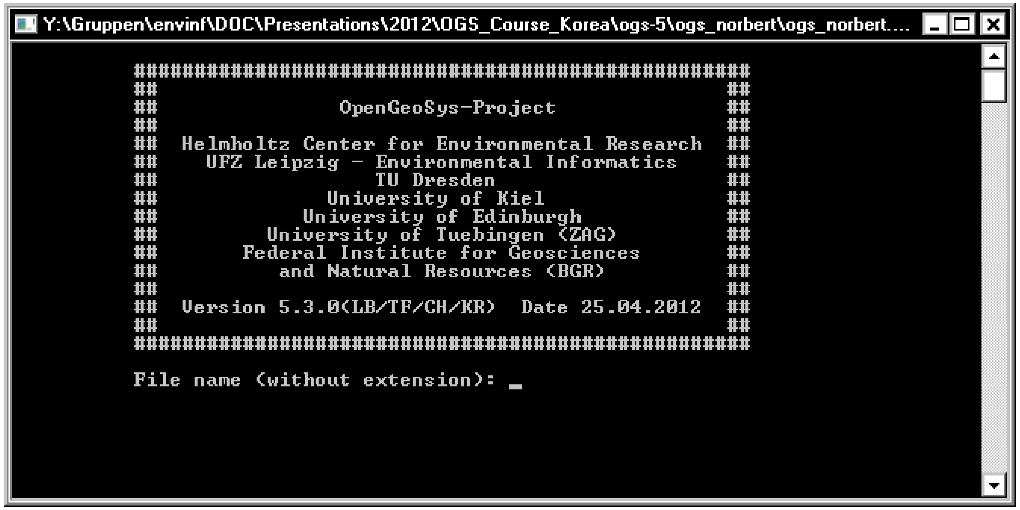
Running the Simulation



The OGS executable is already in your model folder

1. double-click on ogs.exe
2. Type the common filename (without extension)
3. Press ENTER

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Output temperature at a observation point

You can make OGS output results at a particular point.

Let’s change *.out file to check temperature change during the entire simulation

```
#OUTPUT
 $NOD_VALUES
  TEMPERATURE1
 $GEO_TYPE
  DOMAIN
 $DAT_TYPE
  PVD
$TIM_TYPE
  STEPS 1
#STOP
```

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Output temperature at a observation point

You can make OGS output results at a particular point.

Add the following into *.out file to see temperature change at the middle point during the entire simulation

Check whether the model is reaching a steady state or not

```
#OUTPUT
 $NOD_VALUES
  TEMPERATURE1
 $GEO_TYPE
  POINT POINT_MIDDLE
 $DAT_TYPE
  TECPLOT
 $TIM_TYPE
  STEPS 1
```

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Try with different materials

T=300K

property	Granite	Limestone	Soil	Water	Air
Density [kg/m^3]	2630	2320	2050	1000	1.1614
Heat capacity [J/kg/K]	775	810	1840	4179	1007
Thermal conductivity [W/m/K]	2.79	2.15	0.52	0.613	0.0263

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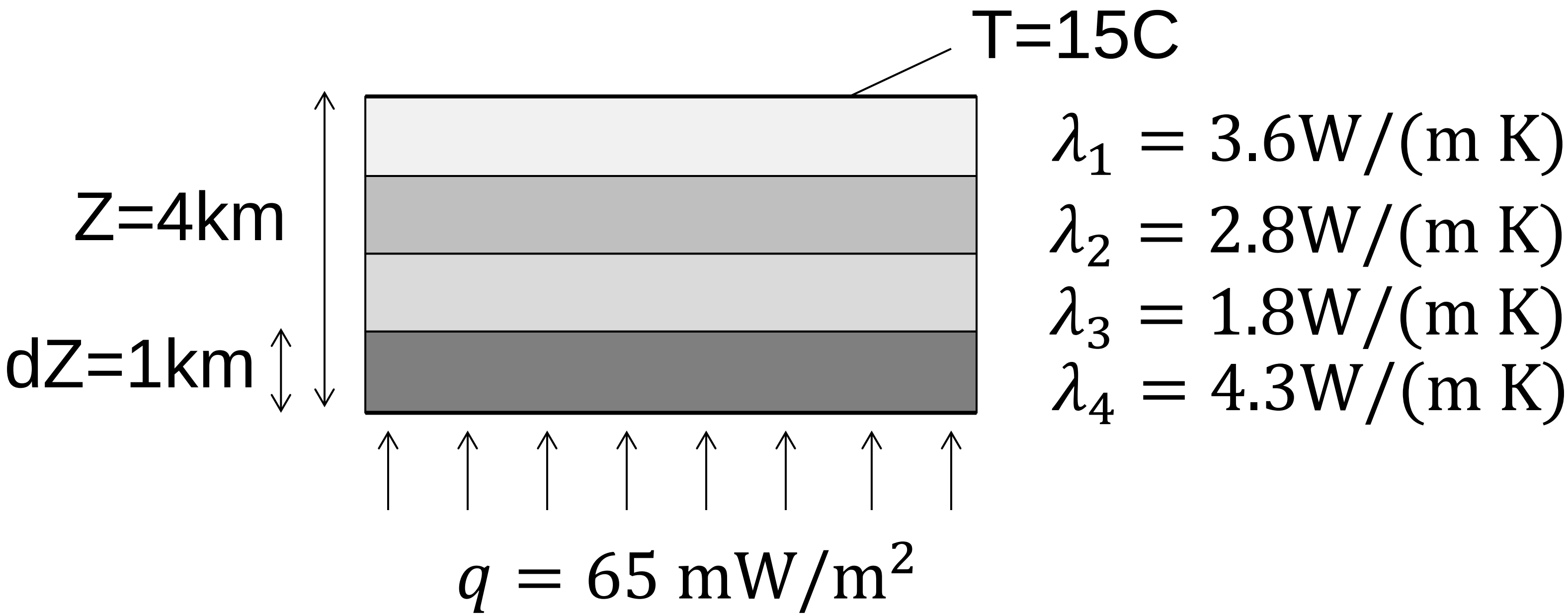
Exercises

Session 1 – Heat Transport Processes

Heat Transport Example 2



- Steady heat conduction in a composite material with heat flux

Input file description

7) Source terms - *.st file

```
#SOURCE_TERM
 $PCS_TYPE
  HEAT_TRANSPORT
 $PRIMARY_VARIABLE
  TEMPERATURE1
 $GEO_TYPE
  POINT POINT4
 $DIS_TYPE
  CONSTANT_NEUMANN .065
#STOP
```

Source terms refer to *Neumann*-boundary conditions.

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- complete the Input-files
- run the simulation
- check the simulation results using Paraview or using a spreadsheet software

- Modify some model parameters to learn how they influence the simulation results

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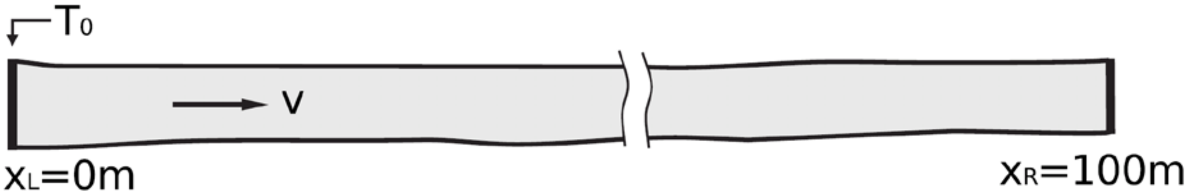
Exercises
Session 1 – Heat Transport Processes

Heat Transport Example 3

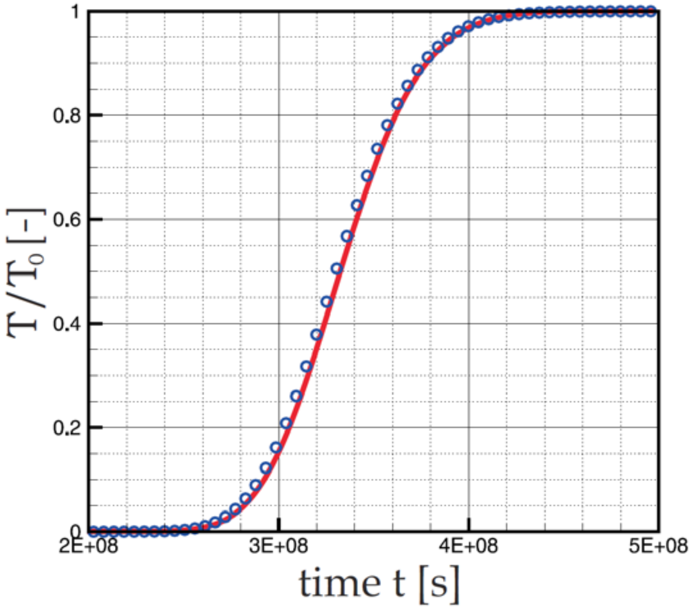


- Ogata-Banks Problem
- Heat transport by convection and conduction along a fracture
- Analytical solution:

$$T(x,t) = \frac{T_0}{2}\left(\operatorname{erfc}\frac{x - v_x \cdot t}{\sqrt{4\alpha t}} + e^{\frac{v_x \cdot x}{\alpha}}\operatorname{erfc}\frac{x + v_x \cdot t}{\sqrt{4\alpha t}}\right)$$

where α is heat diffusivity

$$\alpha = \lambda / c\rho$$



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Exercises
Session 1 – Heat Transport Processes

Heat Transport Example 3

- complete the Input-files
- run the simulation
- check the simulation results using Paraview or using a spreadsheet software

- Modify some model parameters to learn how they influence the simulation results

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Input file description

1) Process definition - *.pcs file

```
#PROCESS
 $PCS_TYPE
  LIQUID_FLOW
#PROCESS
 $PCS_TYPE
  HEAT_TRANSPORT
#STOP
```

We need LIQUID_FLOW process to have groundwater flow

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Input file description

7) Source terms - *.st file

```
#SOURCE_TERM
 $PCS_TYPE
  LIQUID_FLOW
 $PRIMARY_VARIABLE
  PRESSURE1
 $GEO_TYPE
  POINT POINT0
 $DIS_TYPE
  CONSTANT_NEUMANN 1E-6
```

Inflow velocity q [m/s]

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- complete the Input-files
- run the simulation
- check the simulation results using Paraview or using a spreadsheet software

- Modify some model parameters to learn how they influence the simulation results

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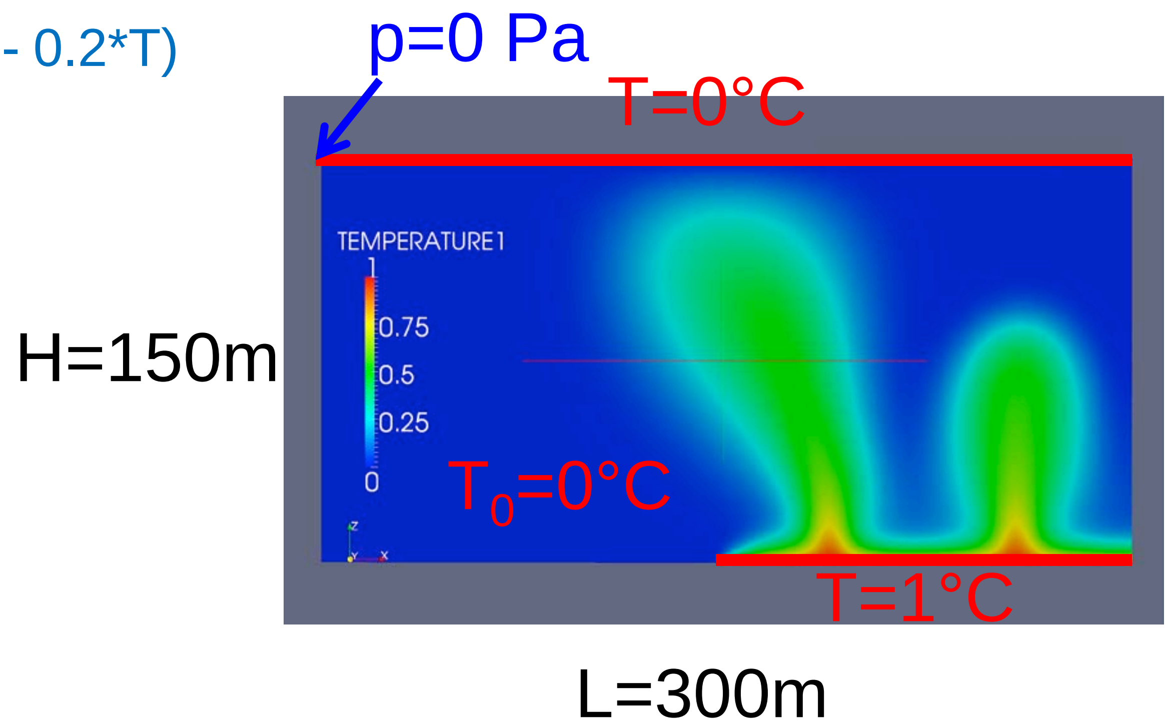
Exercises

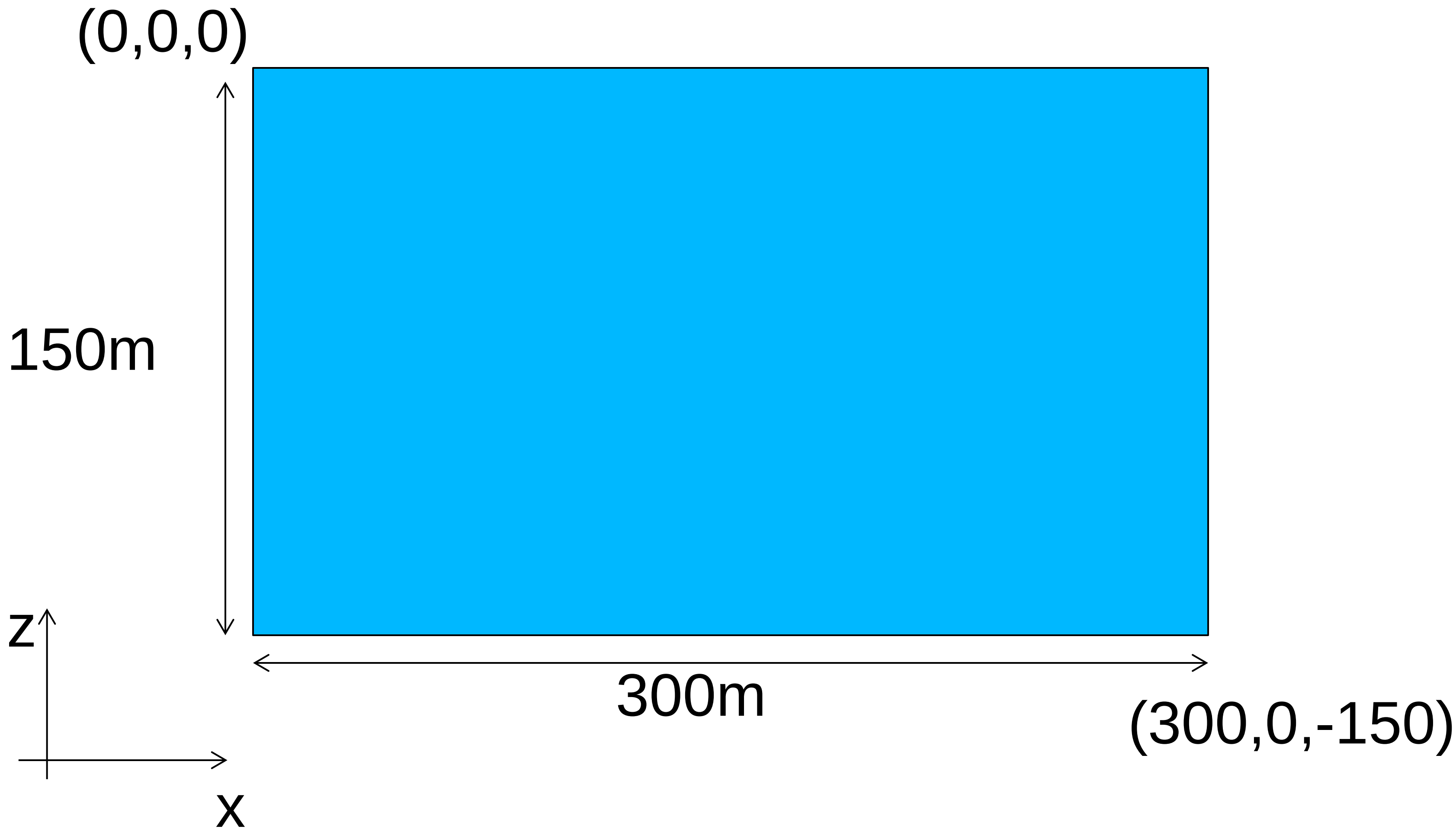
Session 1 – Heat Transport Processes

Heat Transport Example 4

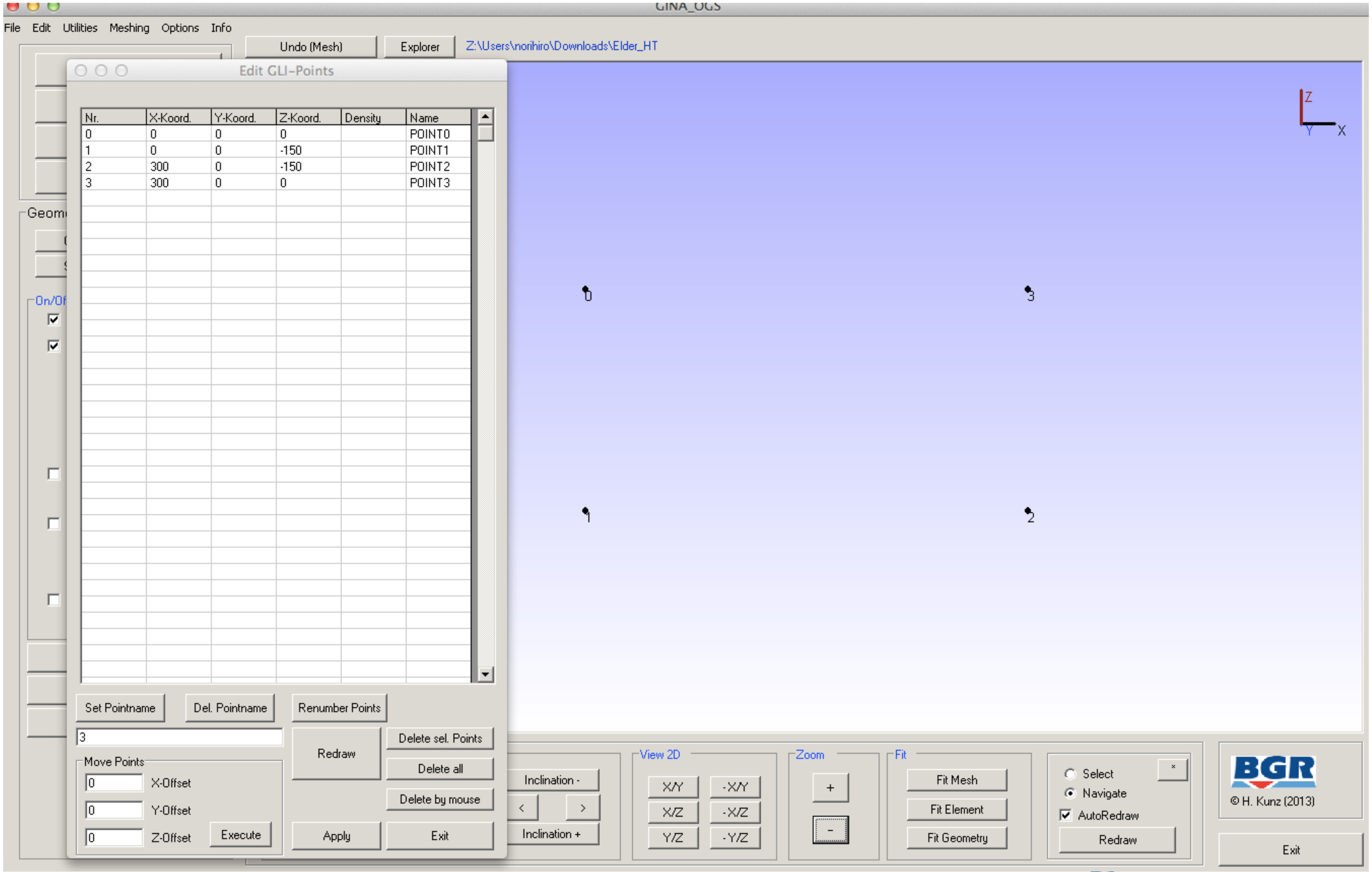
- Thermohaline flow
- Fluid density
  - Rho_f(T) = 1000*(1- 0.2*T)



Geometry layout



Geometry pane -> Edit Points



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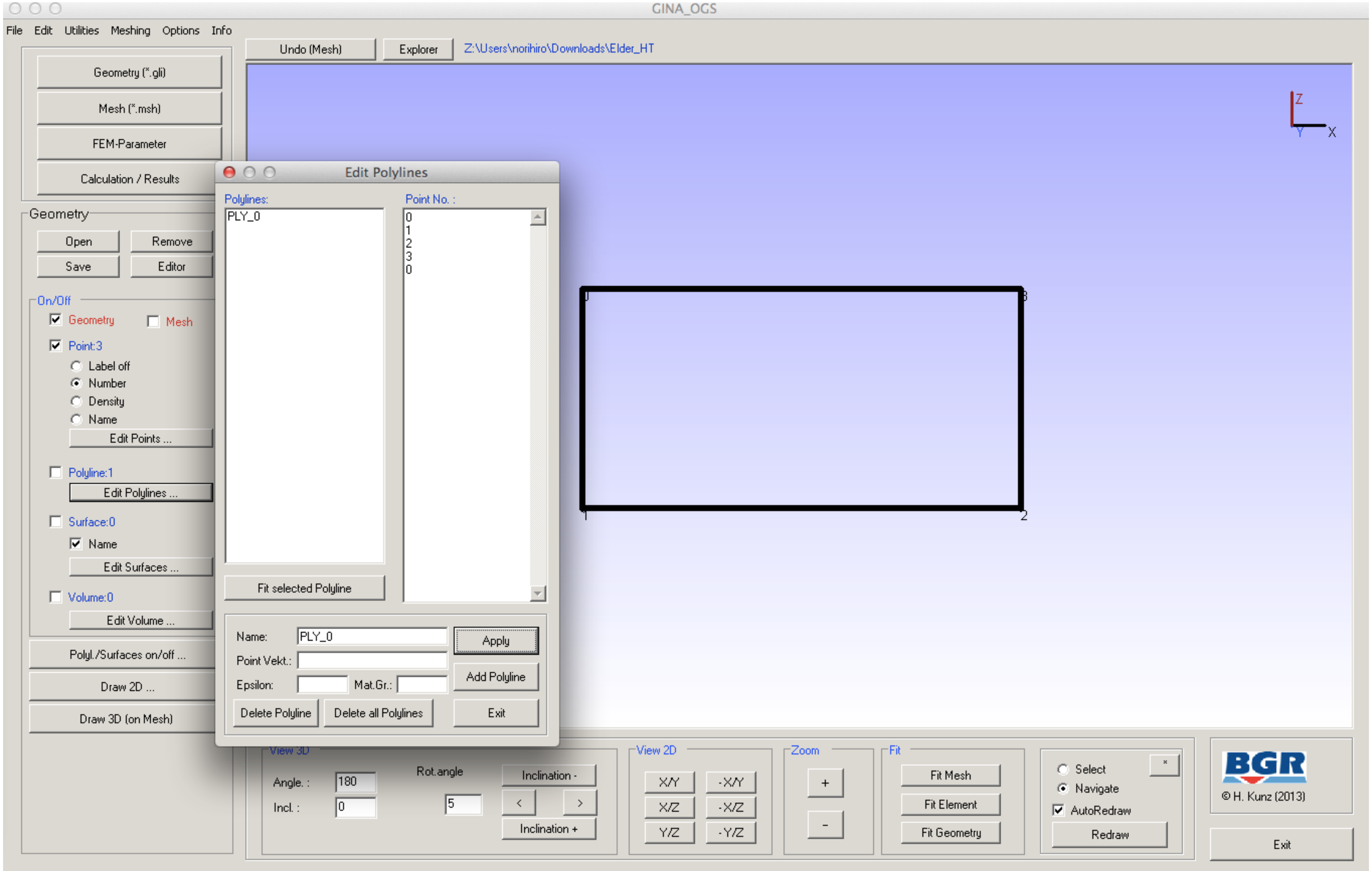
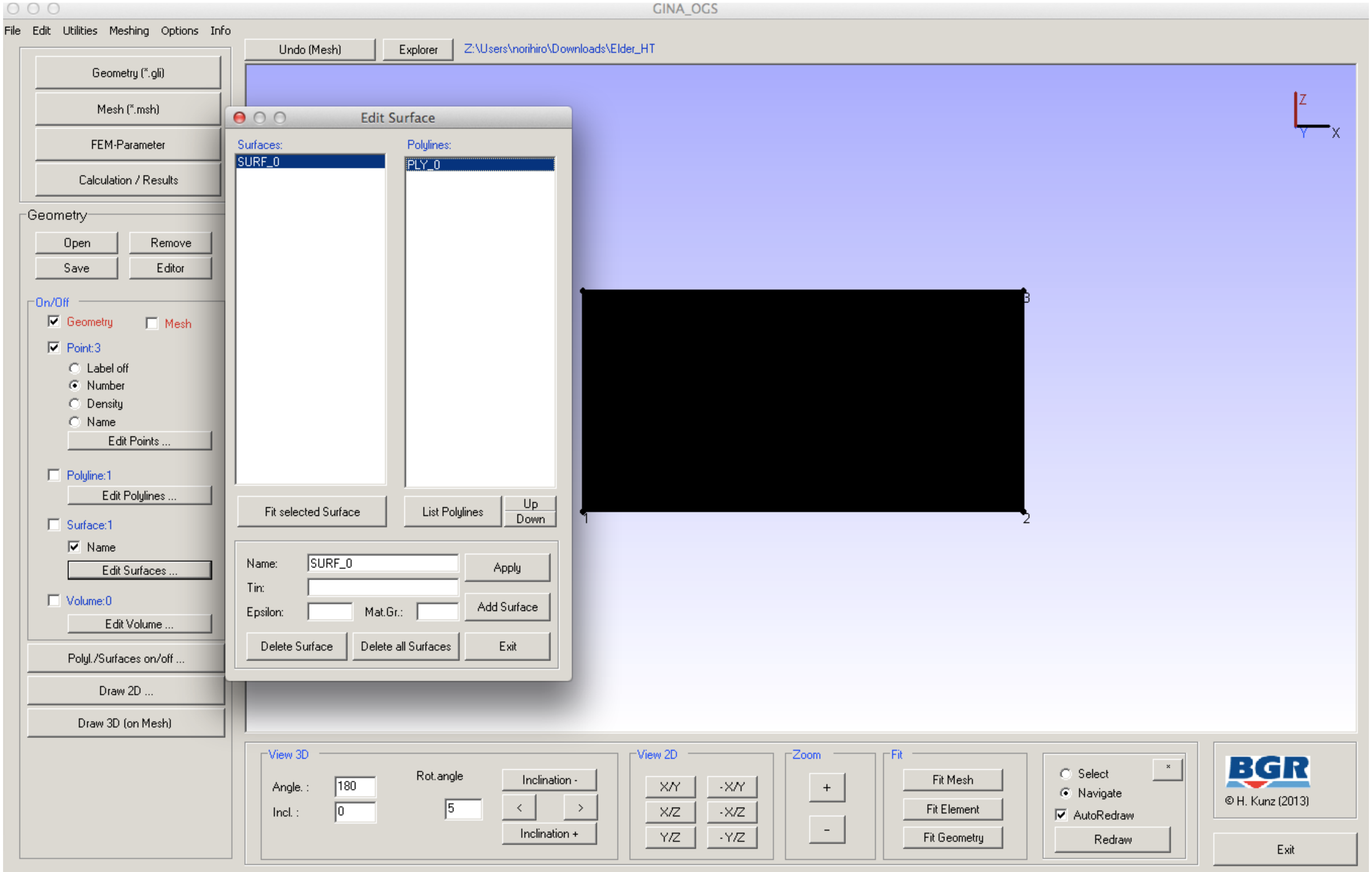
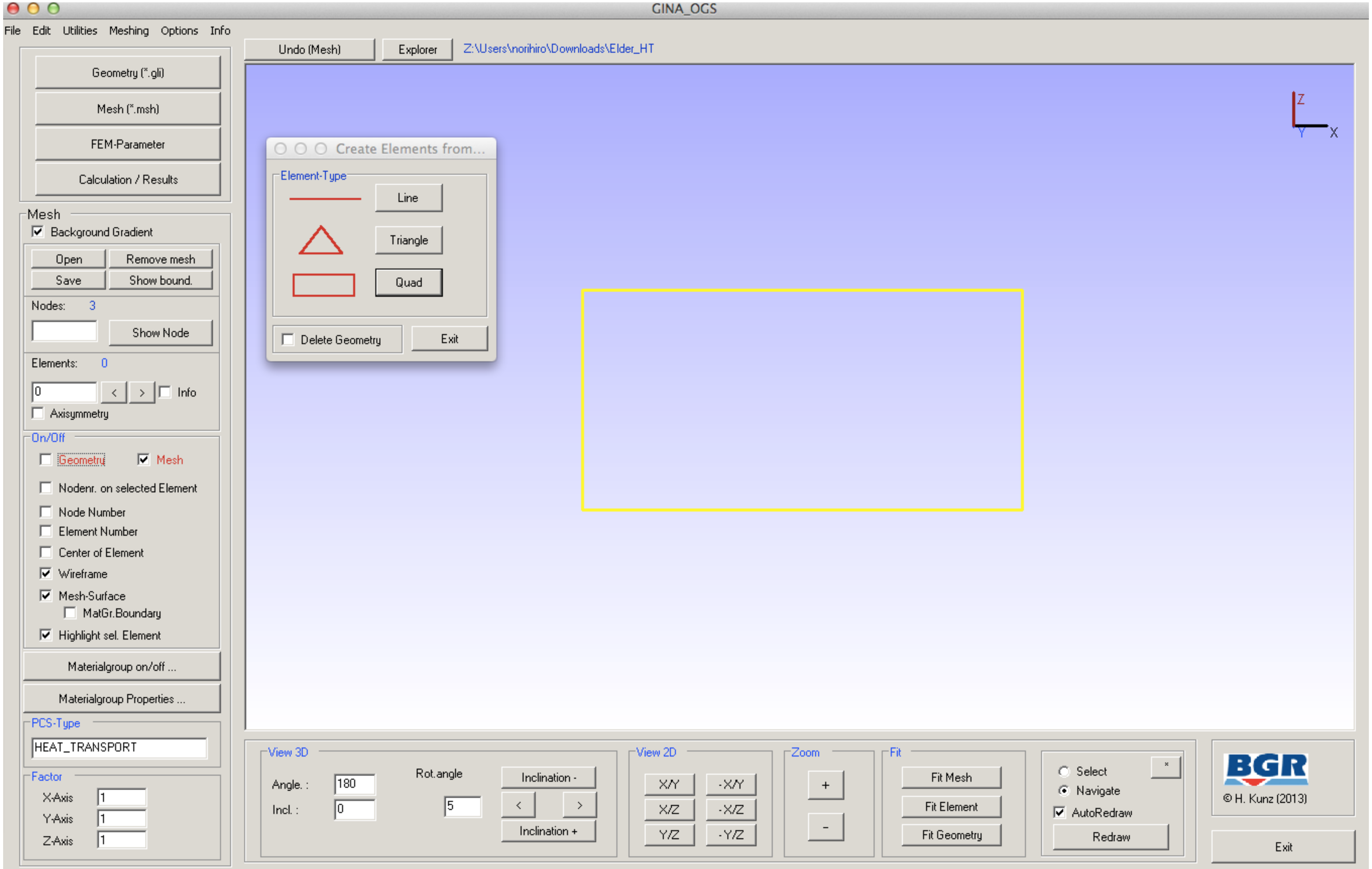
Geometry pane -> Edit Polylines



Geometry pane -> Edit Surface



Meshing menu -> Create Elements from Geometry



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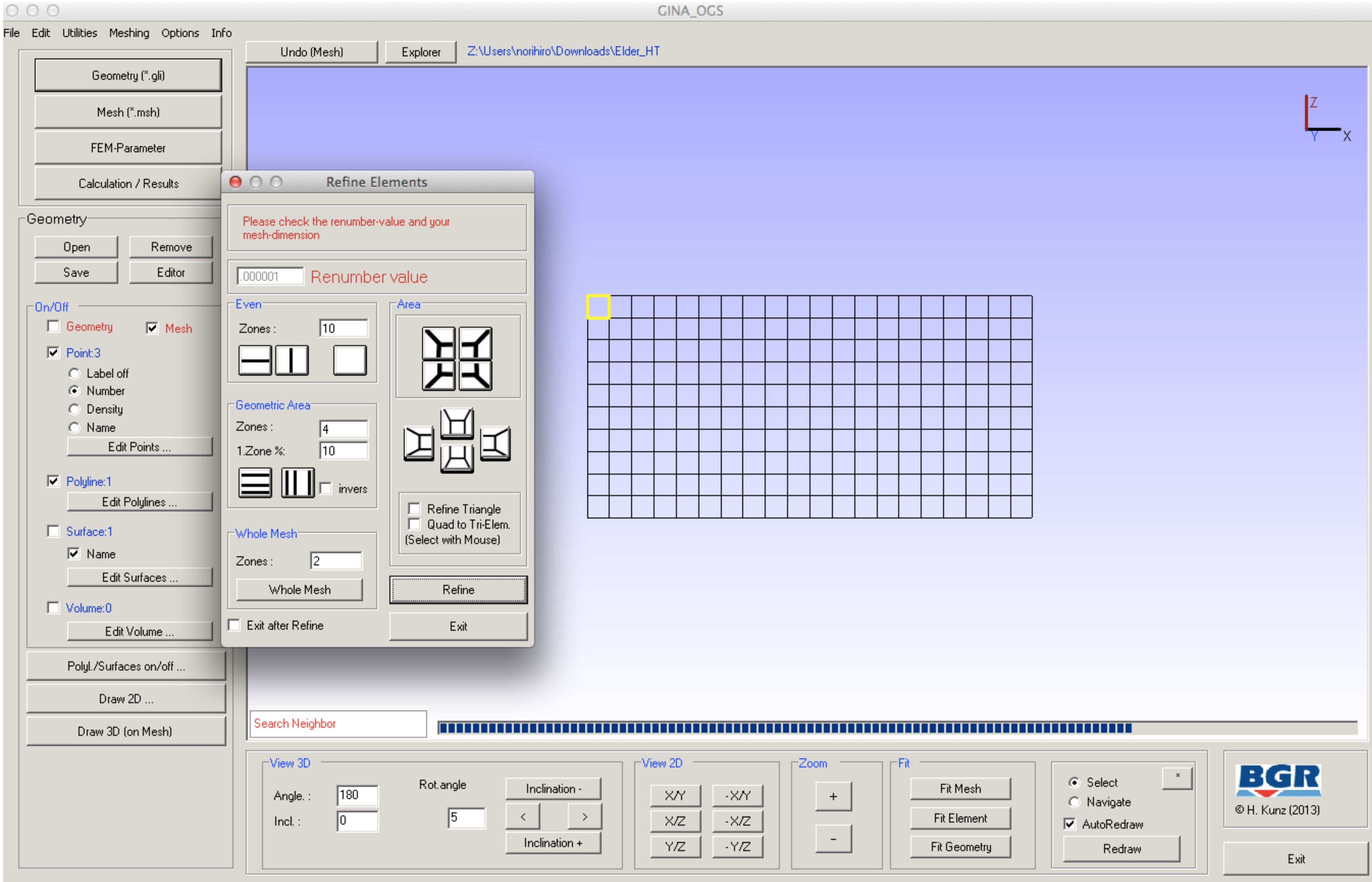
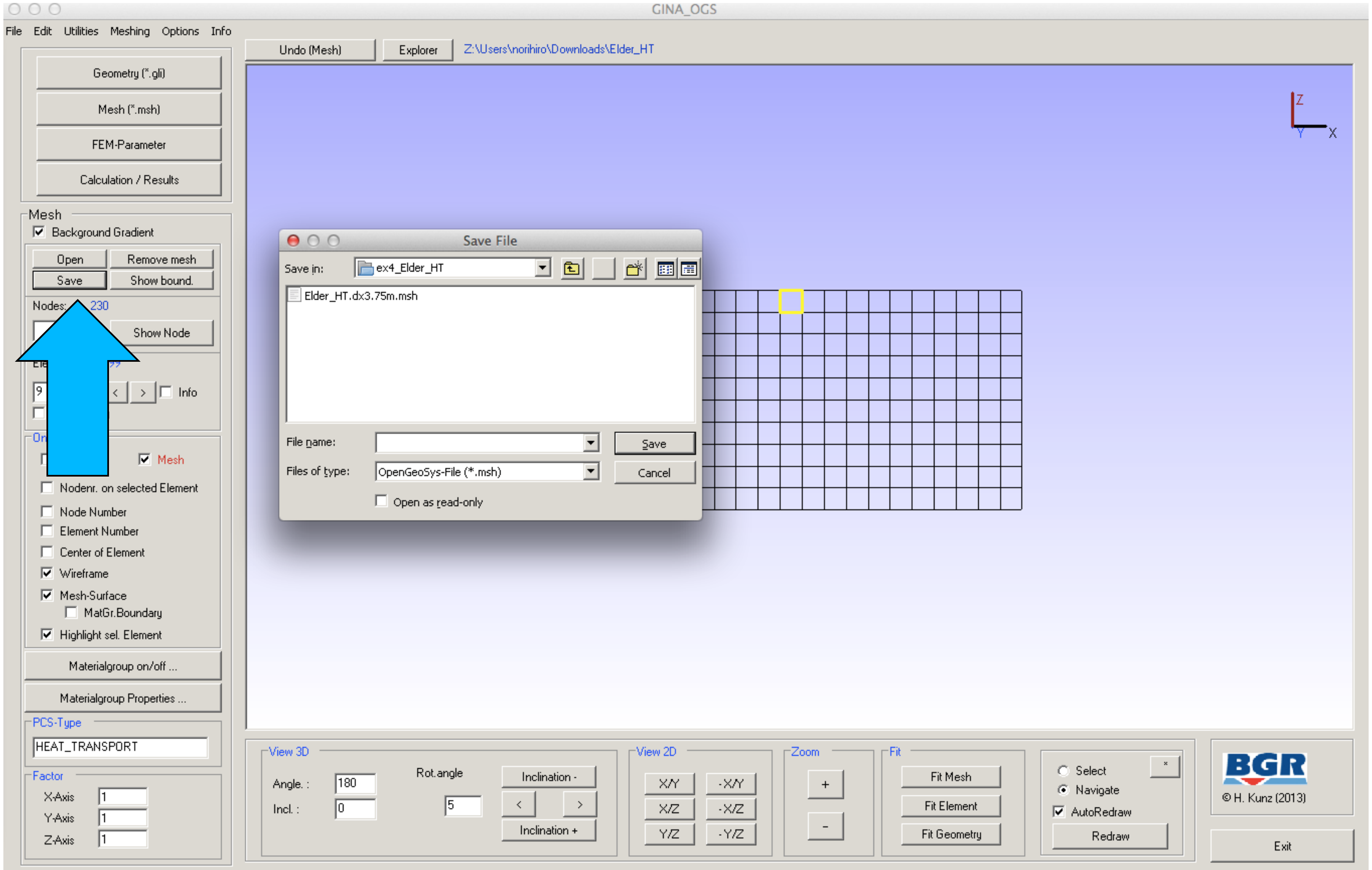
Meshing menu -> Refine 2D Elements



Save the mesh into a file “Elder_HT.msh”



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Fluid material definition - *.mfp file

```
#FLUID_PROPERTIES
 $FLUID_TYPE
  LIQUID
 $DENSITY
  4 1000 0 -0.2
 $VISCOSITY
  1 0.001
 $SPECIFIC_HEAT_CAPACITY
  1 4200.0
 $HEAT_CONDUCTIVITY
  1 0.65
#STOP
```

Fluid density model 4

- Rho = rho0 * (1+beta_T * (T-T0))
- Parameters
  - rho0: Reference density
  - T0: Reference temperature
  - beta_T: volumetric thermal expansion coefficient

Numerical characteristics - *.num file

```
$OVERALL_COUPLING
;min_iter – max_iter
 2          25
#NUMERICS
 $PCS_TYPE
  LIQUID_FLOW
…
#NUMERICS
 $PCS_TYPE
  HEAT_TRANSPORT
 $LINEAR_SOLVER
; mthd – er_mthd - er_tol - max_it - theta - precond - stor
  2       1     1.e-012   1000    0.5     100     4
 $NON_LINEAR_ITERATIONS
  PICARD  LMAX 25 0.0 1e-3
…
#STOP
```

If fluid density depends on temperature, nonlinear solver is required

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Numerical characteristics - *.num file

```
$OVERALL_COUPLING
;min_iter – max_iter
 2          25
#NUMERICS
 $PCS_TYPE
  LIQUID_FLOW
…
 $COUPLING_CONTROL
  LMAX 10
#NUMERICS
 $PCS_TYPE
  HEAT_TRANSPORT
…
$COUPLING_CONTROL
  LMAX 1e-3
#STOP
```

Coupling between groundwater flow and heat transport is necessary.

Coupling converged if changes in new solutions are smaller than these values

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- complete the Input-files
- run the simulation
- check the simulation results using Paraview

- Modify some model parameters to learn how they influence the simulation results

- Density dependent flow is largely affected by mesh resolution.
- Try with refined meshes