DRUtES

TUTORIAL: HEAT MODULE – PART 1

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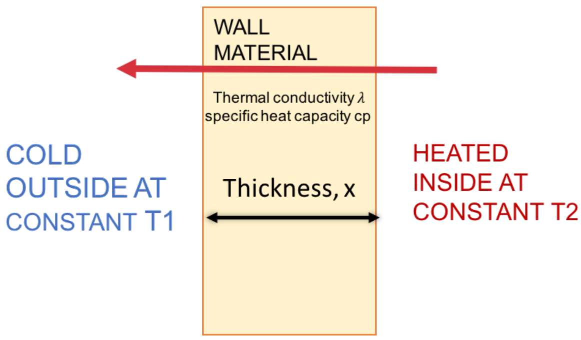
1 GOAL AND COMPLEXITY

Complexity: Beginner

Prerequisites: None

The goal of this tutorial is to get familiar with the *DRUtES* heat module and *DRUtES* configuration in 1D by simulating heat conduction through a wall.



Heat flow is important in the soil. To simplify, we're assuming heat flow through a wall. We test different insulation materials by assigning different heat capacities and thermal conductivity values of several real-world materials.

In this tutorial three configuration files will be modified step by step. All configuration files are located in the folder *drutes.conf* and respective subfolders.

1. For selection of the module, dimension and time information we require *global.conf*. *global.conf* is located in *drutes.conf / global.conf*.

2. To define the mesh or spatial discretization in 1D, we require *drumesh1D.conf*. *drumesh1D.conf* is located in *drutes.conf / mesh / drumesh1D.conf*.

3. To define heat conduction, we require *heat.conf*. *heat.conf* is located in *drutes.conf / heat / heat.conf*.

DRUtES works with configuration input file with the file extension .conf. Blank lines and lines starting with # are ignored. The input mentioned in this tutorial therefore needs to be placed one line below the mentioned keyword, unless stated otherwise.

2 SOFTWARE

1. Install *DRUtES*. You can get *DRUtES* from the github repository drutes-dev or download it from the drutes.org website.

2. Follow website instructions on drutes.org for the installation.

3. Working R installation (optional, to generate plots you can execute freely distributed R script)

3 SCENARIOS

For all scenarios, we assume that the wall is between a heated room, which is maintaining a constant temperature of 20 °C, and the outside world during winter, which for the sake of simplicity is at a constant temperature of 0 °C.

Table 1: Material properties needed for scenarios.

Material	specific heat capacity c_p [J kg^{-1} K^{-1}]	density ρ [kg m^{-3}]	thermal conductivity λ [W m^{-1} K^{-1}]
Stone concrete	750	1400	1.7
Sand stone	920	2800	1.7
Cotton	1340	1550	0.04

SCENARIO 1

Heat conduction through a 20 cm thick stone concrete wall.

global.conf: Choose correct model, dimension, time discretization and observation times.

1. Open ***global.conf*** in a text editor of your choice.
2. Model type: Your first input is the module. Input is **heat**.
3. Initial mesh configuration
   a) The dimension of our problem is 1. Input: 1.
   b) We use the internal mesh generator. Input: 1.
4. Error criterion (not needed here, leave at default value)
   a) Maximum number of iteration of the Picard method: 20
   b) h tolerance: 1e-2.
5. Time information
   a) Time units are in hours: input h
   b) Initial time: 1e-3.
   c) End time: 24.
   d) Minimum time step: 1e-6.
   e) Maximum time step: 0.1.
6. Observation time settings
   a) Observation time method: 2
   b) Set file format of observation: pure. Output in 1D is always in raw data. Different options will not impact output in 1D.
   c) Make sequence of observation time: n
   d) Number of observation times: 11
   e) Observation time values: 2, 4, 6, 8, 10, 12 ,14, 16, 18, 20, 22. Use a new line for each input. *DRUtES* automatically generates output for the initial time and final time. DRUtES will generate 13 output files, e.g. *heat_temperature-x.dat*, where x is the number of the file and not the output time. The initial time is assigned an x value of 0.

7. Observation point settings
   a) Observation point coordinates: 0.0, 0.2. Use a new line for each input. *DRUtES* will generate 2 output files, e.g. *obspt_heat-x.out*, where x is the ID of the observation point.
8. Ignore other settings for now.
9. Save $global.conf$

$drumesh1D.conf$: Mesh definition, i.e. number of materials and spatial discretization

1. Open ***drumesh1D.conf*** in a text editor of your choice.
2. Geometry information: 0.2 m - domain length
3. Amount of intervals: 1
4.

density	bottom	top
0.005	0	0.2

5. number of materials: 1
6.

id	bottom	top
1	0	0.2

heat.conf: Heat module after Sophocleous (1979).

1. Open *heat.conf* in a text editor of your choice.
2. Couple with Richards equation: n
3. Number of materials or layers: 1
4. Specific heat capacity of the wall material:
   750 J kg^{-1} K^{-1} x 1400 kg m^{-3} = 1.05E6 J m^{-3} K^{-1} = $\frac{1.05E6 \text{ W s m}^{-3} \text{ K}^{-1}}{3600 \text{ s h}^{-1}}$ = 291 W h m^{-3} K^{-1}.
5. Specific heat capacity of liquid: 0
6. Anisotropy: There is no anisotropy. The value is 0.
7. Heat conductivity of the wall material: 1.7 W m^{-1} K^{-1}.
8. There is NO heat convection of water: 0.
9. The initial temperature is 0°C across the entire domain: 0.
10. There is no heat source: 0.
11. We have 2 boundaries at both ends of the wall. We assume a constant temperature of 0 °C outside. We assume the inside is heated and the temperature maintained at exactly 20°C. We therefore know the temperature at the boundaries. We also know that these values do not change in time. They can be describes as time-constant Dirichlet boundary conditions.

boundary id	boundary type	use bc.dat	value
101	1	n	20.0
102	1	n	0.0

12. Save heat.conf.

RUN SCENARIO 1

Run the simulation in the terminal console.

1. Make sure you are in the right directory.
2. To execute *DRUtES*:
   $ bin/drutes
3. After the simulation finishes, to generate png plots execute provided R script:
   $ Rscript heatplots.R concrete
4. The output of the simulation can be found in the folder out

TASKS FOR SCENARIO 1

1. How long does it take for the temperature distribution to become linear between the two observation points?
2. How large is the steady state heat flux through the wall?
3. Let's assume a wall area of A=15 m^2. Use the observation point at the boundary between the wall and the inside of room. How large was the cumulated heat loss 24 h. How much will be lost after 48 h when the set-up does not change?

RESULT OF SCENARIO 1

Question 1

Figure 1 shows that the temperature distribution becomes linear quite quickly and reaches a steady state after observation time 2, which was set to 4 h. Figure 2 shows the heat flux ϕ_p in observation points 1 (red) and 2 (blue) bordering the wall to the outside and heated inside, respectively. The heat flux is extremely large at observation point 2 in the beginning. Observation point 2 evidently defines the boundary between the wall and the heated inside. After approximately 3 hours, the heat flux of observation point 1 and 2 become identical. This occurs when the simulation reaches steady state and a linear temperature distribution. Figure 2 allows a more exact estimation of when the system becomes steady state.

Question 2

The constant heat flux value is at ϕ_p=170 W m^{-2}. This value can also be calculated using the equation:

$$\phi_\mathrm{p} = -\lambda\frac{dT}{dx} = -1.7\frac{20-0}{0.2} = 170 \text{ W m}^{-2}$$

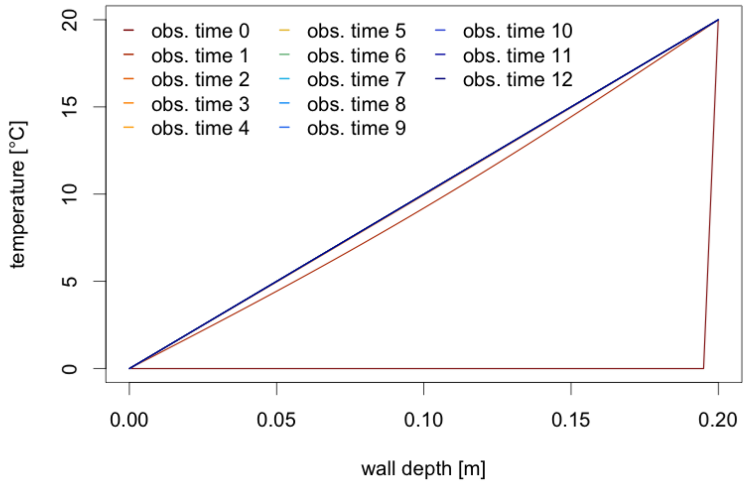


Figure 1: Plot of observation times for stone concrete generated with Rscript heat-plots.R

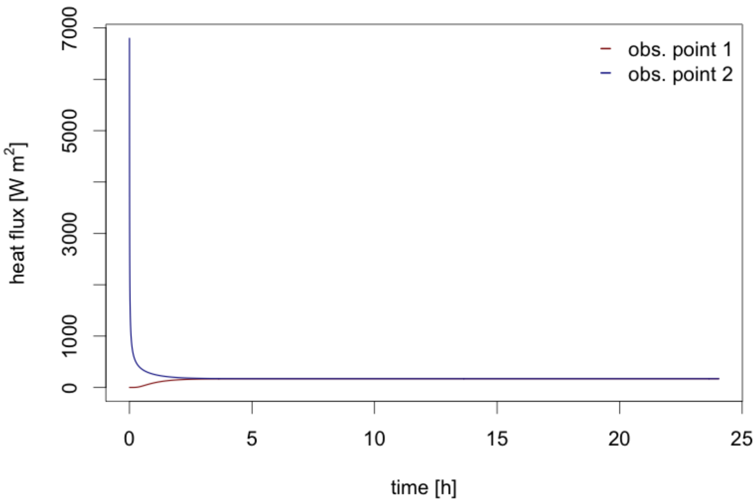


Figure 2: Heat flux at observation points 1 and 2 for stone concrete generated with Rscript heatplots.R

Question 3

Figure 3 shows the cumulative heat flux in observation points 1 and 2, both ends of the wall. The cumulative heat flux after 24 h at observation point is 4468 W m^{-2}. With a wall area of 15 m^2 this results in $Q =$ 4468 W h m^{-2} · 15 m^2 = 67020 W h. For the next 24 h, the heat flux will be constant at 170 W m^{-2}. The total heat loss will therefore be $Q =$ 170 W m^{-2} · 24 h · 15 m^2 = 61200 W h.

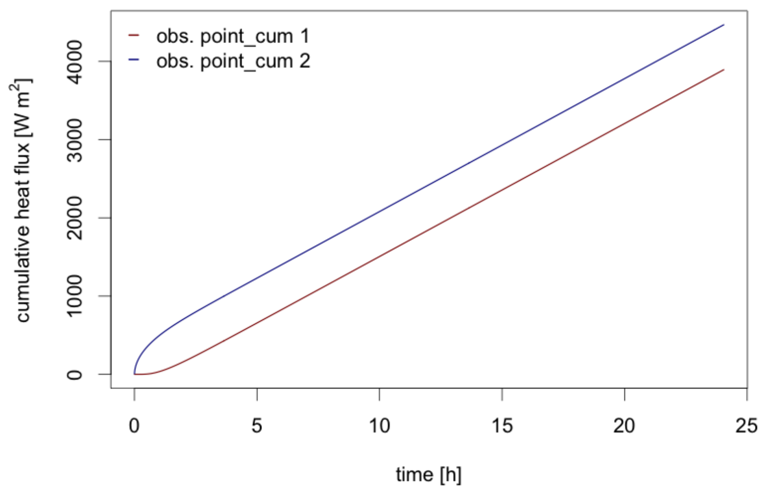


Figure 3: Cumulated heat flux at observation points 1 and 2 for stone concrete generated with Rscript heatplots.R

SCENARIO 2

Heat conduction through a 20 cm thick sandstone wall.

1. Open *heat.conf* in a text editor of your choice.
2. Leave all settings the same, except for specific heat capacity.
3. Replace the specific heat capacity with values of sand stone.
4. Save heat.conf.

RUN SCENARIO 2

Run the simulation in the terminal console.

1. Make sure you are in the right directory.
2. To execute *DRUtES*:
   $ bin/drutes
3. After the simulation finishes, to generate png plots execute provided R script:
   $ Rscript heatplots.R sandstone
4. The output of the simulation can be found in the folder out

TASKS FOR SCENARIO 2

1. Answer the same questions as for scenario 1. What is different?

RESULT OF SCENARIO 2

Question 1

Figure 4 shows that it takes longer for the temperature distribution to become linear in sandstone than in concrete sand. Also taking Fig. 5 into account, it takes approximately 5 h. This is because sandstone has a larger specific heat capacity than stone concrete.

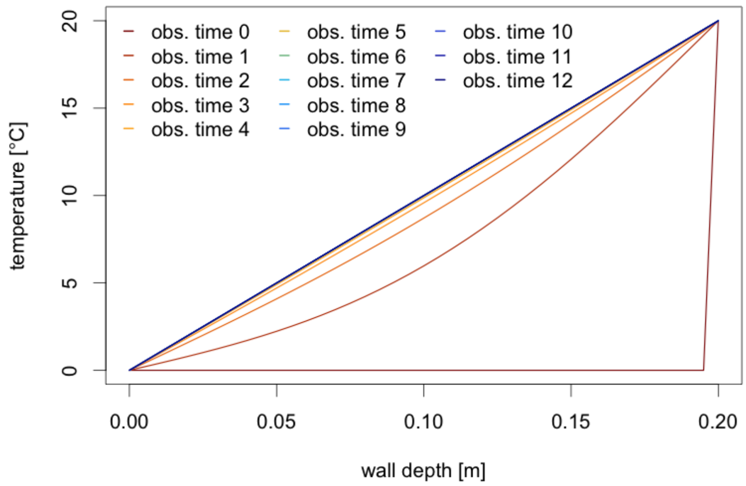


Figure 4: Plot of observation times for sandstone generated with Rscript heatplots.R

Question 2

The constant heat flux when the system is in steady state is also at ϕ_p=170 W m^{-2}. Both materials have the same thermal conductivity and therefore the same thermal heat flux.

Question 3

Heat conduction through a 20 cm thick cotton fibre wall.

The cumulative heat flux after 24 h at observation point 2 in sandstone is higher than in concrete stone, namely 5014 W m^{-2}. With a wall area of 15 m^2 this results in $Q = 5014$ W h $m^{-2} \cdot$ 15 m^2 $= 75210$ W h. For the next 24 h, the heat flux will be constant at 170 W m^{-2}. The total heat loss will therefore also be $Q = 170$ W m^{-2} $\cdot$ 24 h $\cdot$ 15 m^2 $= 61200$ W h.

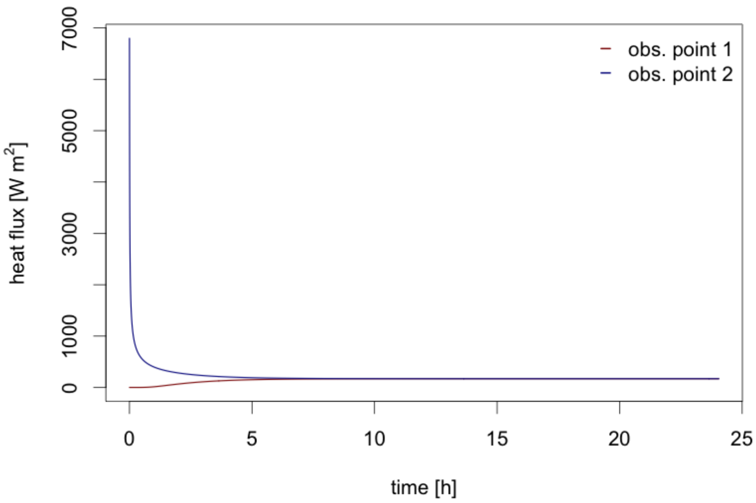


Figure 5: Heat flux at observation points 1 and 2 for sandstone generated with Rscript heatplots.R

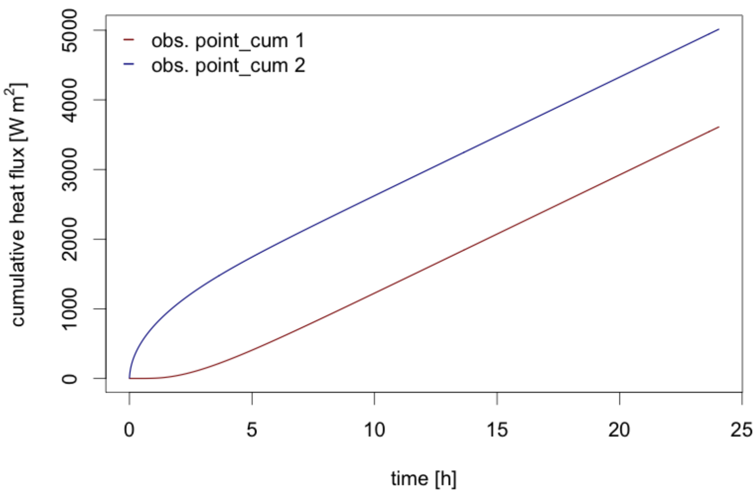


Figure 6: Cumulated heat flux at observation points 1 and 2 for sandstone generated with Rscript heatplots.R

SCENARIO 3

1. Open *heat.conf* in a text editor of your choice.
2. Change the specific heat capacity and thermal conductivity with values of cotton.
3. Save heat.conf.

RUN SCENARIO 3

Run the simulation in the terminal console.

1. Make sure you are in the right directory.
2. To execute *DRUtES*:
   $ bin/drutes
3. After the simulation finishes, to generate png plots execute provided R script:
   $ Rscript heatplots.R cotton
4. The output of the simulation can be found in the folder out

TASKS FOR SCENARIO 3

1. Answer the same questions as for scenario 1. What is different to scenario 1 and 2?

RESULT OF SCENARIO 3

Question 1

In contrary to scenario 1 and 2, figure 7 and 8 show that we have not reached steady-state within 24 h. This is because of the very low thermal heat conductivity of cotton fibre.

Question 2

We cannot estimate the constant heat flux during steady-state with our results. Using the heat flux equation mentioned during scenario 1, we can calculate the heat flux during steady state:

$$\phi_{\mathrm{p}} = -\lambda \frac{dT}{dx} = -0.04 \frac{20-0}{0.2} = 4 \text{ W m}^{-2}$$

Question 3

The cumulative heat flux after 24 h at observation point 2 in sandstone is higher than in concrete stone, namely 503 W m^{-2}, so about a tenth of sandstone and stone concrete. With a wall area of 15 m^2 this results in $Q = 503 \text{ W h m}^{-2} \cdot 15 \text{ m}^2 = 7545 \text{ W h}$.

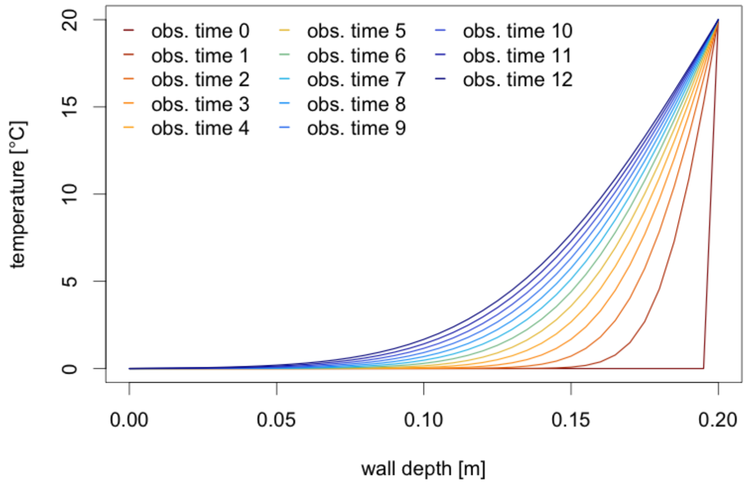


Figure 7: Plot of observation times for cotton generated with Rscript heatplots.R

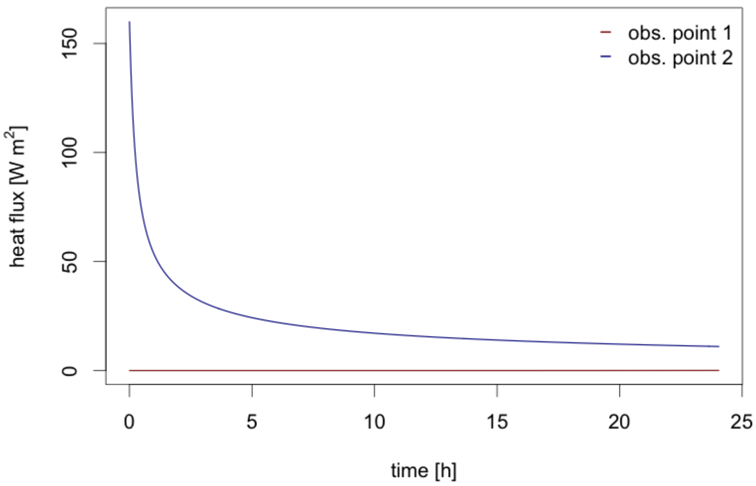


Figure 8: Heat flux at observation points 1 and 2 for cotton generated with Rscript heatplots.R

Since the system is not in steady state, it is difficult to estimate the heat loss for the next 24 h. The answer has to be evaluated numerically by increasing the end time to 48 h.

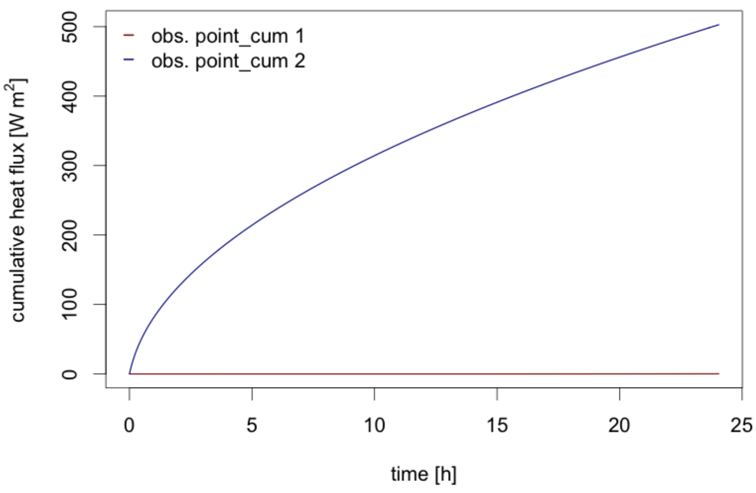


Figure 9: Cumulated heat flux at observation points 1 and 2 for sandstone generated with Rscript heatplots.R

4 OUTCOME

1. You got familiar with the *DRUtES* heat module in 1D.
2. You simulated heat conduction through a wall with different materials
3. You understand the effects of different heat capacities and thermal conductivities.
4. You understand the term *Dirichlet boundary condition*, *initial condition* and *steady state*.