DRUtES

TUTORIAL: HEAT MODULE – PART 2

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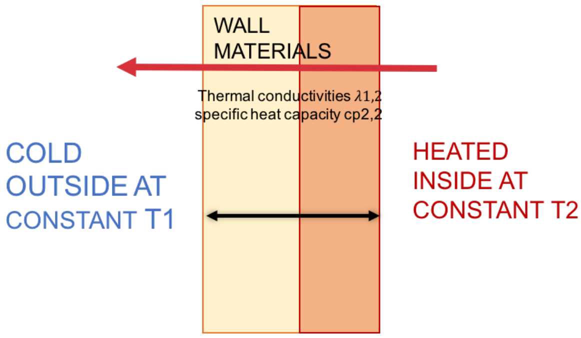
1 GOAL AND COMPLEXITY

Complexity: Beginner

Prerequisites: Tutorial: heat module – part 1.

The goal of this tutorial is to show further applicability of the *DRUtES* heat module in 1D. We simulate heat conduction in a wall with two materials to understand the effects of layering of materials with different thermal properties.



Similar to tutorial 1, 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
Cotton	1340	1550	0.04

SCENARIO 1

Heat conduction through a 20 cm wall. 15 cm are made of stone concrete and 5 cm are made of cotton fibre.

global.conf: Choose correct model, dimension, time discretization and observation times. This is the same as in heat tutorial 1.

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. Here is were the configuration files are different to heat tutorial one.

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: 2
6. | id | bottom | top |
   |---|---|---|
   | 1 | 0 | 0.15 |
   | 2 | 0.15 | 0.2 |

heat.conf: Heat module after Sophocleous (1979). Here, it is important to make sure everything is defined for 2 layers. 2 lines of input are required, even when the input is identical.

1. Open *heat.conf* in a text editor of your choice.
2. Couple with Richards equation: n
3. Number of materials or layers: 2
4. Specific heat capacity of the wall material: Material 1 is stone concrete: 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}.
   Material 2 is cotton fibre:
   1340 J kg^{-1} K^{-1} x 1550 kg m^{-3} = 2.08E6 J m^{-3} K^{-1} = $\frac{2.08E6 \text{ W s m}^{-3} \text{ K}^{-1}}{3600 \text{ s h}^{-1}}$ = 576 W h m^{-3} K^{-1}.
5. Specific heat capacity of liquid: 0 (for both materials)
6. Anisotropy: There is no anisotropy. The value is 0 (for both materials)
7. Heat conductivity of the wall material:
   Material 1: 1.7 W m^{-1} K^{-1}
   Material 2: 0.04 W m^{-1} K^{-1}
8. There is NO heat convection of water: 0 (for both materials)
9. The initial temperature is 0°C across the entire domain: 0 (for both materials)

10. There is no heat source: 0 (for both materials)

11. This is identical to heat tutorial 1. 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 concretecotton1

4. The output of the simulation can be found in the folder out

TASKS FOR SCENARIO 1

1. Describe the temperature distribution. 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 two distinct linear temperature distributions. The temperature distributions appears to have not changed significantly over the last observation times indicating a steady state. A 5 cm thick cotton fibre wall is between the concrete stone and the heated inside. The overall heat flux at the inside border is therefore quite low as the input of heat has to travel through badly conducting material first.

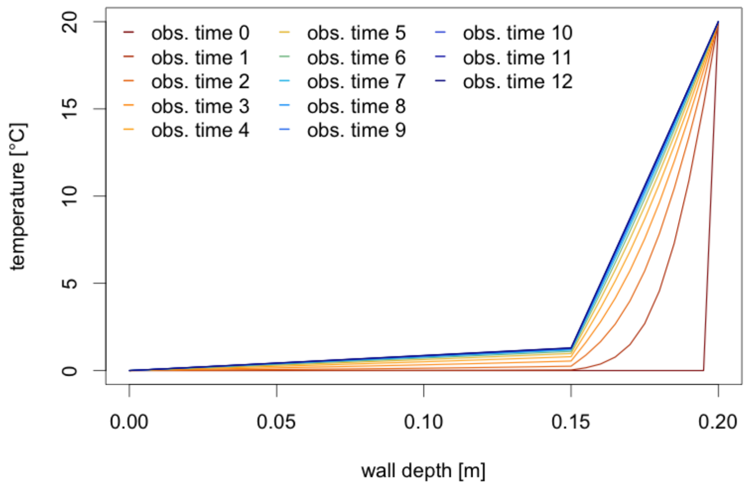


Figure 1: Plot of observation times for a wall with a 15 cm outer stone concrete layer and an inner 5 cm cotton fibre layer generated with Rscript heatplots.R

Question 2

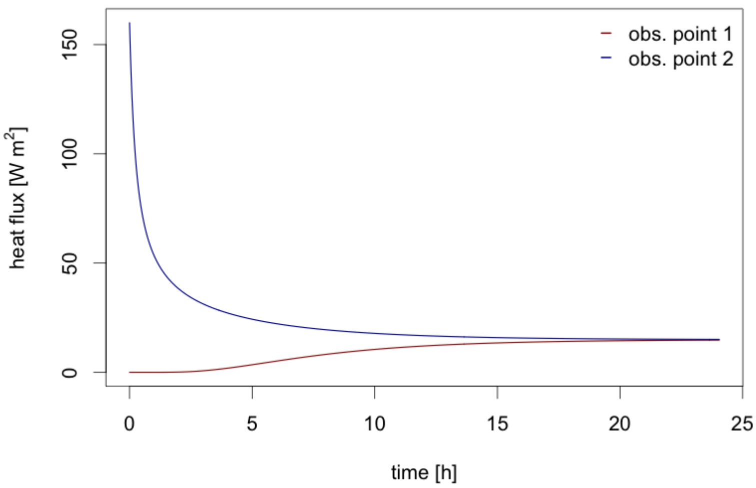


Figure 2: Heat flux at observation points 1 and 2 for a wall with a 15 cm outer stone concrete layer and an inner 5 cm cotton fibre layer generated with Rscript heatplots.R

Looking at the raw data, it appears that steady-state has not actually been reached, but that the change in heat flux is becoming slower and is converging towards 15 W m^{-2}.

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 538 $\mathrm{W\ m^{-2}}$. With a wall area of 15 $\mathrm{m^2}$ this results in $Q = 538\ \mathrm{W\ h\ m^{-2}} \cdot 15\ \mathrm{m^2} = 8070\ \mathrm{W\ h}$. For the next 24 h, the heat flux will be constant at 15 $\mathrm{W\ m^{-2}}$. The total heat loss will therefore be $Q = 15\ \mathrm{W\ m^{-2}} \cdot 24\ \mathrm{h} \cdot 15\ \mathrm{m^2} = 5400\ \mathrm{W\ h}$.

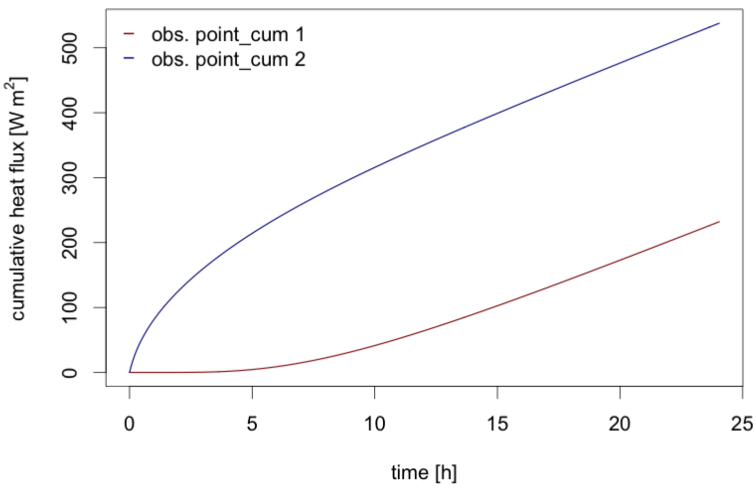


Figure 3: Cumulated heat flux at observation points 1 and 2 for a wall with a 15 cm outer stone concrete layer and an inner 5 cm cotton fibre layer generated with Rscript heatplots.R

SCENARIO 2

1. Open *heat.conf* in a text editor of your choice.
2. Swap the order of materials for specific heat capacity and thermal conductivity. Now, the the outer wall layer is made of cotton fibre and the inner layer is made of concrete.
3. 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 cottonconcrete
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 the inner concrete layer becomes linear quite quickly, but that the outer cotton fibre layer has not reached linearity after 24 h. Also taking Fig. 5

Question 2

The system has not reached a constant heat flux, but the heat flux will be between 0.7 and 111 W m^{-2}. A long simulation (not shown) of 240 h shows that the steady state hea flux converges towards 53 W m^{-2}.

Question 3

The cumulative heat flux after 24 h at the inner boundary is higher than in scenario 1, namely 797 W m^{-2}. With a wall area of 15 m^2 this results in $Q = 797 \text{ W h m}^{-2} \cdot 15 \text{ m}^2 = 11955 \text{ W h}$. For the next 24 h, the heat flux will not be constant and needs to be numerically simulated.

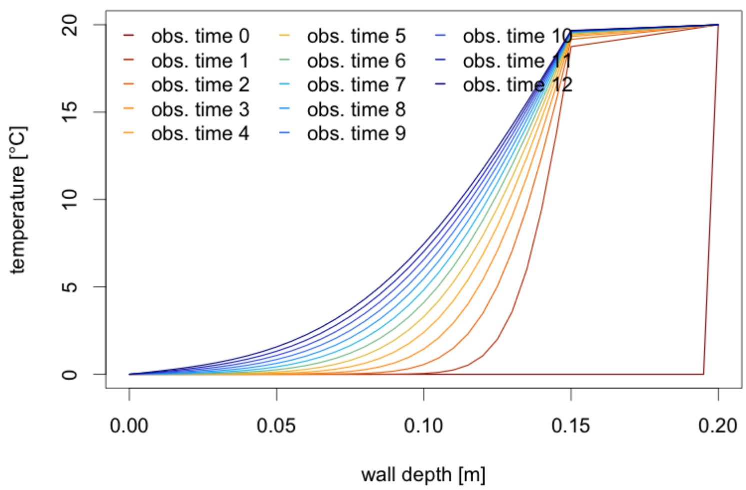


Figure 4: Plot of observation times for a wall with a 15 cm thick outer cotton layer and a 5 cm inner concrete stone layer generated with Rscript heatplots.R

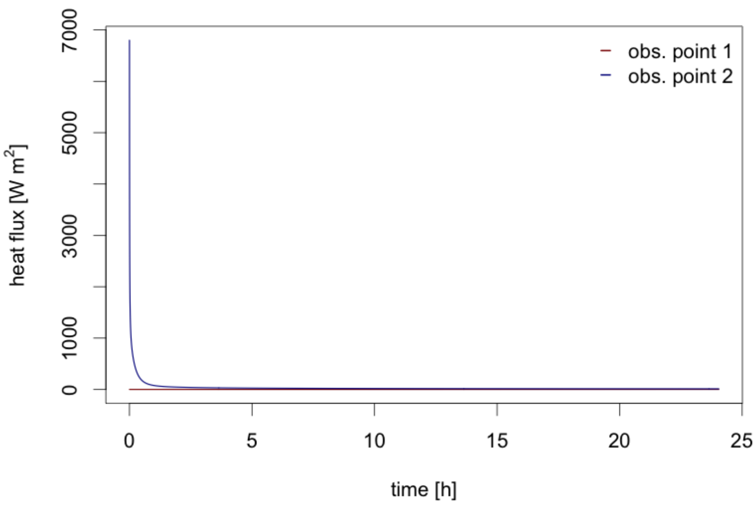


Figure 5: Heat flux at observation points for a wall with a 15 cm thick outer cotton layer and a 5 cm inner concrete stone layer generated with Rscript heatplots.R

4 OUTCOME

1. You got familiar with the *DRUtES* heat module in 1D with 2 layers.
2. You simulated heat conduction through a wall with layered materials.
3. You understand the effects of layering of materials with different heat capacities and thermal conductivities.
4. You understand how layering affects when a system is in *steady state*.

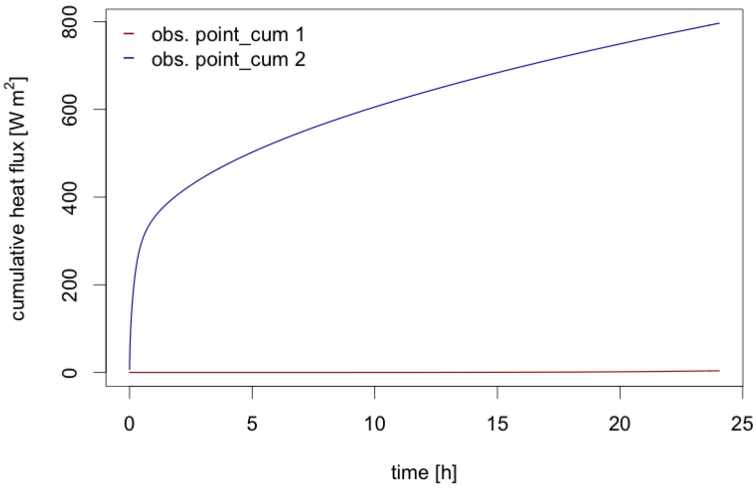


Figure 6: Cumulated heat flux at observation points for a wall with a 15 cm thick outer cotton layer and a 5 cm inner concrete stone layer generated with Rscript heatplots.R