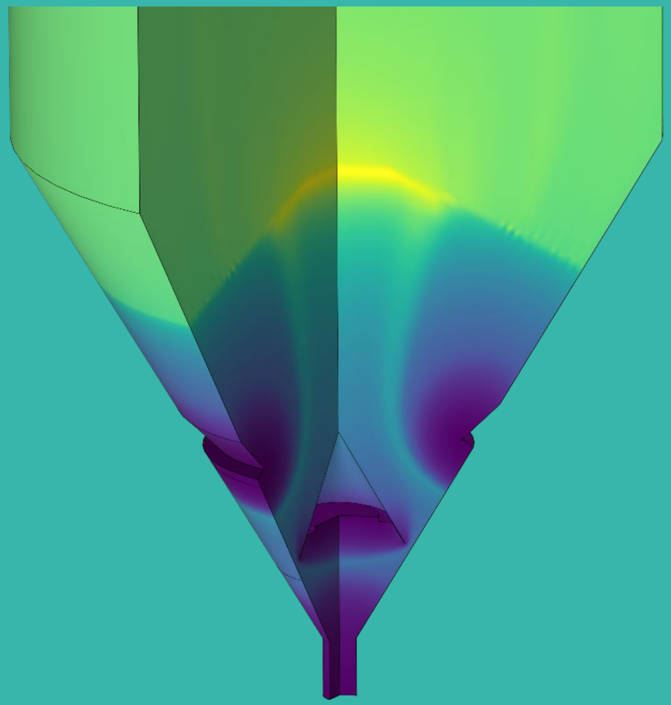


Degassing of PP pellets in a silo;

keeping C9 concentrations below the lower explosion limit

RIEN WESSELINK
RIEN.WESSELINK@DEMCON.COM

PP = polypropylene

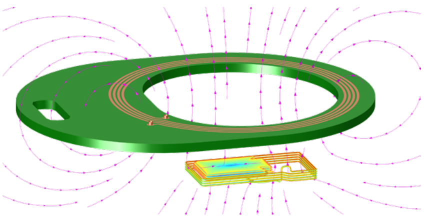
DEMCON | MULTIPHYSICS

Introduction

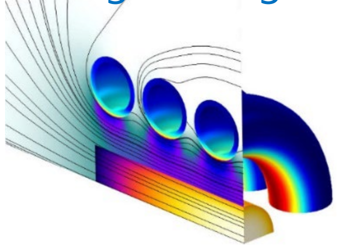
- Demcon group:
  - Engineering group, Netherlands
  - +1000 employees
  - Product and one-off development

- **Demcon Multiphysics**:
  - Physics consultancy division
  - 20 employees
  - Active in flow, thermal, electromagnetism, structural, etc.

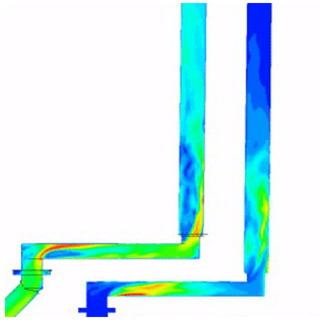
Electromagnetics



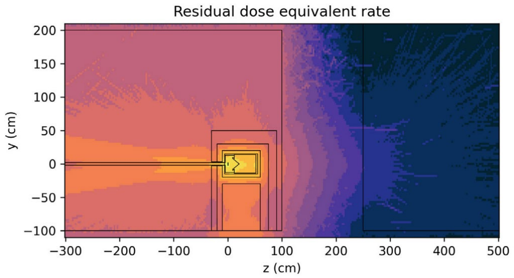
Thermal engineering



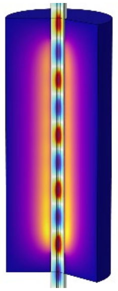
Fluid flows



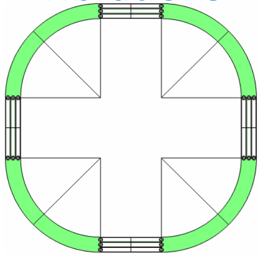
Nuclear physics



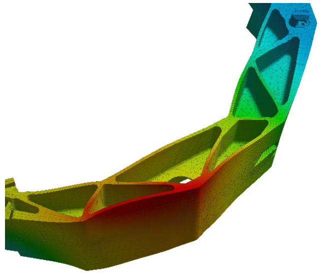
Plasma physics



Acoustics and vibrations



Structural mechanics



Experiments

Multiphysics engineer

DEMCON

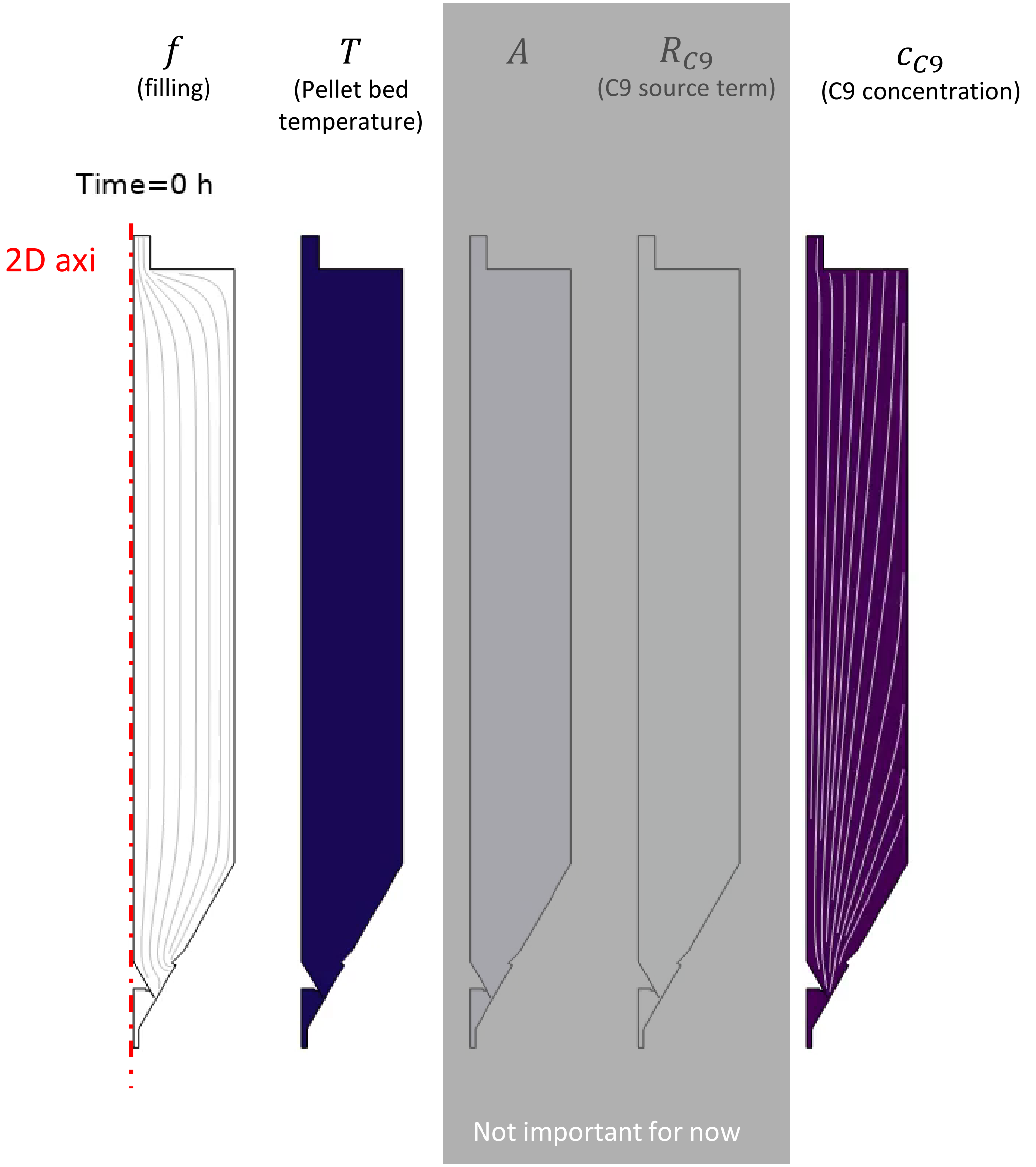
Problem statement

Situation:

- A silo is filled with polypropylene (PP) pellets
- The silo is purged with hot gas so that:
  - Pellets heat up
  - C9 gas is released (faster) due to higher T

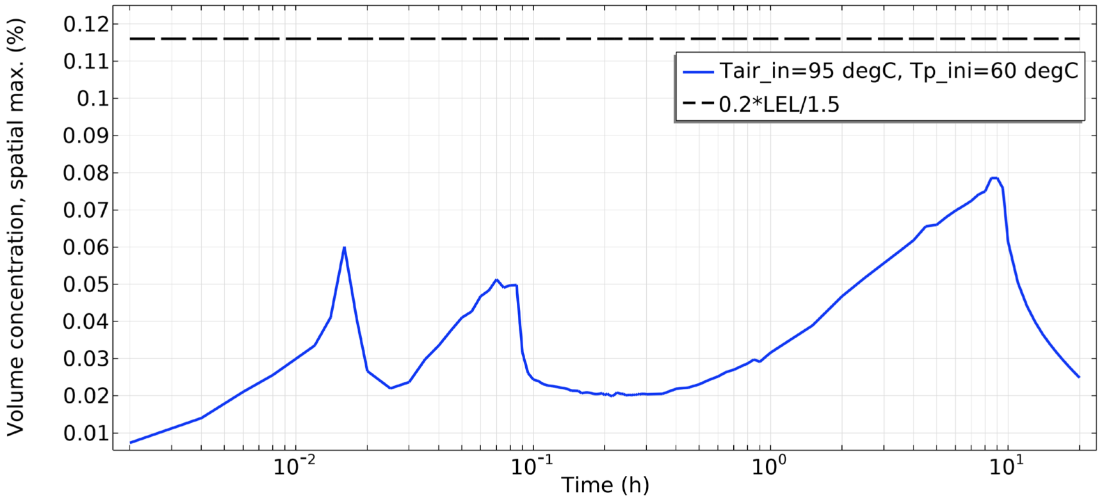
Goal of the model:

- The C9 concentration needs to be below the ‘lower explosion limit’ (LEL)
- The model allows to find the minimum flow rates that are required



Key result

maximum C9 concentration vs time



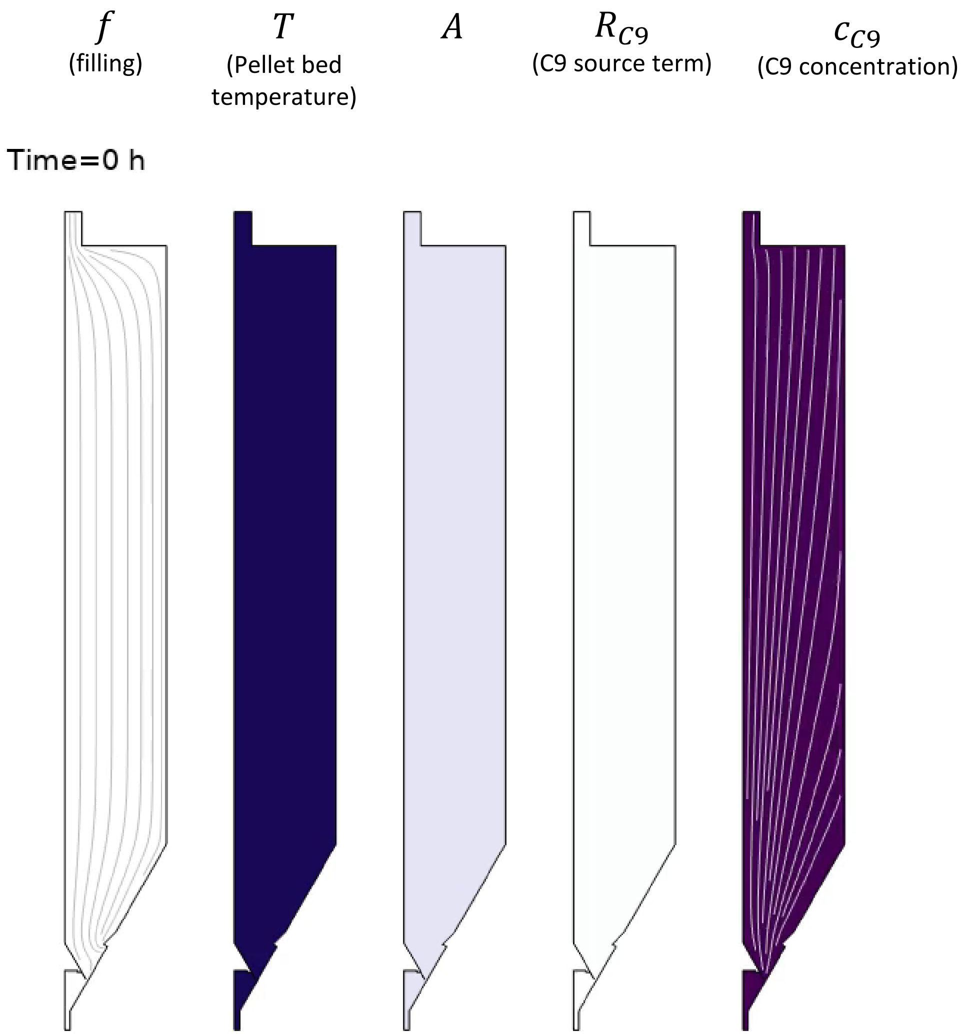
Outline

1. Explanation of the various ingredients in the model
2. Some insights concerning the peaks in concentration

‘Ingredients’

- Changing geometry of the porous bed
- Porous media flow
- Heat transfer
- C9 production rate
  (depends on history)
- Transport of C9

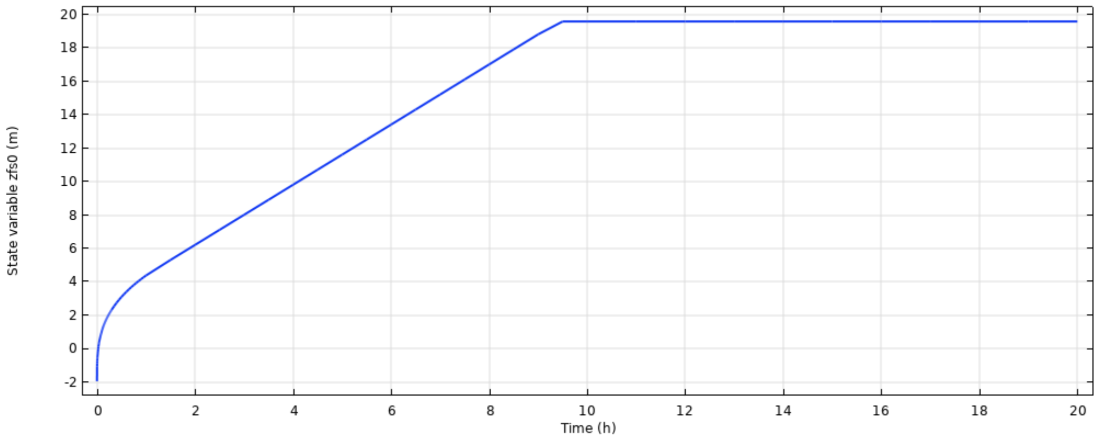
Everything is time-dependent

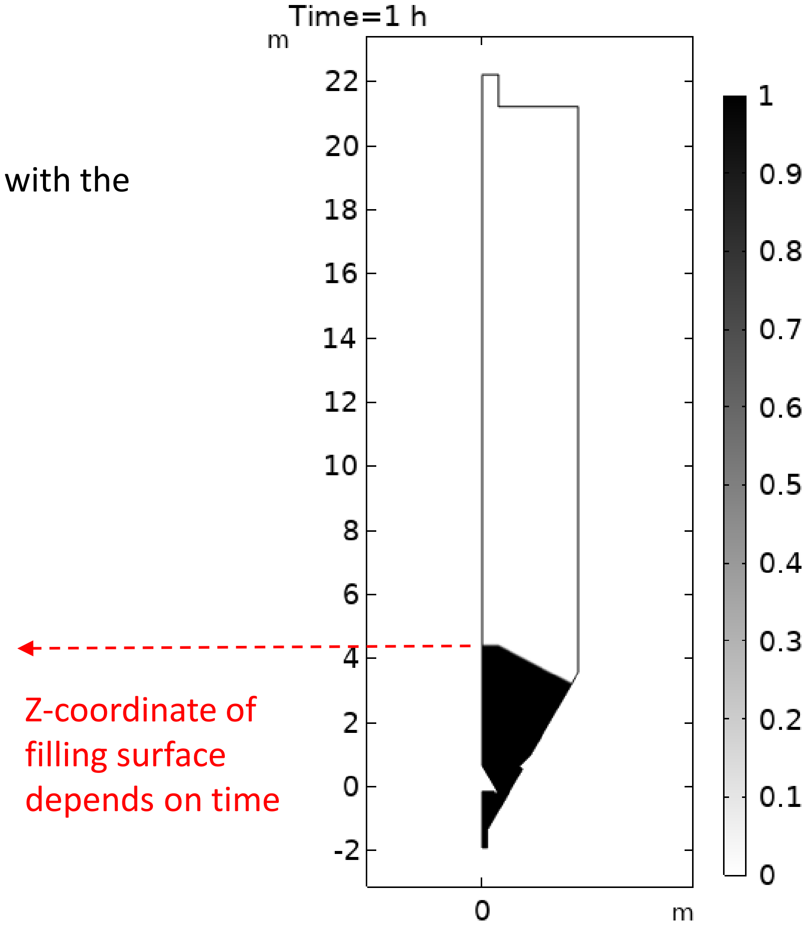


Filling surface

- A fixed shape for the 'filling surface' is assumed
- Below this surface: f = 1, above: f = 0
- The position of the filling surface is solved for, such that it is consistent with the inflow of pellets:

$$\text{pellet mass inflow} = \rho_{bed} \frac{d}{dt} \int f \, dV$$





Porous media flow

- We only use the first term of the Ergun equation:

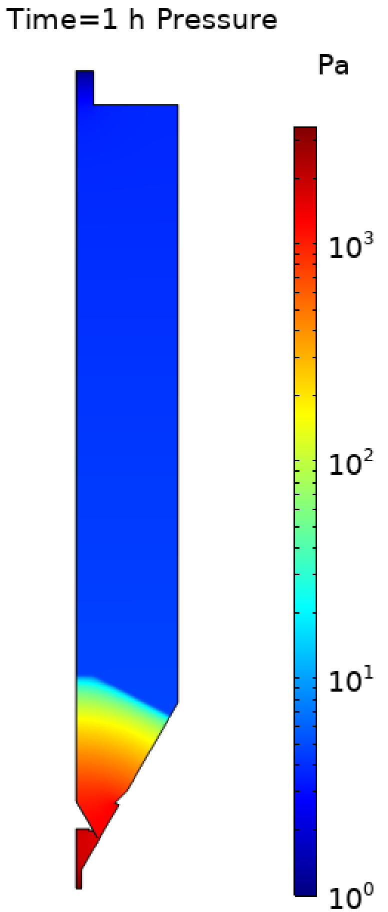
$$\nabla p = \frac{150\mu}{{D_p}^2}\frac{(1-\varepsilon)^2}{\varepsilon^3}\cdot v_s + \frac{1.75\rho}{{D_p}^2}\frac{(1-\varepsilon)}{\varepsilon^3}|v_s|\cdot v_s$$

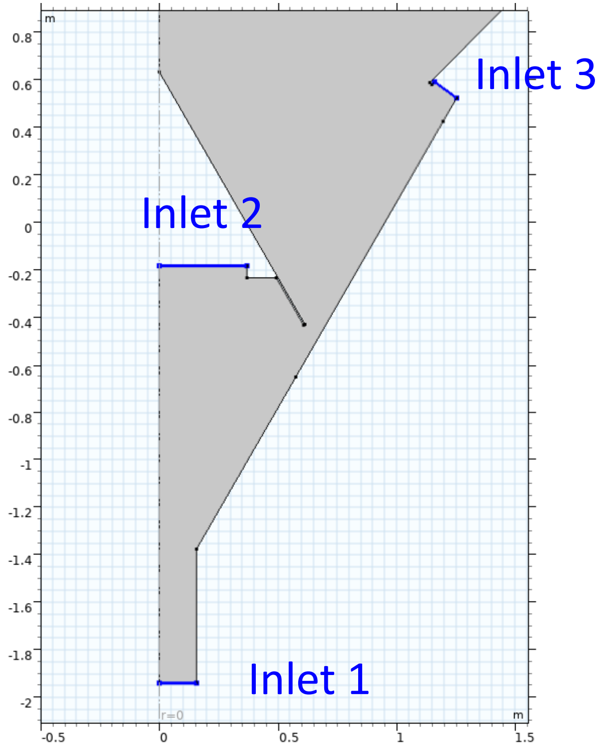
- The second term is only relevant for large flow velocities.
- So this is effectively Darcy's law with permeability

$$k = \frac{{D_p}^2}{150}\frac{\varepsilon^3}{(1-\varepsilon)^2}$$

- Outside the pellet bed (where f = 0) the permeability is scaled to an artificial large value.

D_p: pellet diameter
ε: porosity
v_s: superficial flow velocity





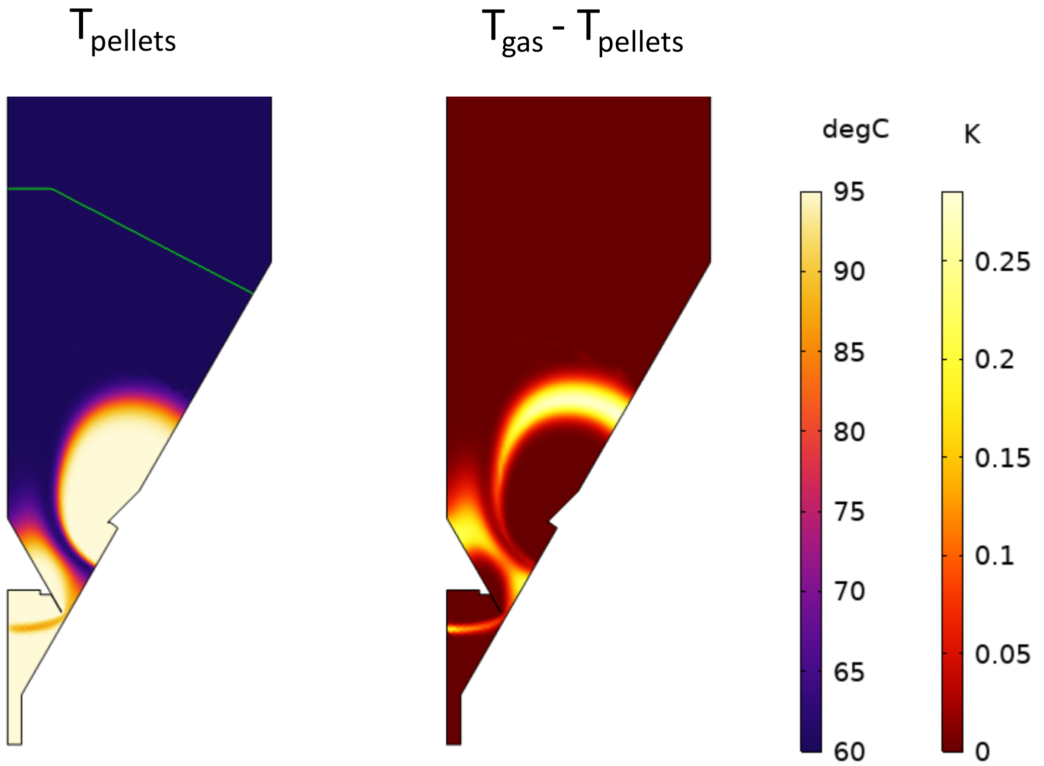
Two temperature model

- a.k.a 'local thermal non-equilibrium'
- The temperature of the pellets and purge gas are solved for separately.
- The exchange of heat between the two media goes via a volumetric heat source term:

$$Q = \frac{3(1-\varepsilon)}{R_p} h(T_{gas} - T_{pellets})$$

whereby h is deduced from some correlation.

- The details do not matter much for the end result, it is just a way to get the energy stored in the hot gas deposited in the right place (heating up 'cold' pellets).

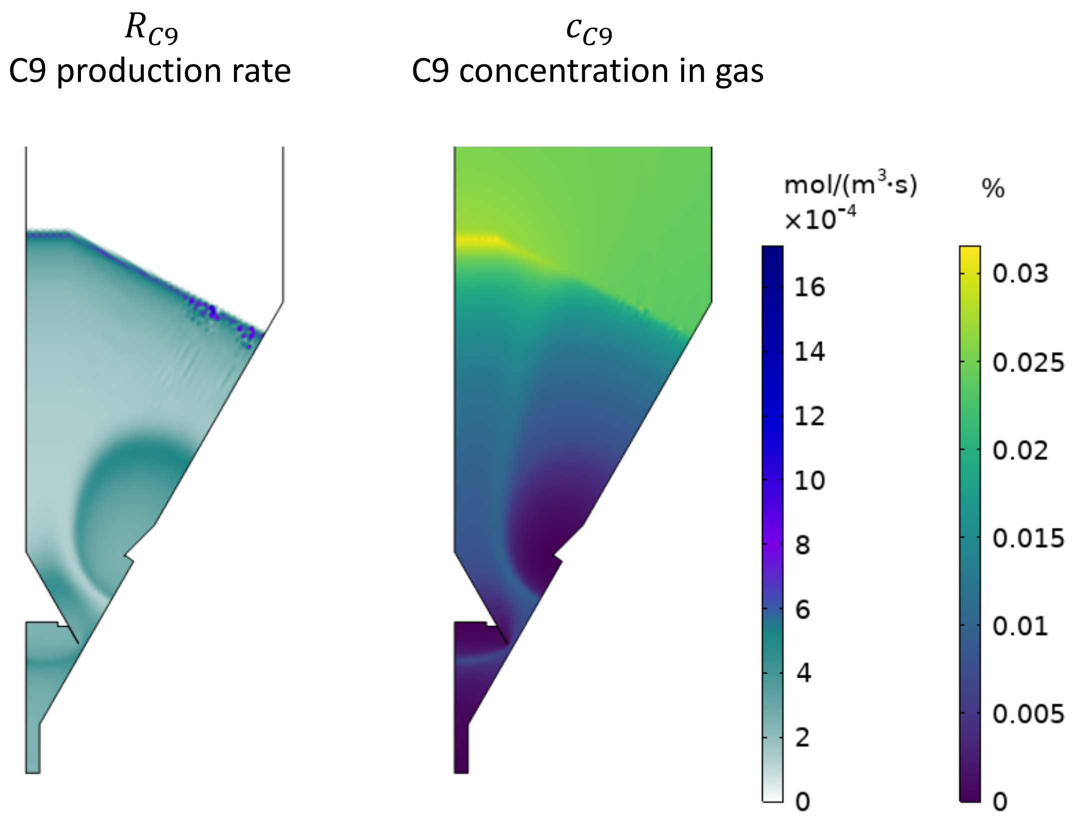


C9 concentration

- The C9 concentration **in the gas** is solved for with a standard convection-diffusion equation.
- The diffusivity of C9 in the gas is put to an artificial low value, so that only the advection matters.
- The tricky thing here is determining the C9 source term or production rate.
- Note that the source term should be proportional to the decrease in average concentration in the pellets:

$$R_{C9} = -\frac{\rho_{\text{bulk}}}{M} \cdot \frac{d}{dt} c_{\text{C9,pellet,av}}$$

ρ_{bulk}: pellet bed density
M: C9 molar mass
$c_{\text{C9,pellet,av}}$: average C9 concentration in pellets (mol/m^3)



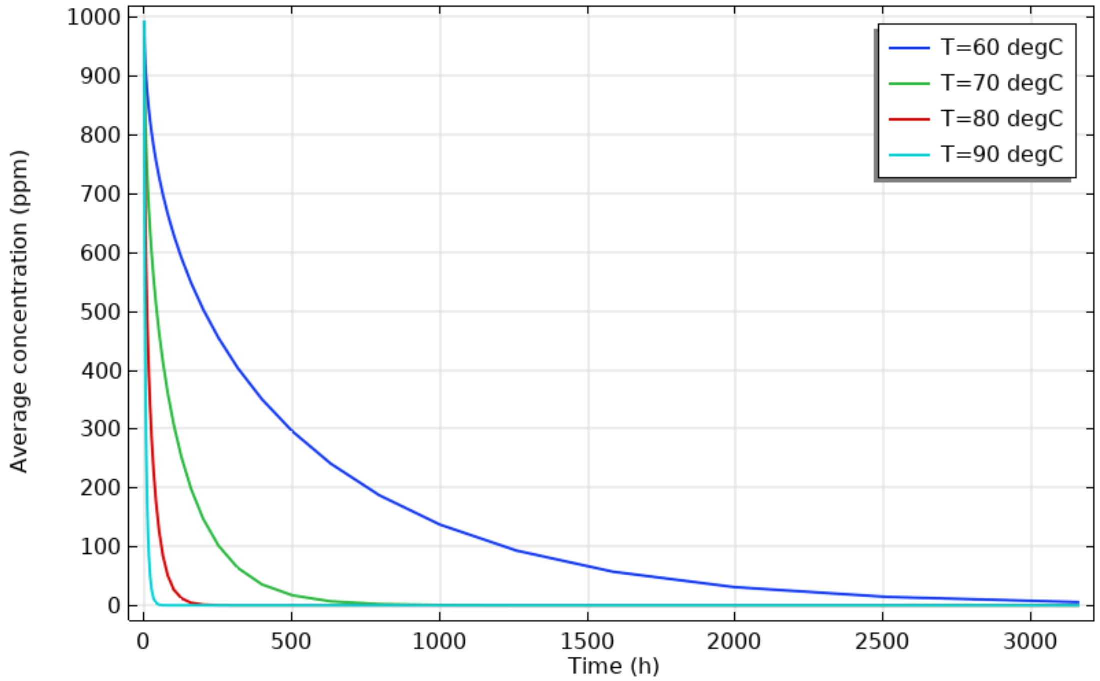
Average C9 concentration in a pellet

- Diffusivity of C9 in PP as function of temperature is given:

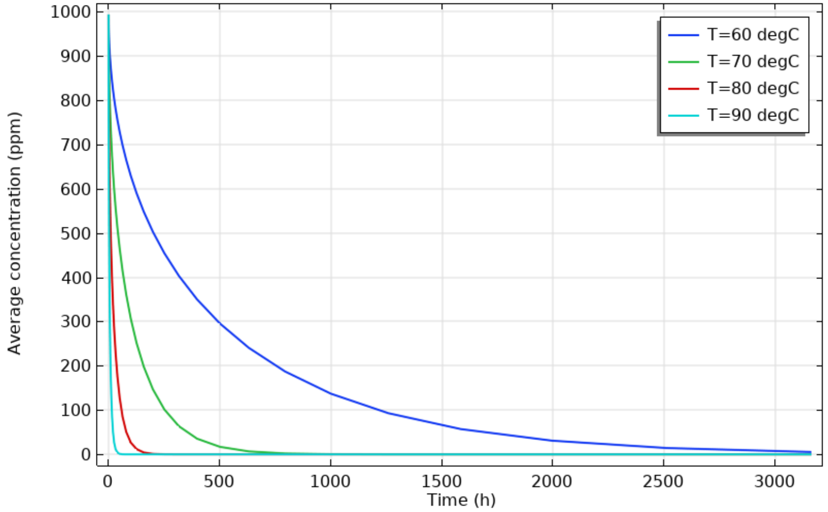
$$D(T)$$

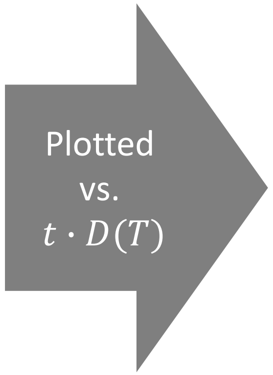
- The average concentration in a pellet over time can be analytically calculated →

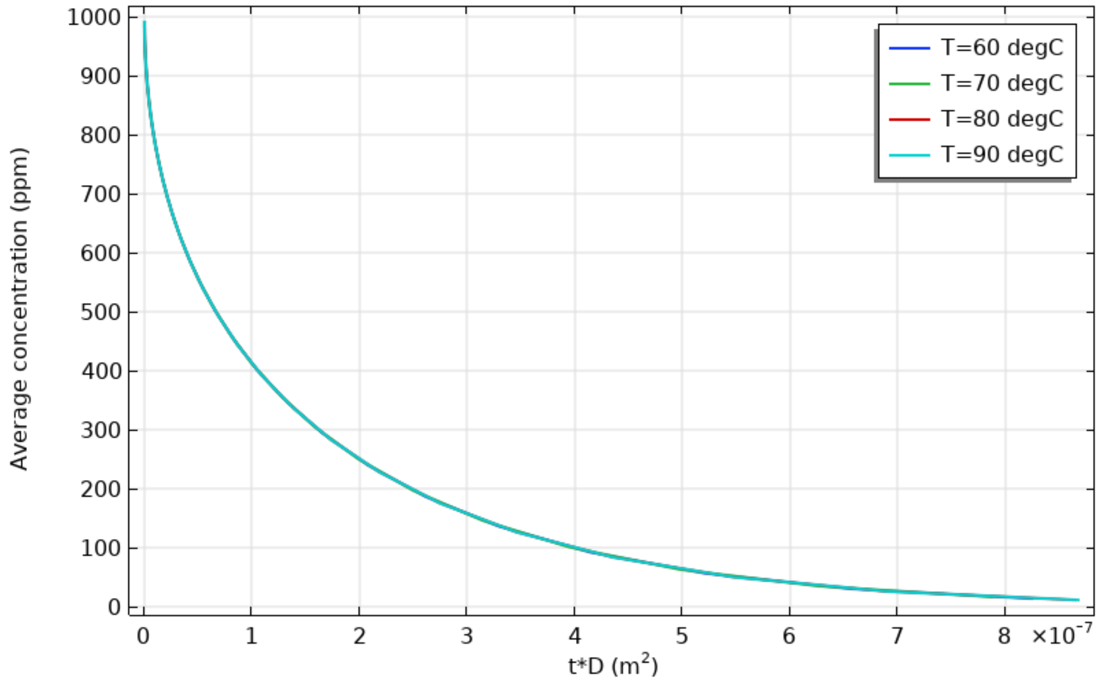
- Problem: this is temperature-dependent and the temperature depends on time



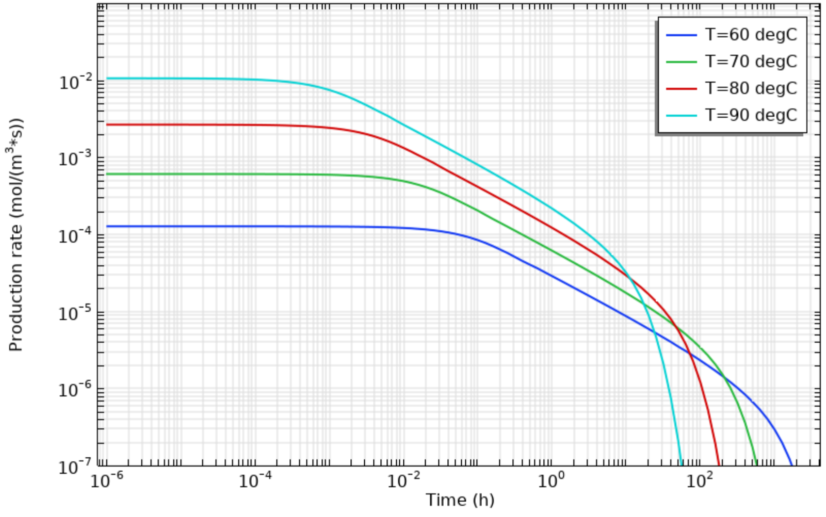
Average C9 concentration in a pellet

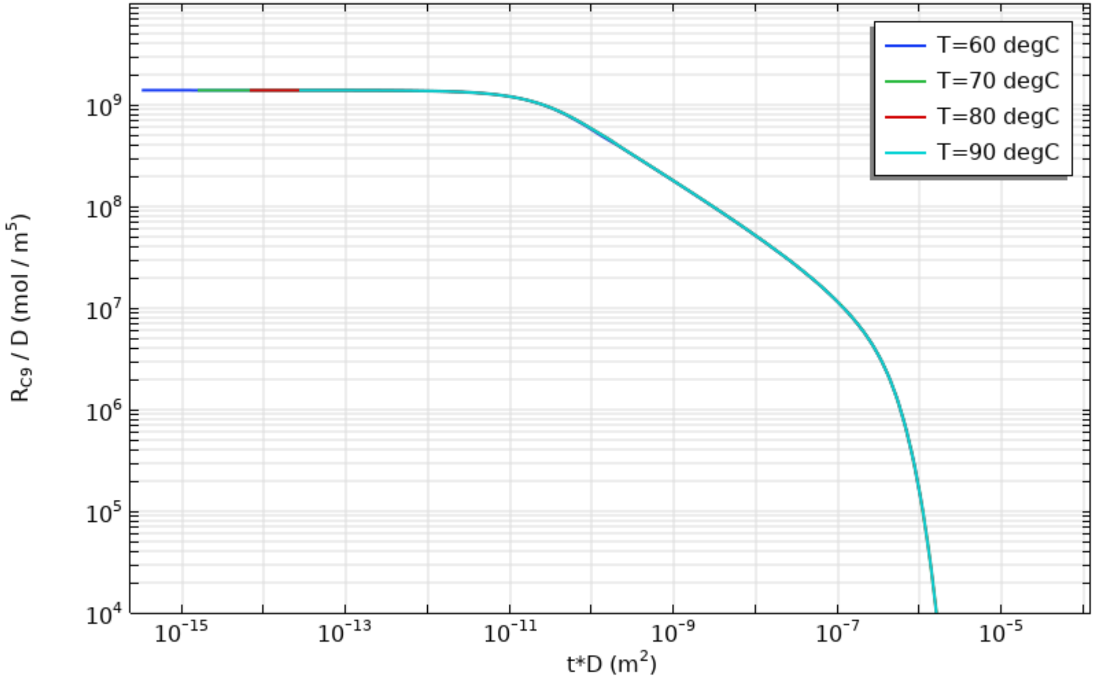






C9 production rate

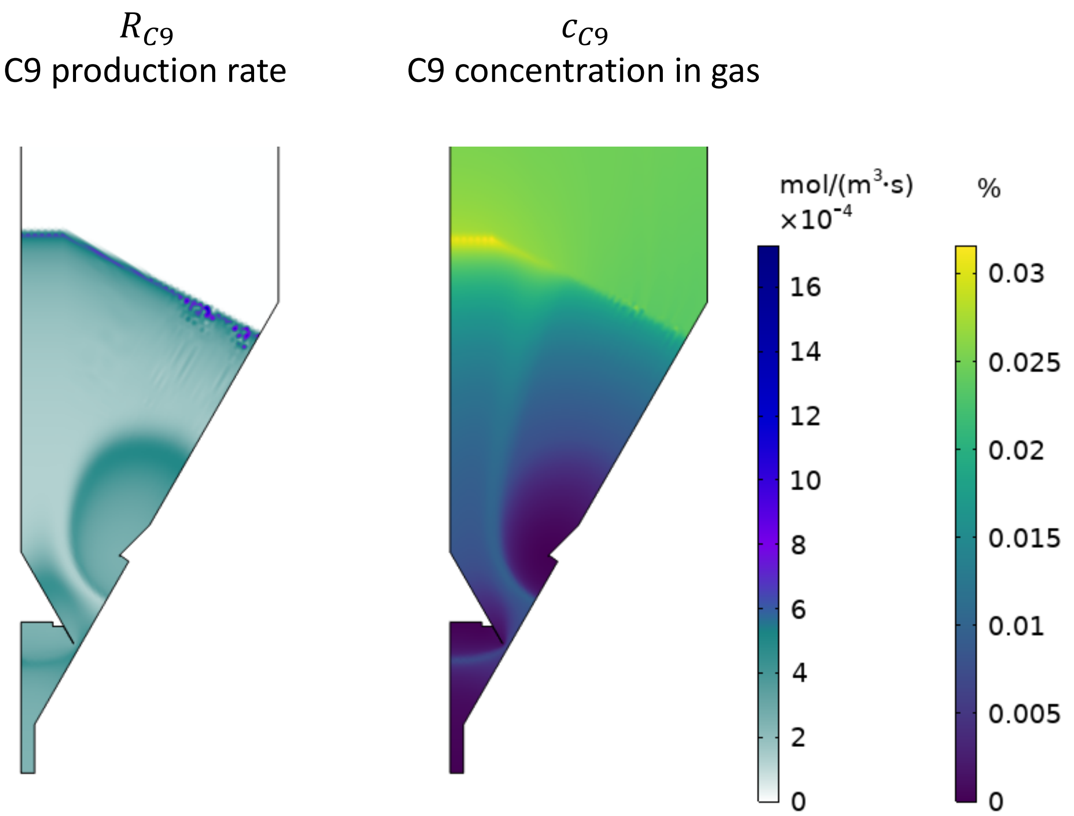




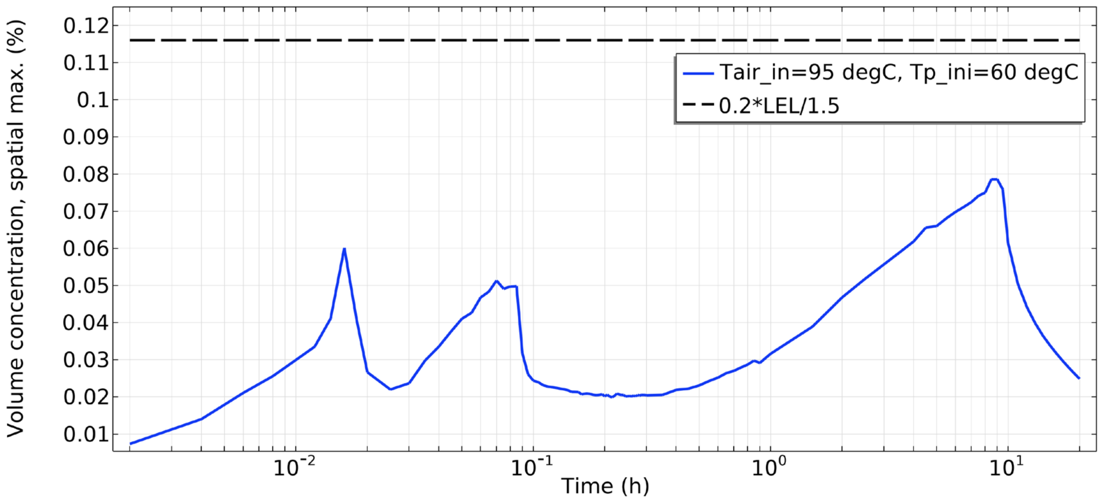
- More general: $R_{C9}/D(T)$ is a fixed function of $A = \int_0^t fD(T)dt$

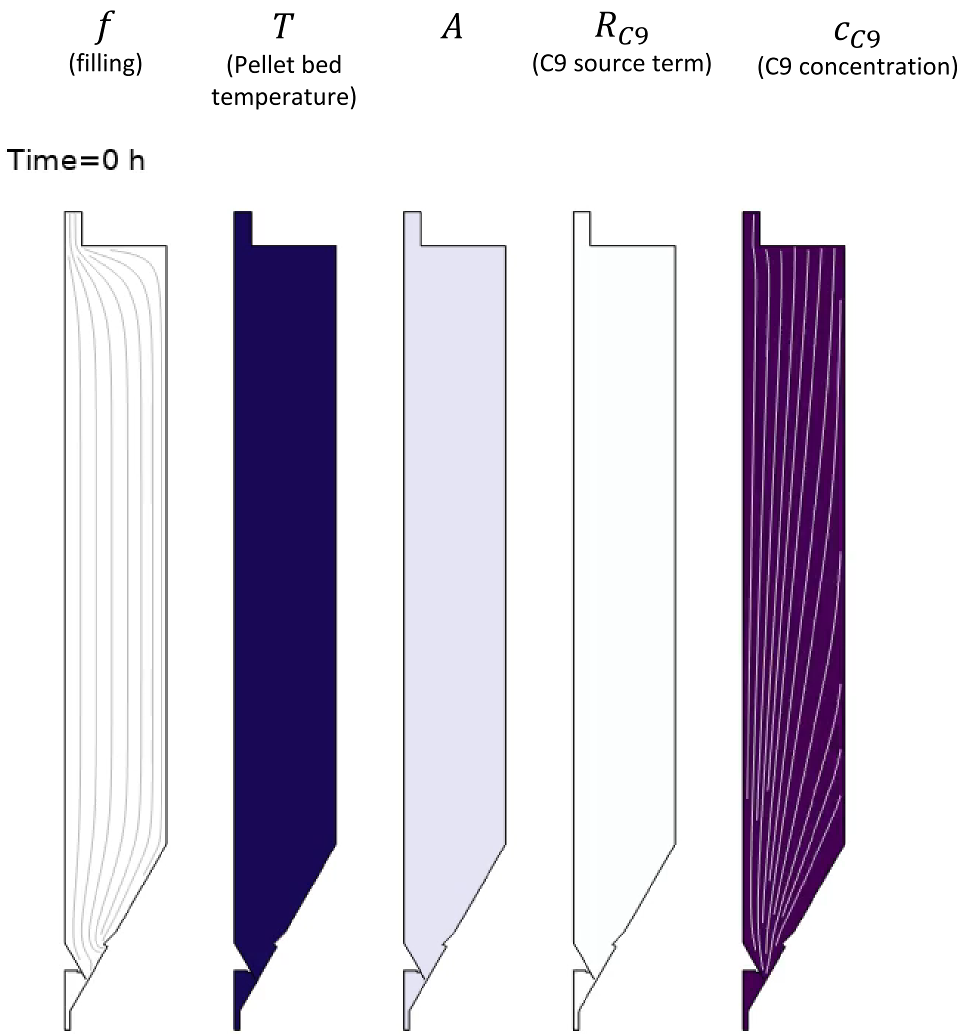
C9 concentration

- The C9 concentration **in the gas** is solved for with a standard convection-diffusion equation.
- The diffusivity of C9 in the gas is put to an artificial low value, so that only the advection matters.
- $R_{C9}/D(T)$ is a fixed function of $A = \int_{t_0}^{t} fD(T)dt$
- The integral for A is determined in the silo model at each location and filled in in an interpolation function from which R_{C9} is determined.

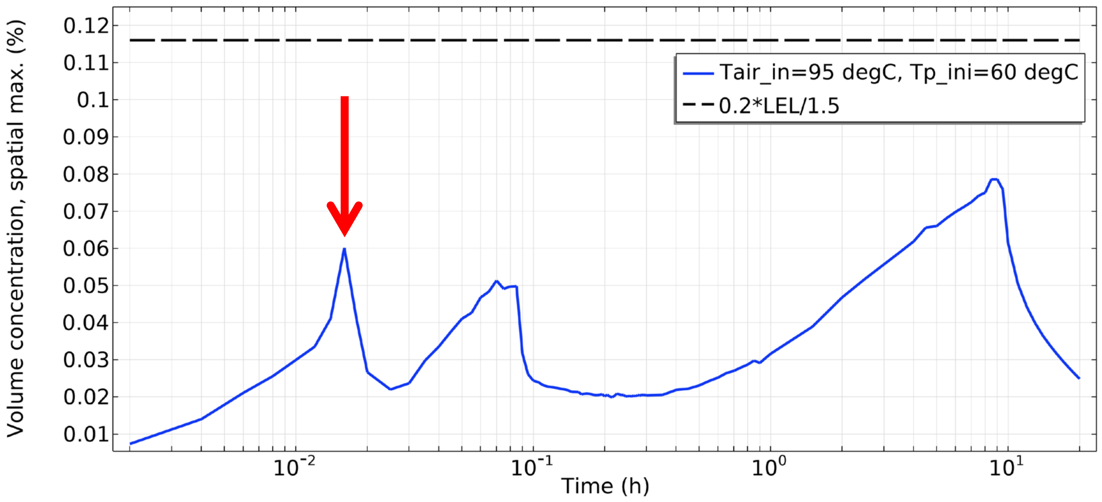


Result

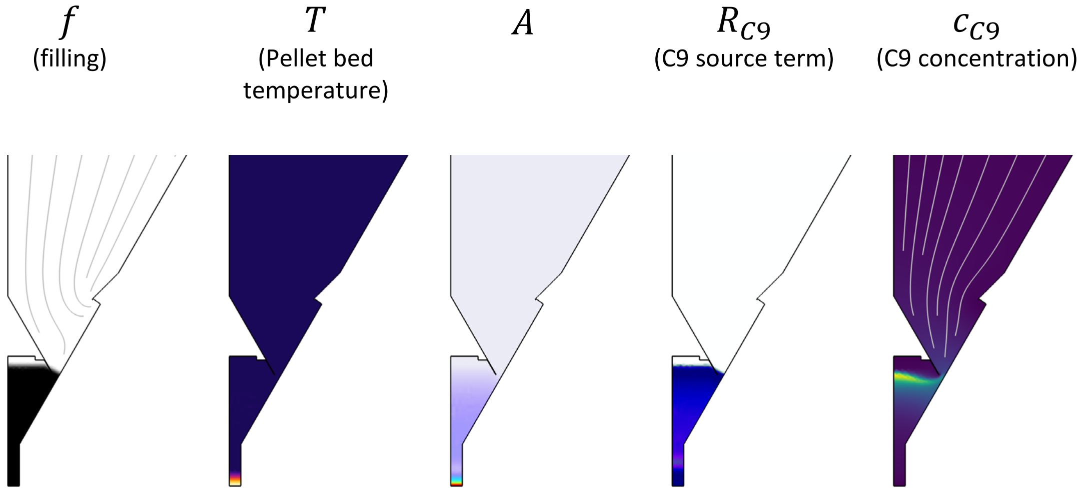

Volume concentration, spatial max. (%)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Tair_in=95 degC, Tp_ini=60 degC
0.2*LEL/1.5
10^{-2}
10^{-1}
10^{0}
10^{1}
Time (h)


f
(filling)
T
(Pellet bed temperature)
A
R_{C9}
(C9 source term)
c_{C9}
(C9 concentration)
Time=0 h

1st peak

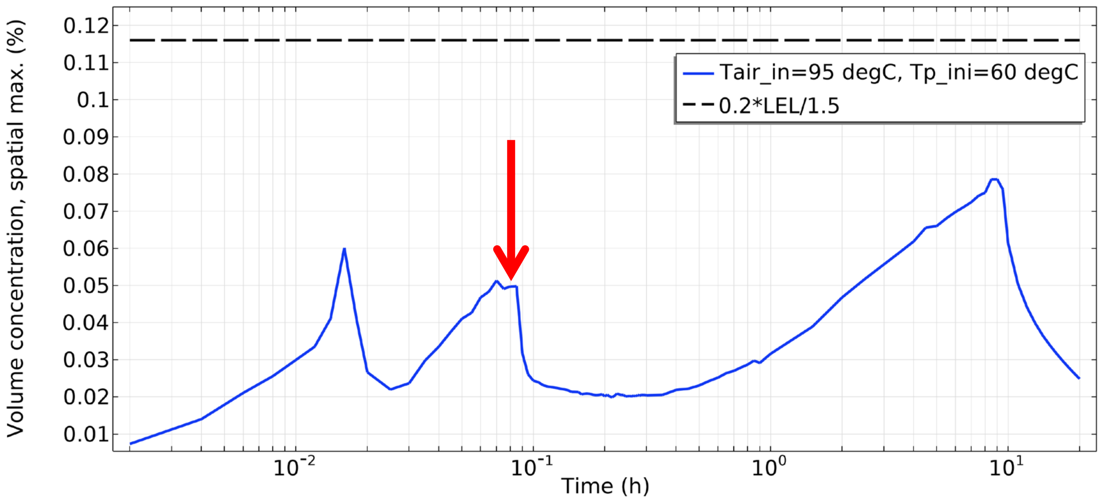


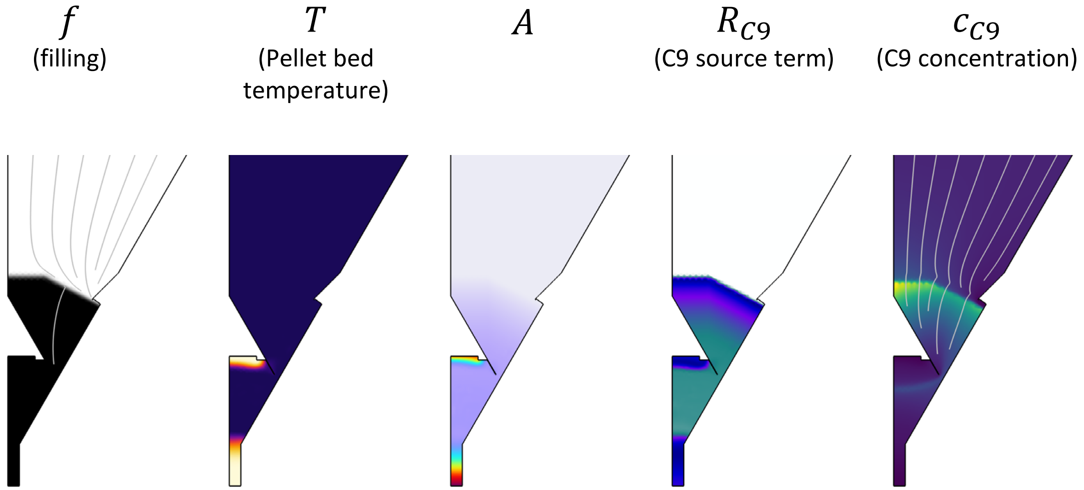
Volume concentration, spatial max. (%)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Tair_in=95 degC, Tp_ini=60 degC
0.2*LEL/1.5
10^-2
10^-1
10^0
10^1
Time (h)



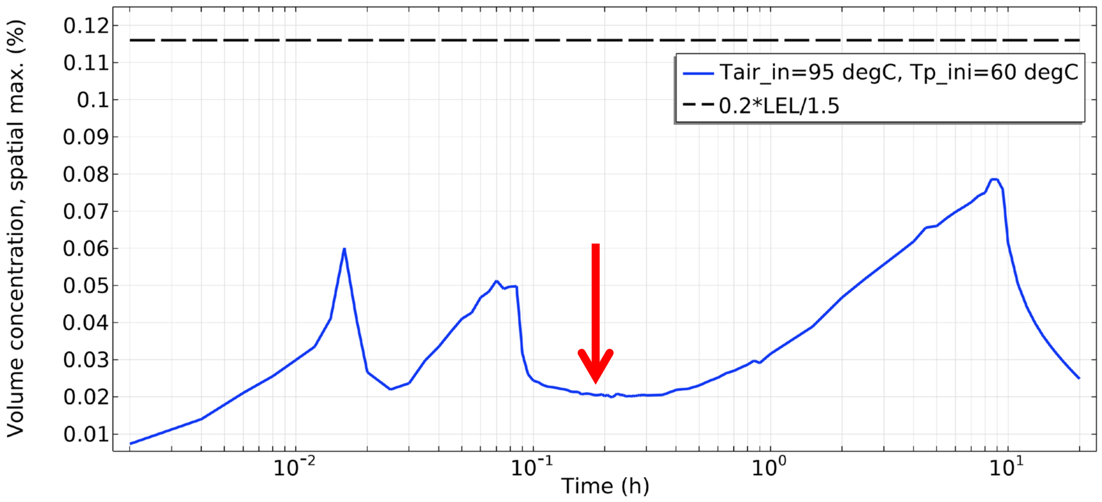
f (filling)
T (Pellet bed temperature)
A
R_{C9} (C9 source term)
c_{C9} (C9 concentration)

2^{nd} peak

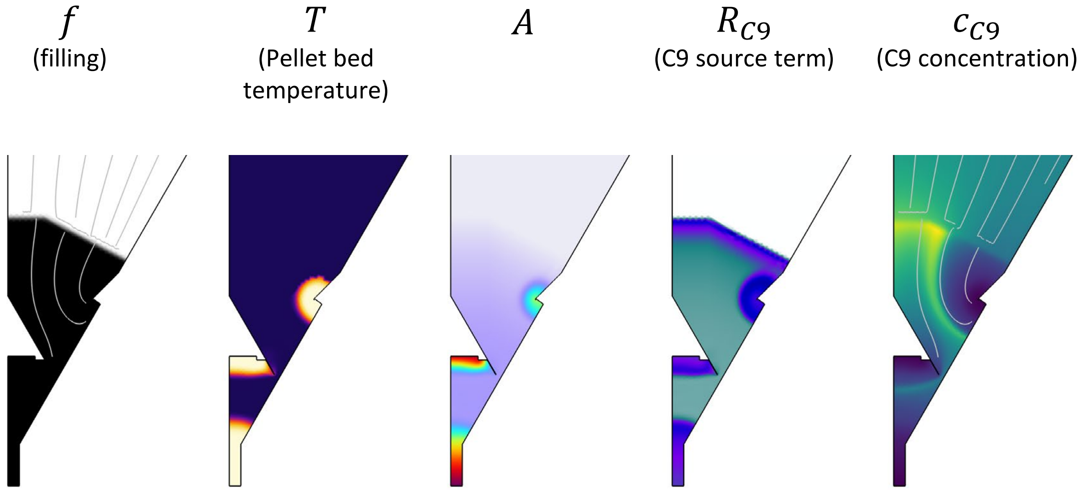

Volume concentration, spatial max. (%)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Tair_in=95 degC, Tp_ini=60 degC
0.2*LEL/1.5
10^-2
10^-1
10^0
10^1
Time (h)


f
(filling)
T
(Pellet bed temperature)
A
R_C9
(C9 source term)
c_C9
(C9 concentration)

t = 0.18 h

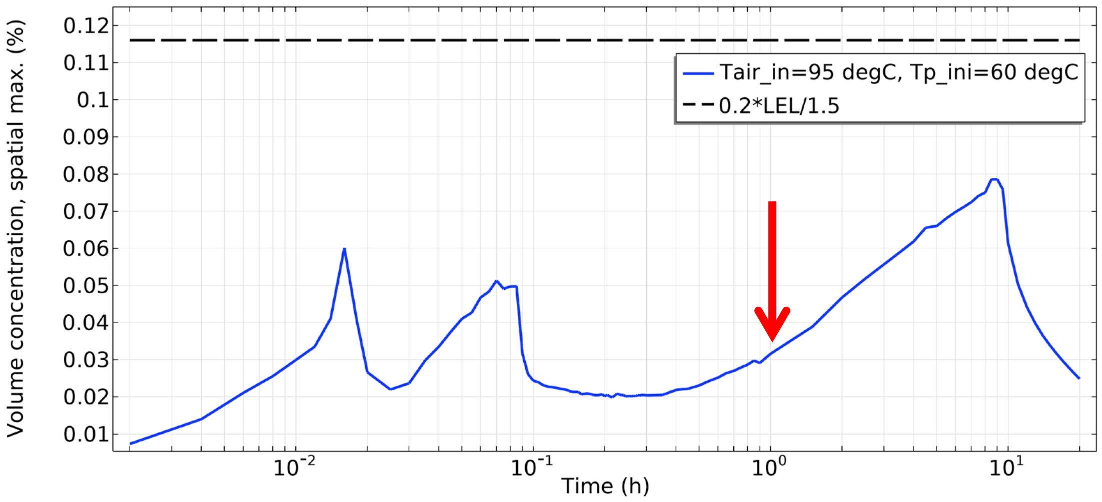


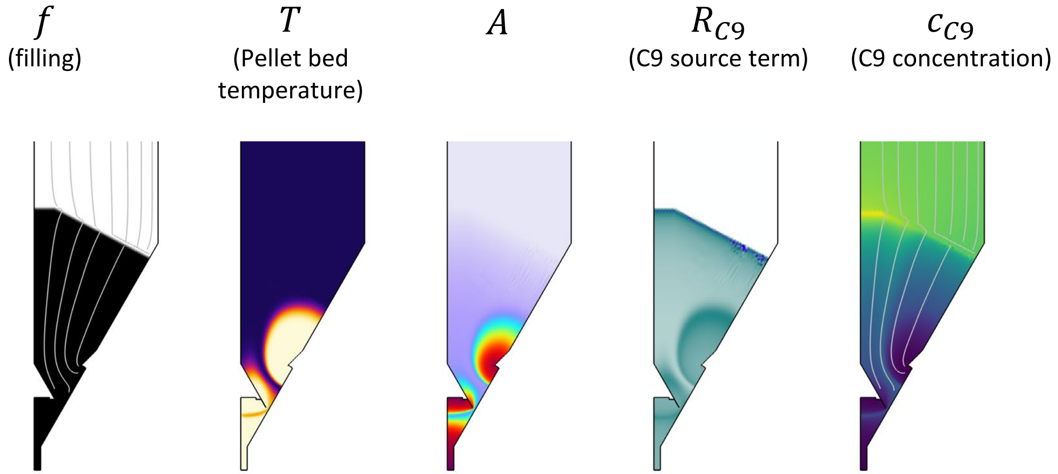
Volume concentration, spatial max. (%)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
10^{-2}
10^{-1}
10^{0}
10^{1}
Time (h)
Tair_in=95 degC, Tp_ini=60 degC
0.2*LEL/1.5



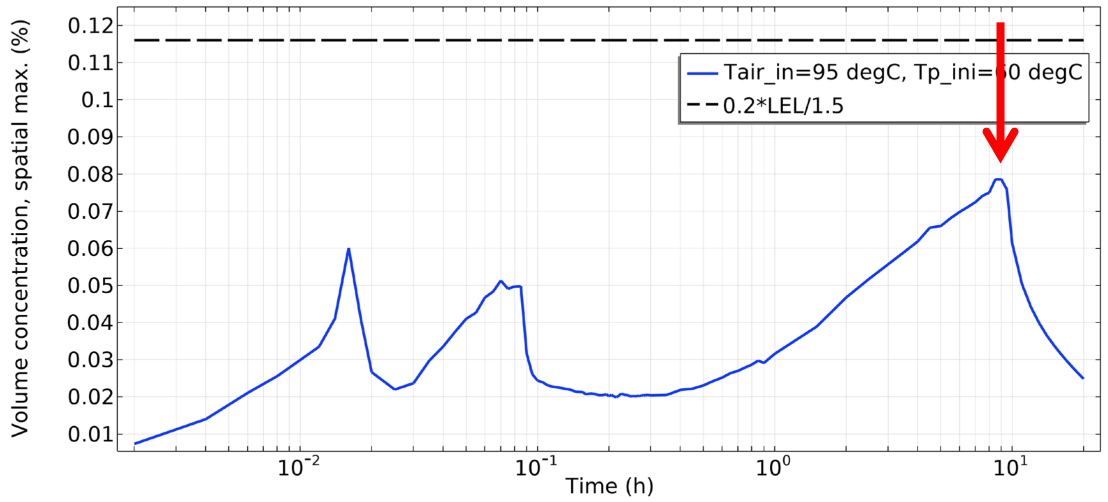
f
(filling)
T
(Pellet bed temperature)
A
R_{C9}
(C9 source term)
c_{C9}
(C9 concentration)

t = 1 h

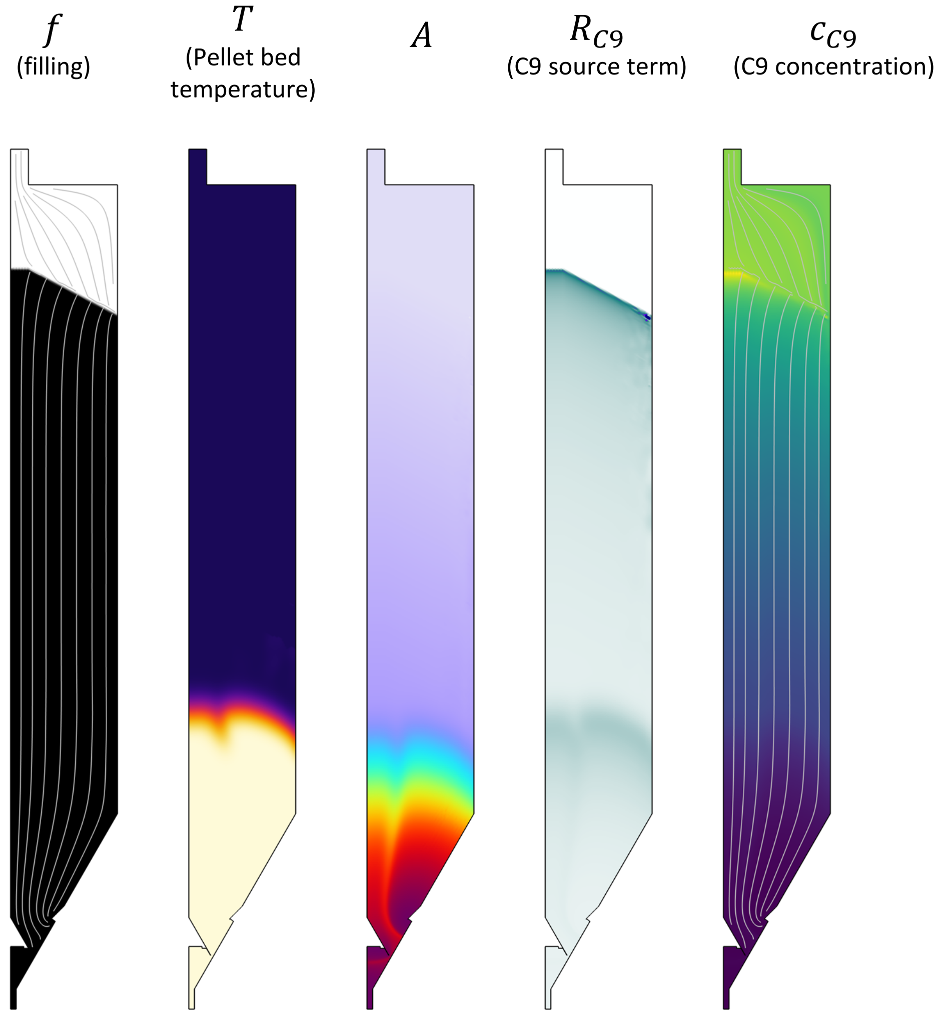

Volume concentration, spatial max. (%)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Tair_in=95 degC, Tp_ini=60 degC
0.2*LEL/1.5
10^{-2}
10^{-1}
10^{0}
10^{1}
Time (h)


f
(filling)
T
(Pellet bed temperature)
A
R_{C9}
(C9 source term)
c_{C9}
(C9 concentration)

3rd peak



Volume concentration, spatial max. (%)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
10^-2
10^-1
10^0
10^1
Time (h)
Tair_in=95 degC, Tp_ini=60 degC
0.2*LEL/1.5



f
(filling)
T
(Pellet bed temperature)
A
R_C9
(C9 source term)
c_C9
(C9 concentration)

Summary

- We built a model to find the minimum flow rates to make sure that the C9 concentration at any point in the silo is always below the lower explosion limit (LEL).
- The peaks in concentration arise:
  (and we can understand this)
  1. just before a certain inlet is covered with pellets
  2. when the silo is full, and the pellet inflow stops

Contact:

rien.wesselink@demcon.com