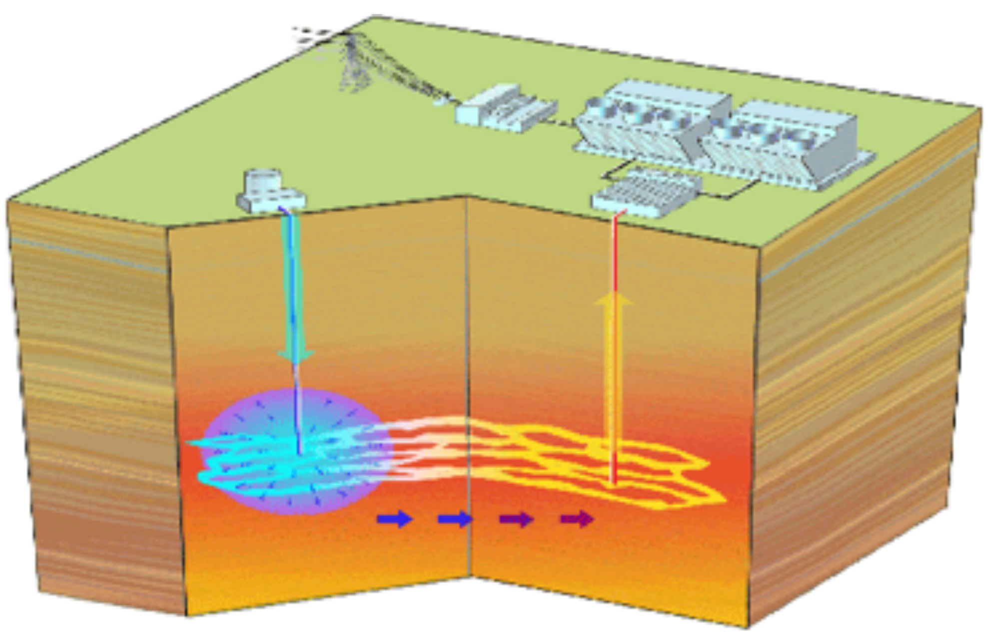
Lourdais Pierre
X2010
Supervisor: Glaser Steven
Coordinator: Specka Arnd

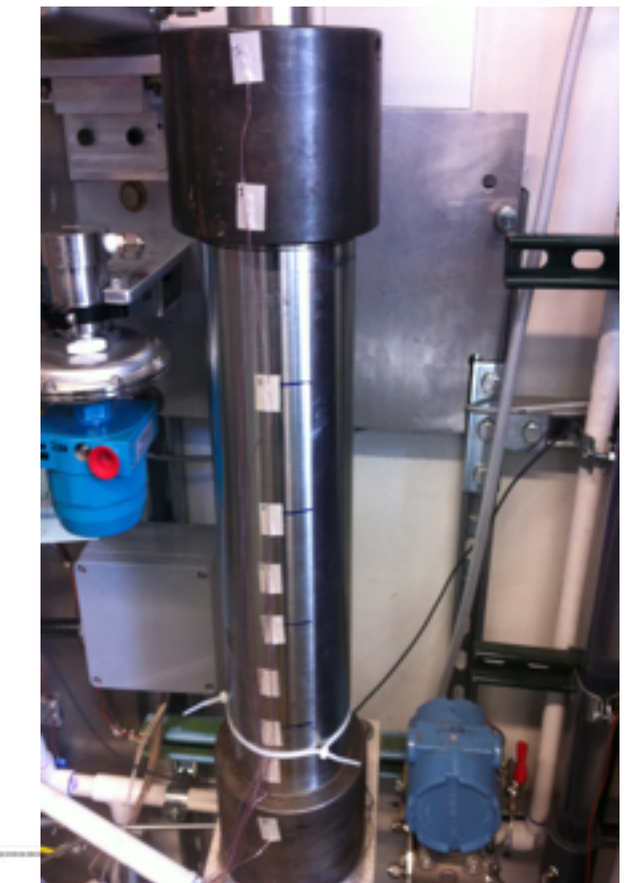
Civil Engineering Department

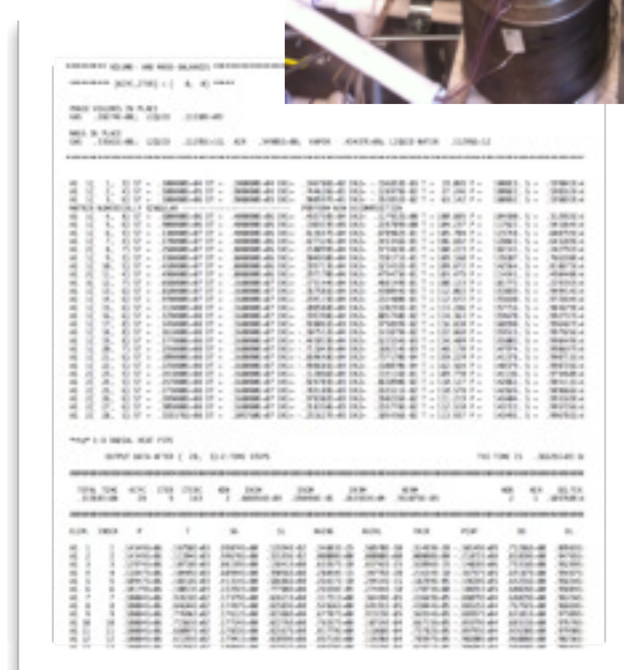
Heat extraction from a porous media with supercritical CO2

General Features

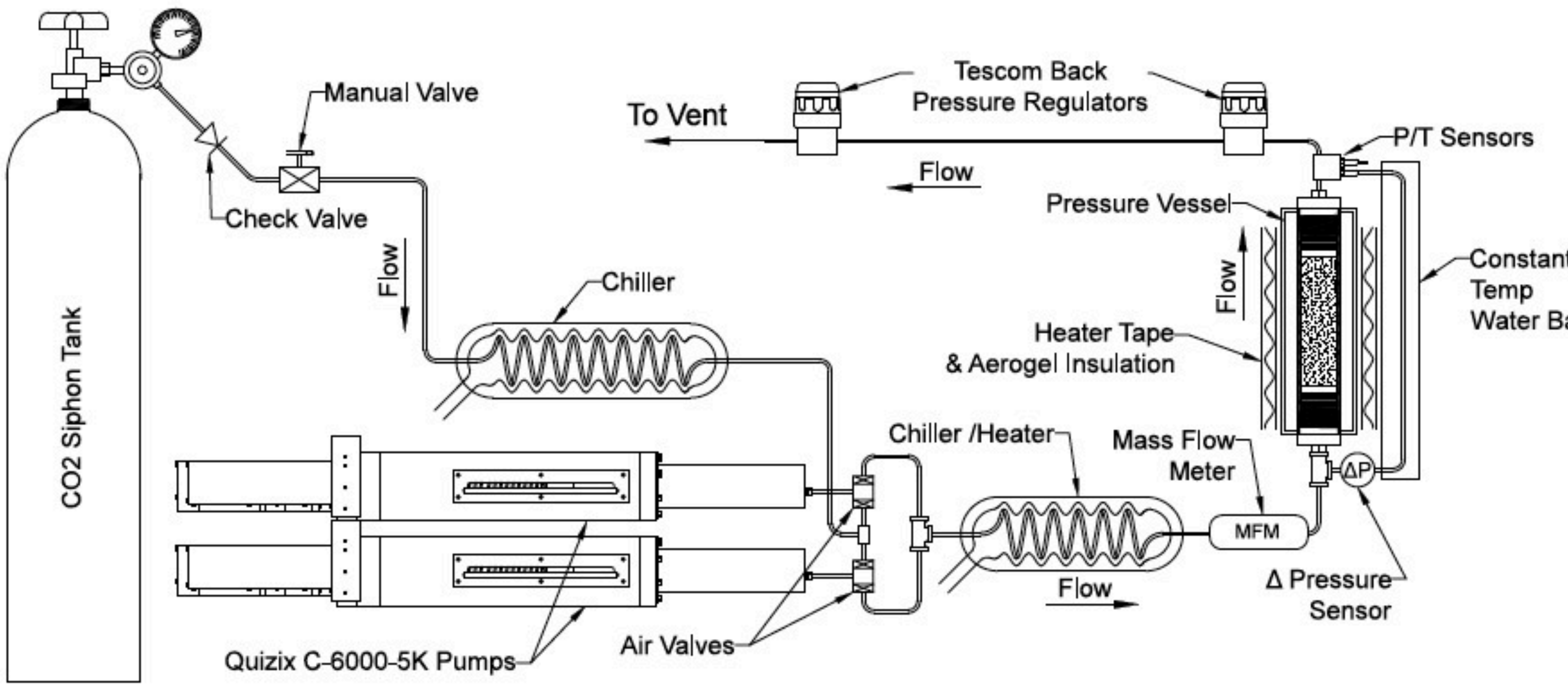
- 14 weeks: 04/07/13 - 07/12/13
- EGS: Enhanced Geothermal Systems
- Modelisation and experimentation works
- Contribute to Mario Magliocco's project







Main experiment



Laboratory and Numerical Studies of Heat Extraction from Hot Porous Media by Means of supercritical CO_2
Mario Magliocco

Main lines

- Vertical inhomogeneity of temperature
- Time dependent simulation
- Pytough implementation
- Experiments

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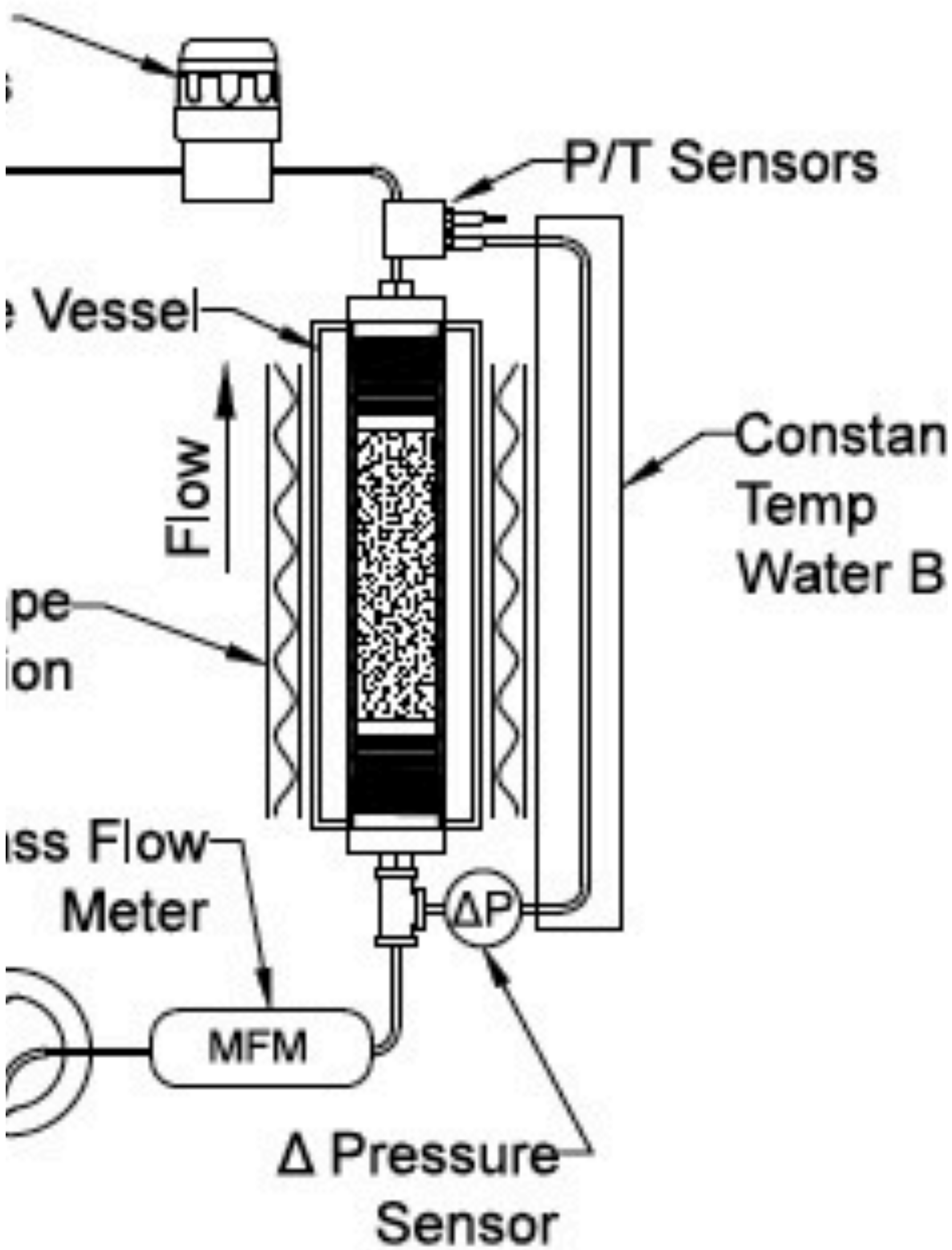
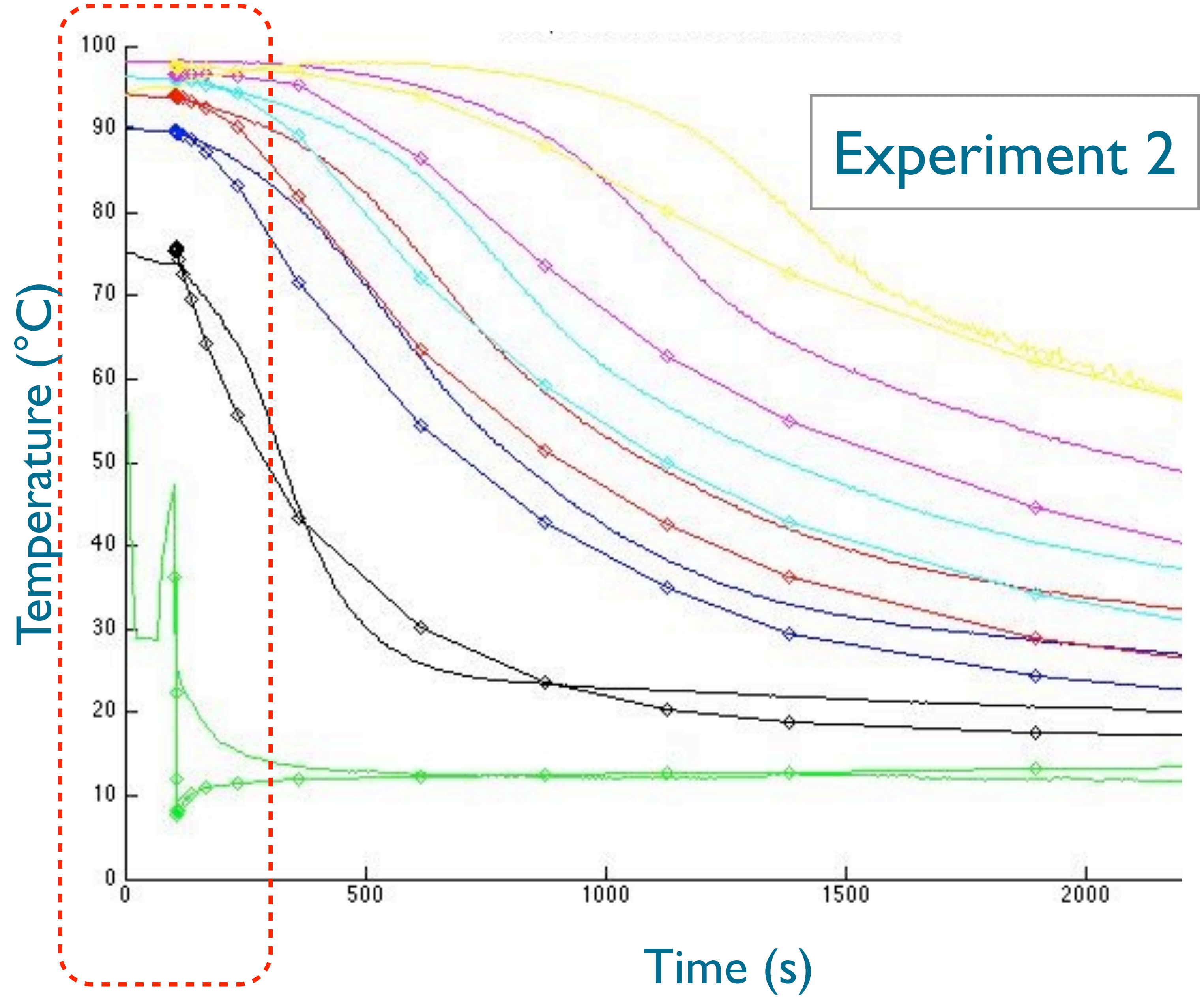
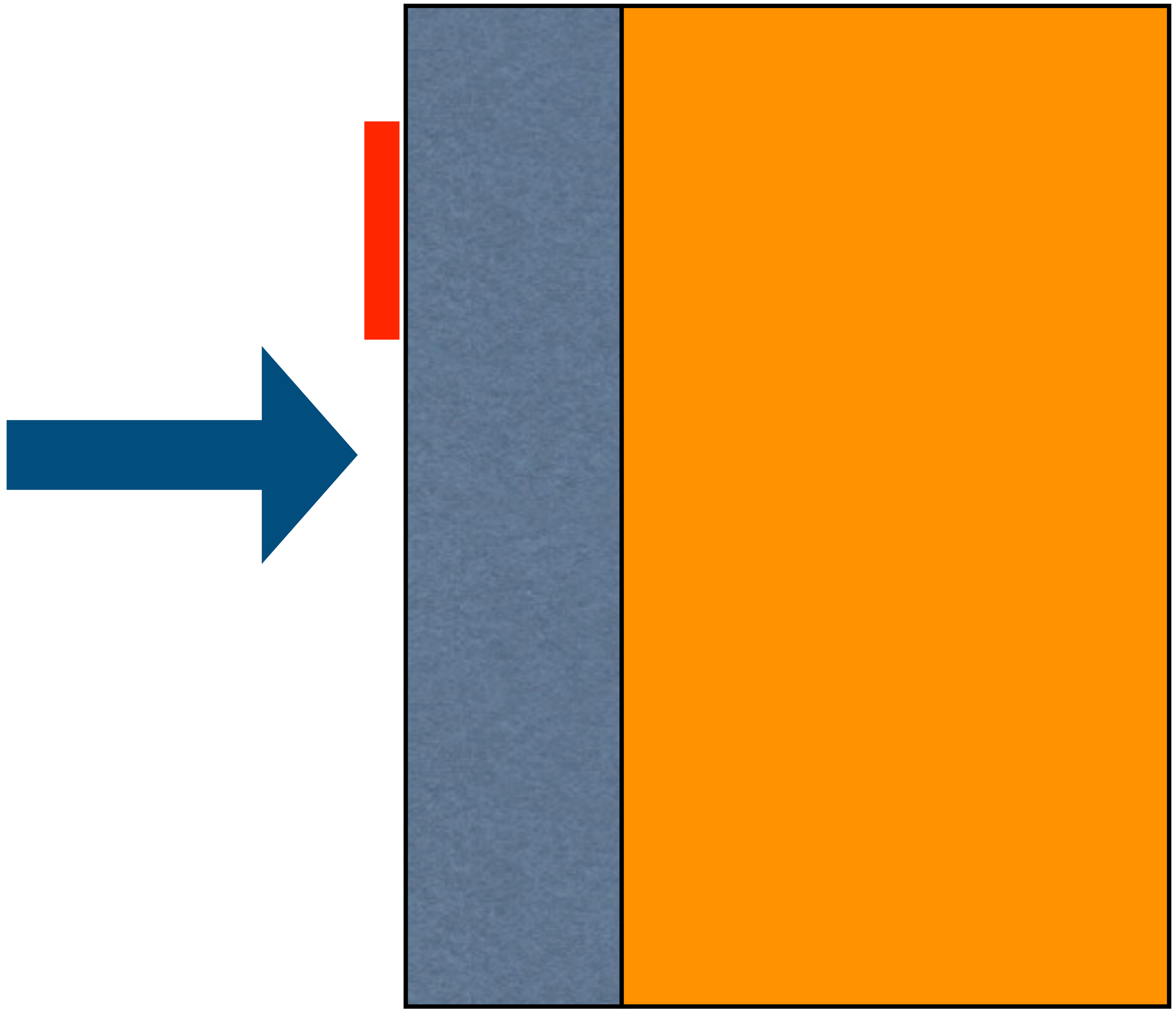
Vertical Inhomogeneity





Initial Conditions:
[35°C - 98°C]

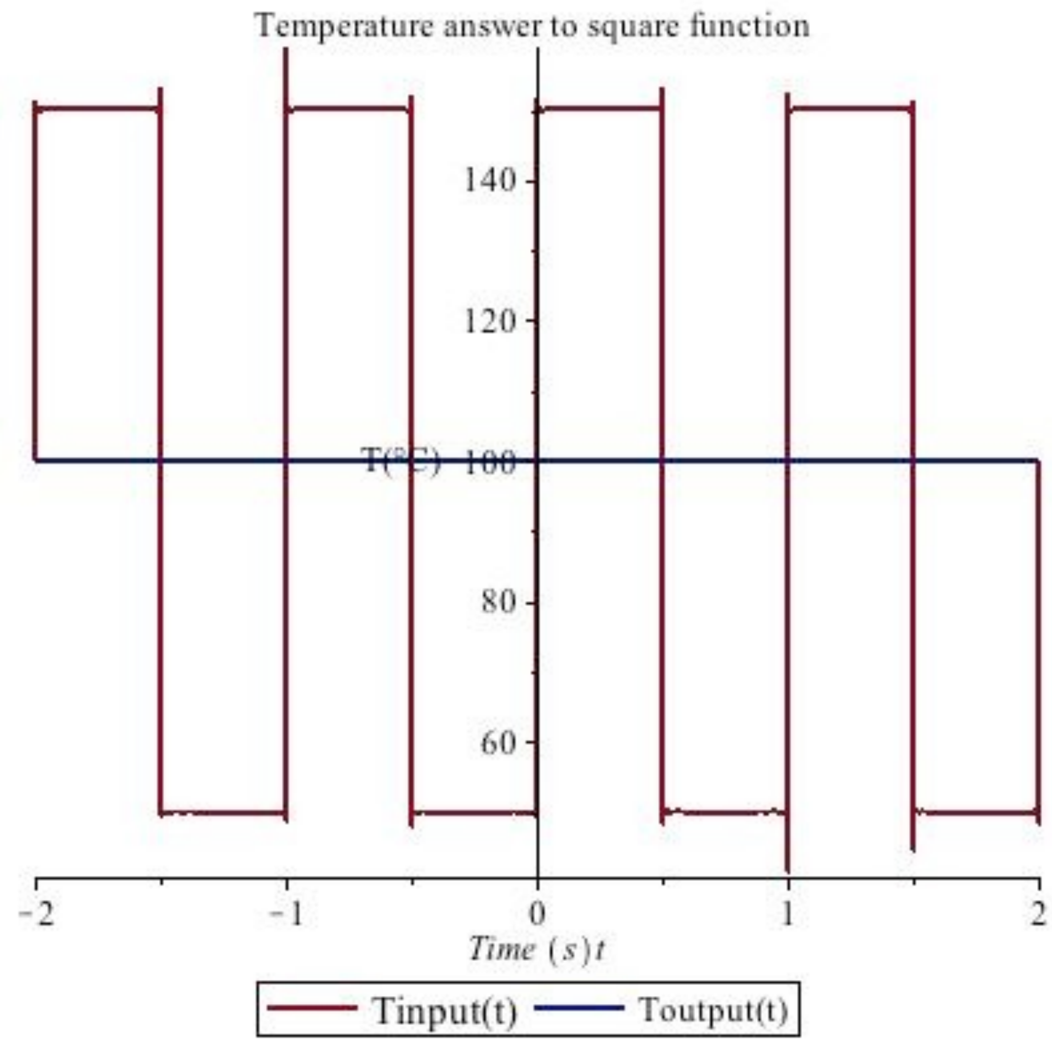
Temperature regulation



Stainless steel

Temperature regulation

$$First\ correction\ term:$$
$$\propto\ A\,sin(wt)$$
$$A\ \sim\ 10^{-12}$$



Convection

Gravity

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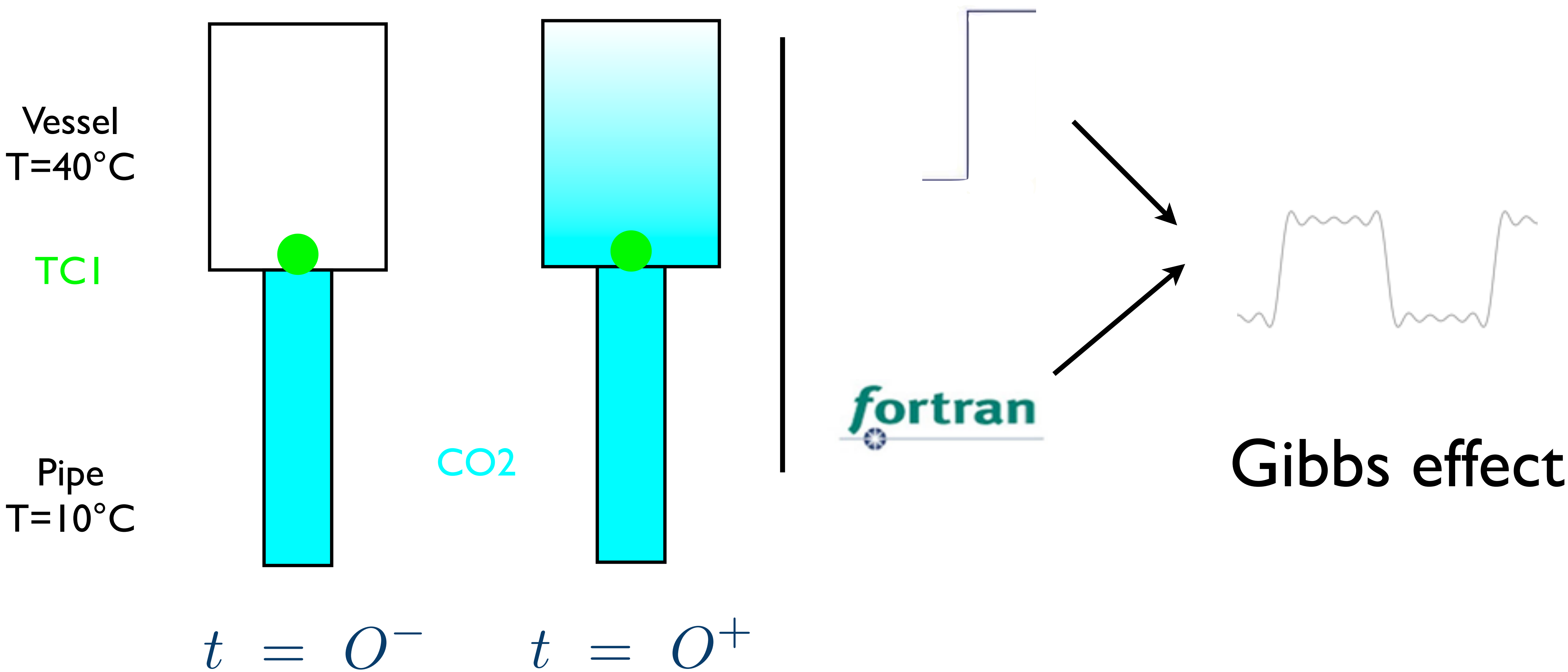
Time dependent Simulation



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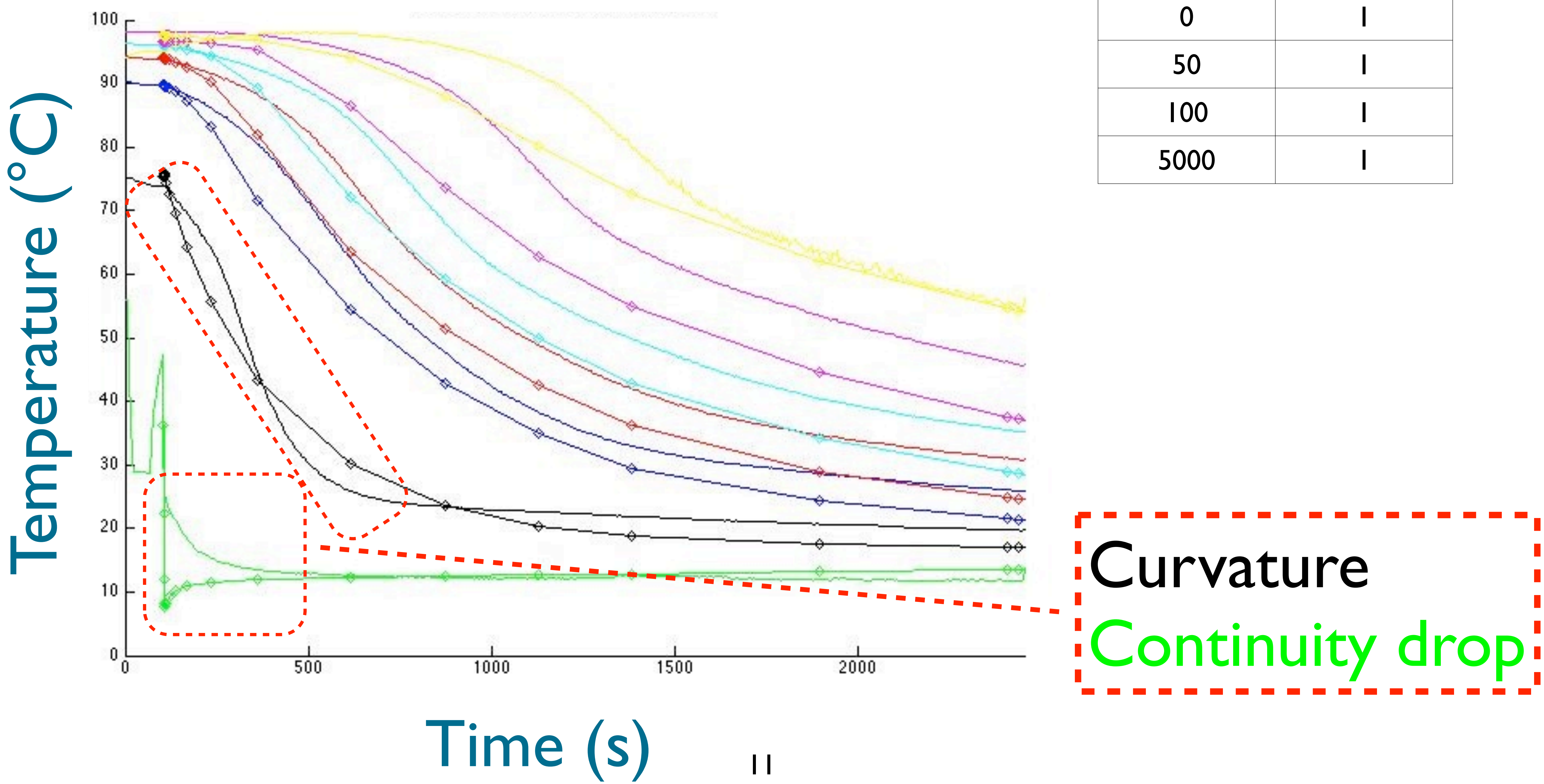
Original Simulation

Injection (Flow(t))

Time (s)	Flow ()
0	1
50	1
100	1
5000	1



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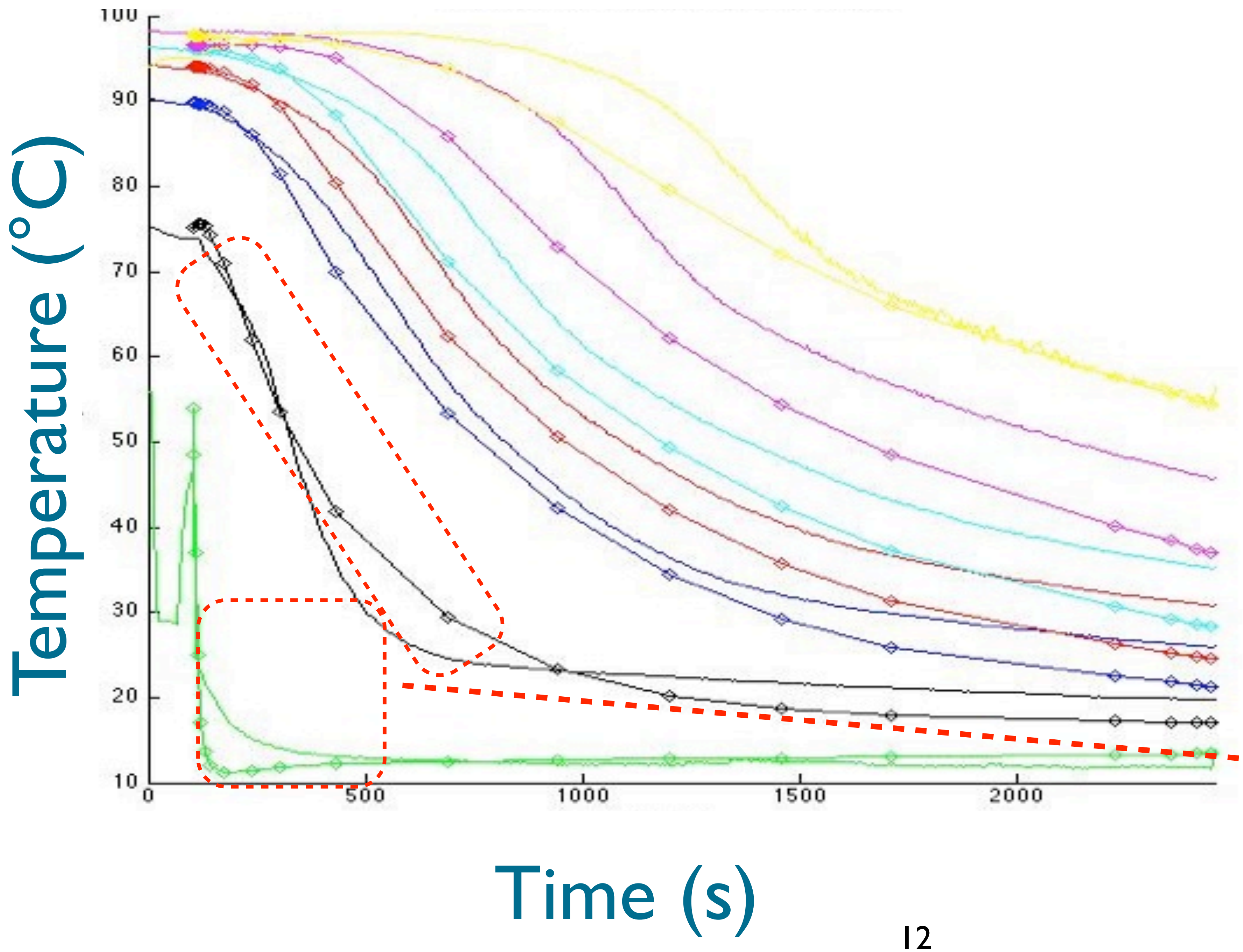
Simulation 2

Injection (Flow(t))

Time (s)	Flow ()
0	0
50	1
100	1
5000	1



= Curvature

≃Continuity drop

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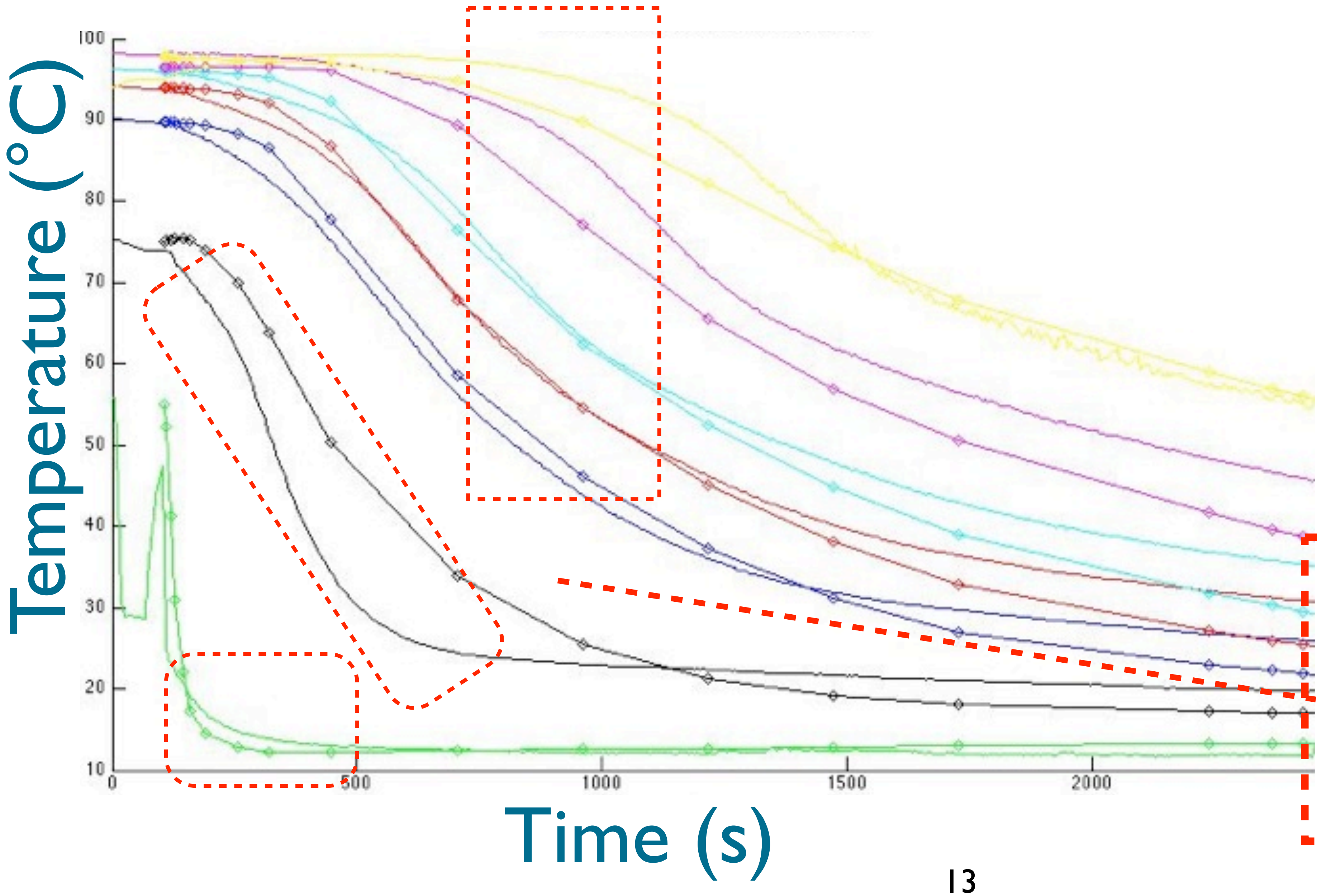
Simulation 3

Injection (Flow(t))

Time (s)	Flow ()
0	0
50	1/2
100	1
5000	1



Closer
= Curvature (dist)
Continuity

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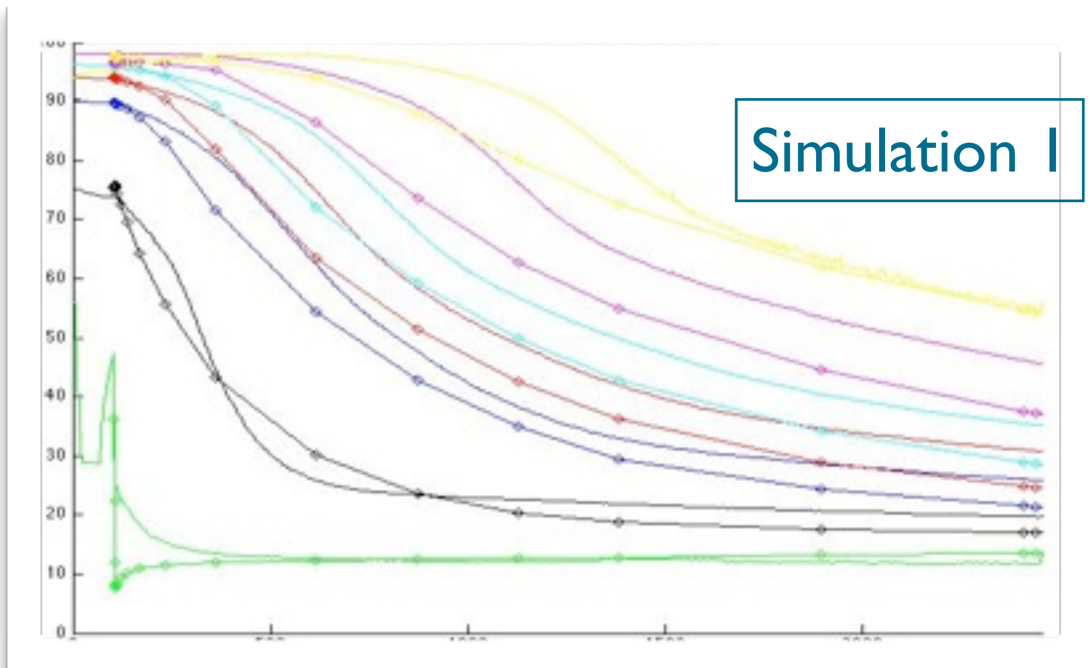
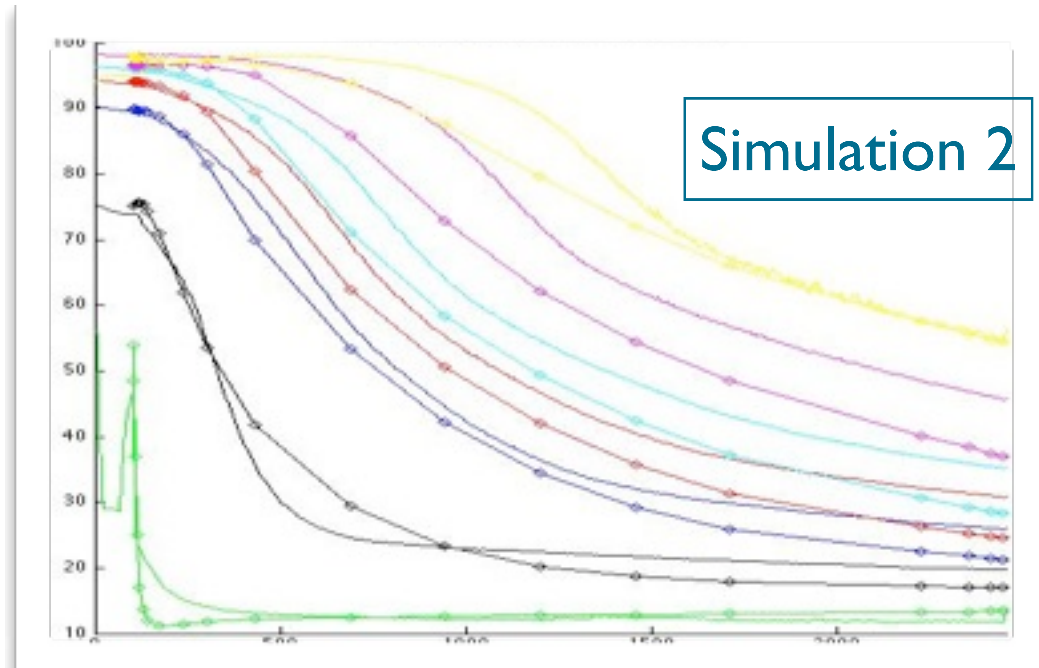
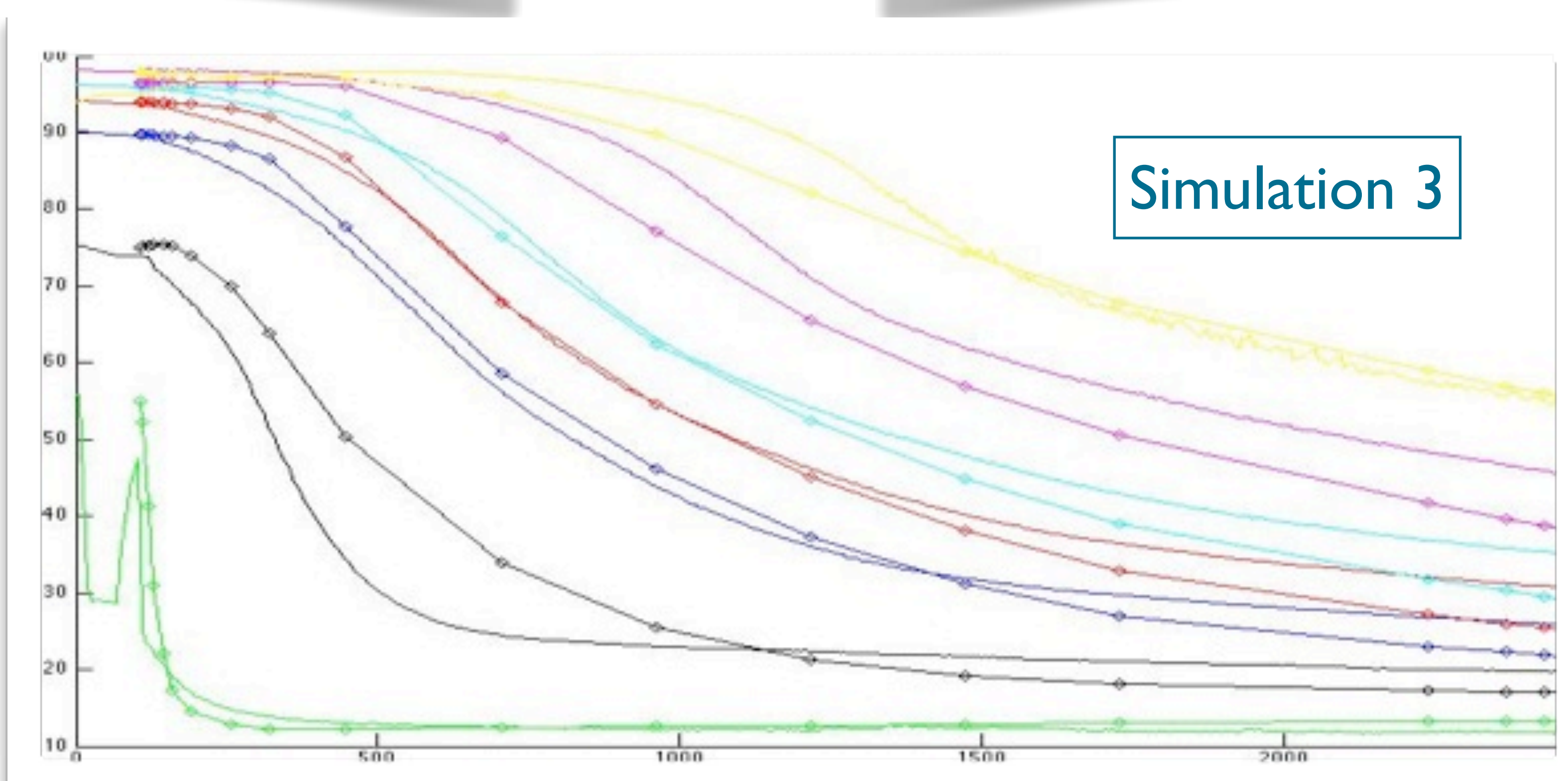
Comparison







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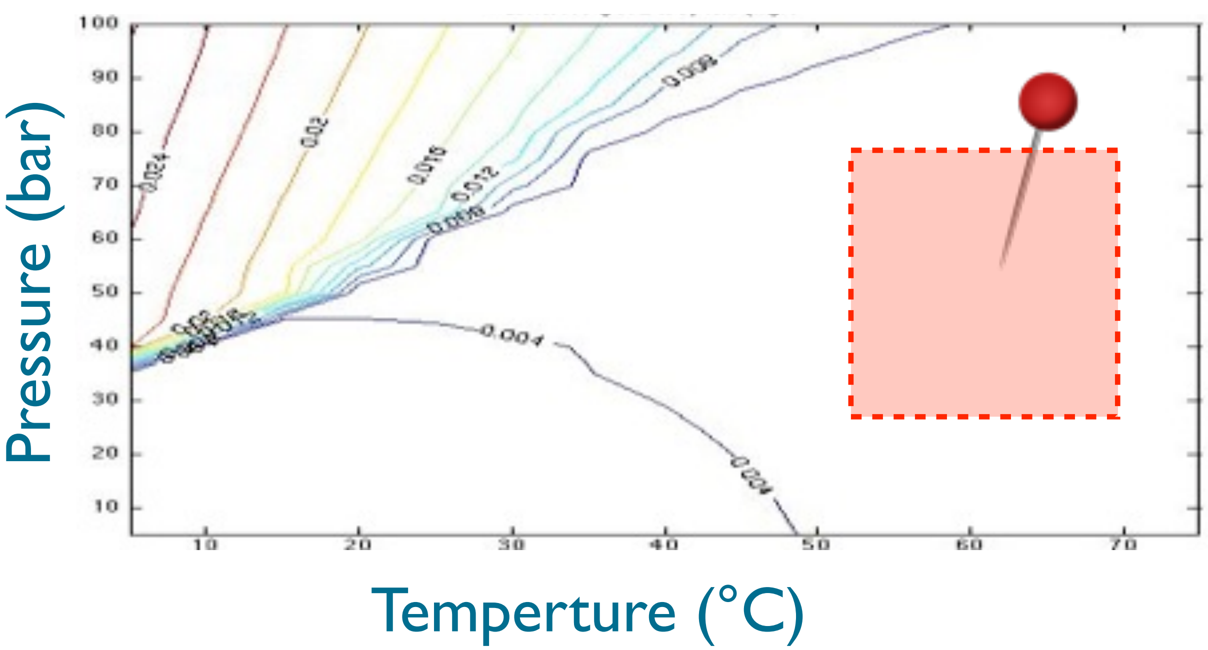
Realistic?

Not use the experimental results (but 40 sec)

$$Q_{max}(T,P) \;= \{Q \setminus Re(T,P,Q) = 10\}$$



$$2g.s^{-1} \;<\; 4g.s^{-1}$$

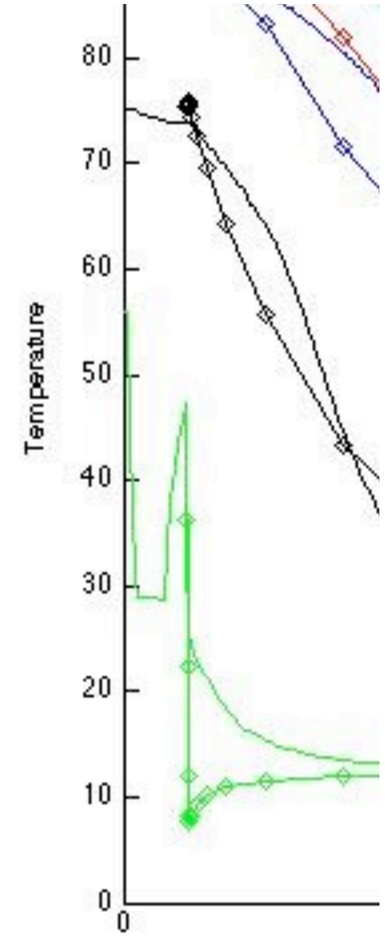
Darcy law ✔

$$v \;\sim\; 1\ mm.s^{-1}$$

$D \;=\; 10\ cm$

TC4

TC1



$$t_{delay} \sim \;100\ sec$$

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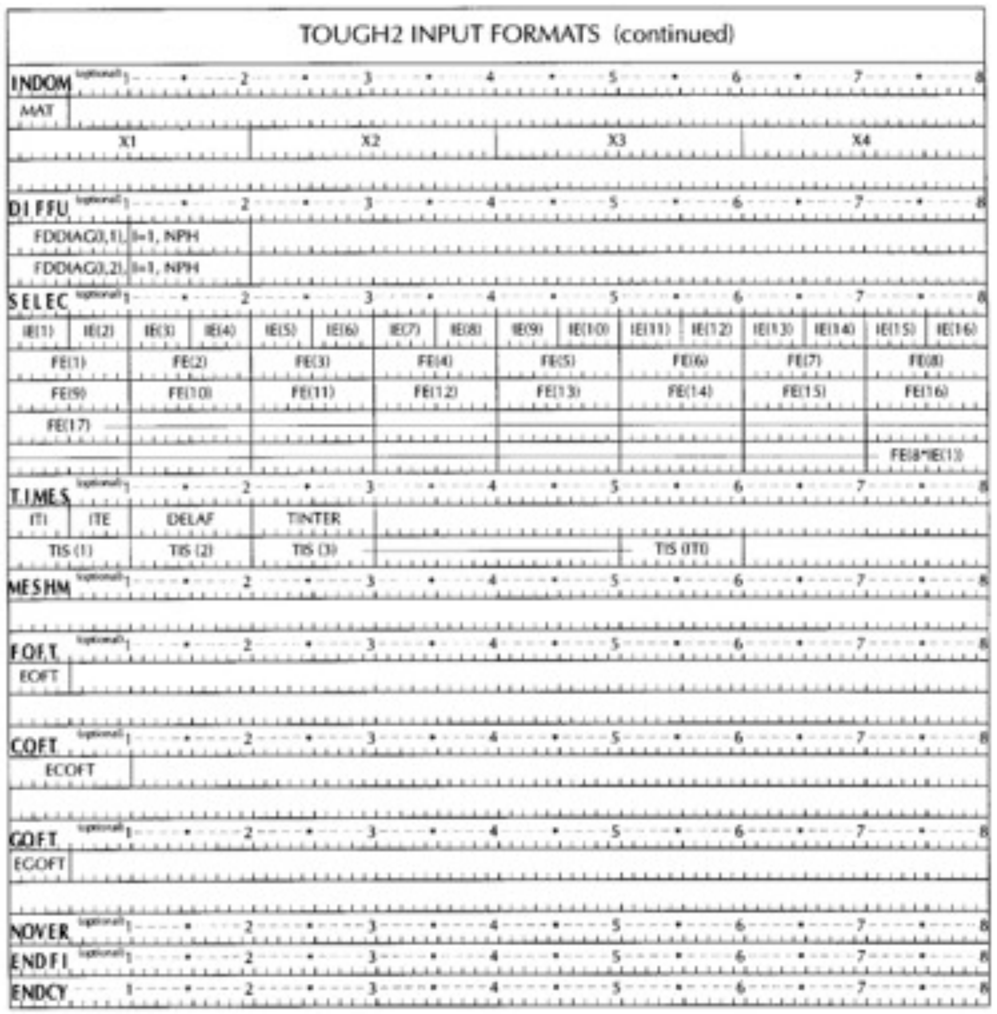
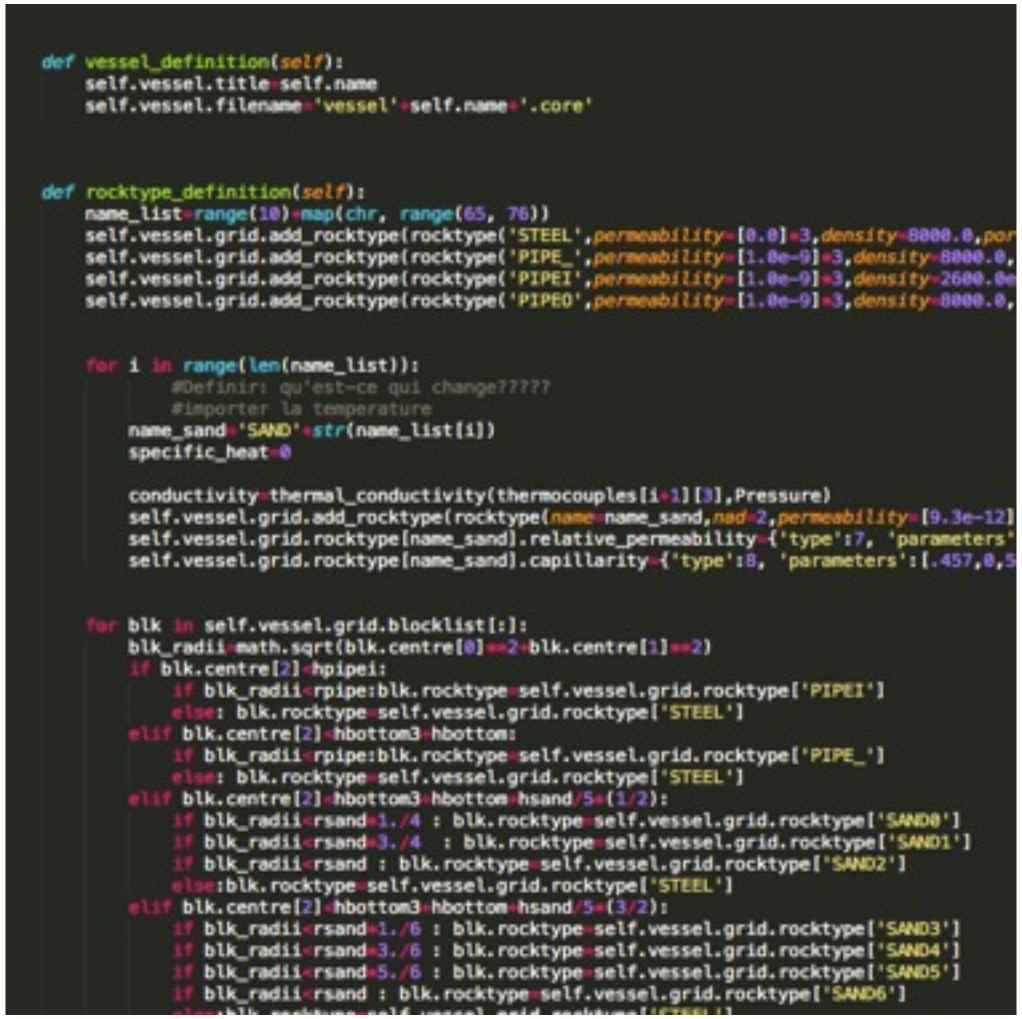
Pytough Implementation



Fortran input

vs



```
def vessel_definition(self):
    self.vessel.title=self.name
    self.vessel.filename='vessel'+self.name+'.core'


def rocktype_definition(self):
    name_list=range(10)+map(chr, range(65, 76))
    self.vessel.grid.add_rocktype(rocktype('STEEL',permeability=[0.0]*3,density=8000.0,por
    self.vessel.grid.add_rocktype(rocktype('PIPE_',permeability=[1.0e-9]*3,density=8000.0,
    self.vessel.grid.add_rocktype(rocktype('PIPEI',permeability=[1.0e-9]*3,density=2600.0e
    self.vessel.grid.add_rocktype(rocktype('PIPEO',permeability=[1.0e-9]*3,density=8000.0,

    for i in range(len(name_list)):
            #Definir: qu'est-ce qui change?????
            #importer la temperature
        name_sand='SAND'+str(name_list[i])
        specific_heat=0

        conductivity=thermal_conductivity(thermocouples[i+1][3],Pressure)
        self.vessel.grid.add_rocktype(rocktype(name=name_sand,nad=2,permeability=[9.3e-12]
        self.vessel.grid.rocktype[name_sand].relative_permeability={'type':7, 'parameters'
        self.vessel.grid.rocktype[name_sand].capillarity={'type':8, 'parameters':[.457,0,5

    for blk in self.vessel.grid.blocklist[:]:
        blk_radii=math.sqrt(blk.centre[0]**2+blk.centre[1]**2)
        if blk.centre[2]<hpipei:
            if blk_radii<rpipe:blk.rocktype=self.vessel.grid.rocktype['PIPEI']
            else: blk.rocktype=self.vessel.grid.rocktype['STEEL']
        elif blk.centre[2]<hbottom3+hbottom:
            if blk_radii<rpipe:blk.rocktype=self.vessel.grid.rocktype['PIPE_']
            else: blk.rocktype=self.vessel.grid.rocktype['STEEL']
        elif blk.centre[2]<hbottom3+hbottom+hsand/5*(1/2):
            if blk_radii<rsand*1./4 : blk.rocktype=self.vessel.grid.rocktype['SAND0']
            if blk_radii<rsand*3./4  : blk.rocktype=self.vessel.grid.rocktype['SAND1']
            if blk_radii<rsand : blk.rocktype=self.vessel.grid.rocktype['SAND2']
            else:blk.rocktype=self.vessel.grid.rocktype['STEEL']
        elif blk.centre[2]<hbottom3+hbottom+hsand/5*(3/2):
            if blk_radii<rsand*1./6 : blk.rocktype=self.vessel.grid.rocktype['SAND3']
            if blk_radii<rsand*3./6 : blk.rocktype=self.vessel.grid.rocktype['SAND4']
            if blk_radii<rsand*5./6 : blk.rocktype=self.vessel.grid.rocktype['SAND5']
            if blk_radii<rsand : blk.rocktype=self.vessel.grid.rocktype['SAND6']
```

Python input

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Why?

PyTOUGH

- Need a wrapping
- Easier to change parameters
- Create 3D Mesh
- Allow 3D rendering

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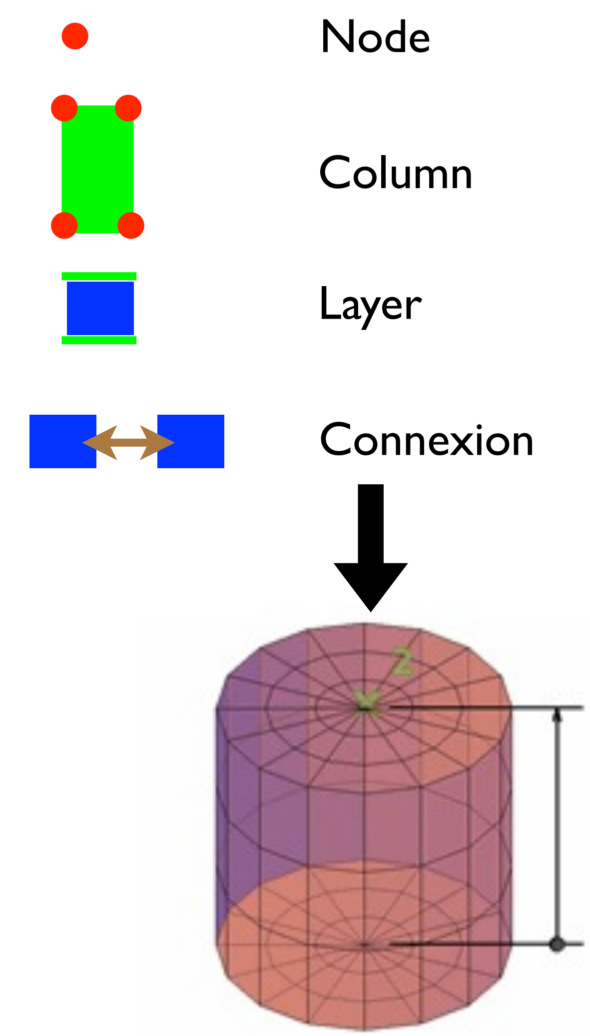
3D Mesh

- Cylinder — create_cylinder.py
- Connection
  - addition — add_cylinder.py
  - substraction — *substract_cylinder.py*
  - vertical connection — *v_connec.py*



2D (well-fitted area and volume) ➔ 3D

computing time vs rendering (accuracy?)

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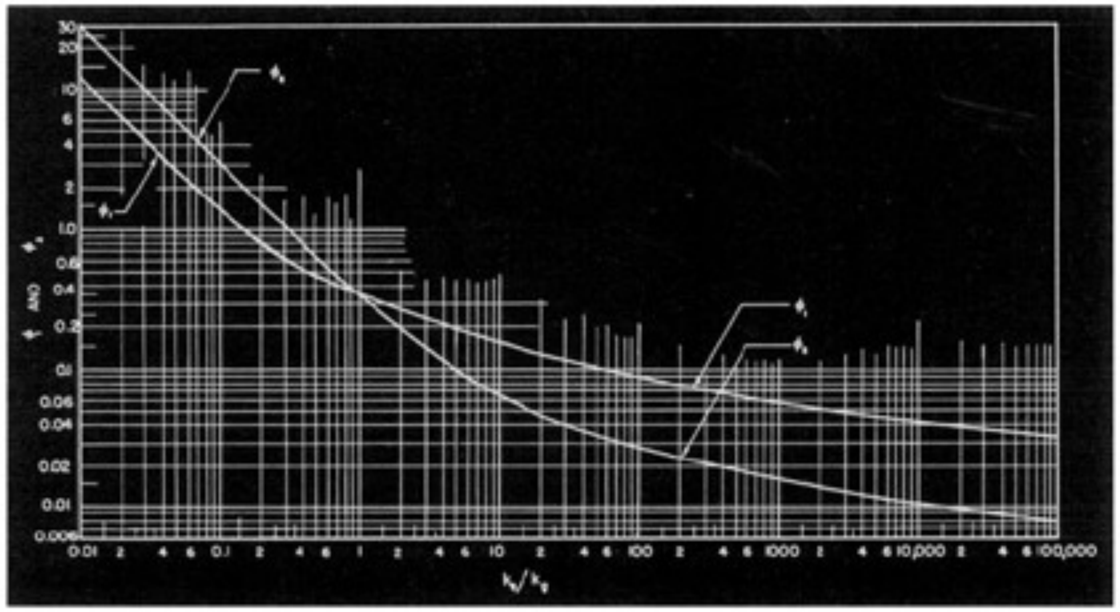
Thermal Conductivity

Heat Transfer Characteristics of Porous Rocks,

DAIZO KUNII and J. M. SMITH (Northwestern University, Evanrton, Illinois)



$$\phi = \phi_2 + (\phi_1 - \phi_2) * \frac{\epsilon - \epsilon_2}{\epsilon_1 - \epsilon_2}$$

$$\begin{aligned} \phi_1 &: loose-packing \\ \phi_2 &: close-packing \\ \epsilon_1 &: porosity_1 = 0.476 \\ \epsilon_2 &: porosity_2 = 0.260 \\ \epsilon &: porosity = 0.41 \end{aligned}$$

$k_{CO2}(T,P) \quad (MATLAB)$
k_{solid}

$$\longrightarrow \phi\ (T,P)$$

$Image\ processing\ (ImageJ):$

$$x = 10^{\frac{7}{1188}*(X-64)-2}$$
$$y = 10^{\frac{3.68}{604}*(620-Y)-2.21}$$

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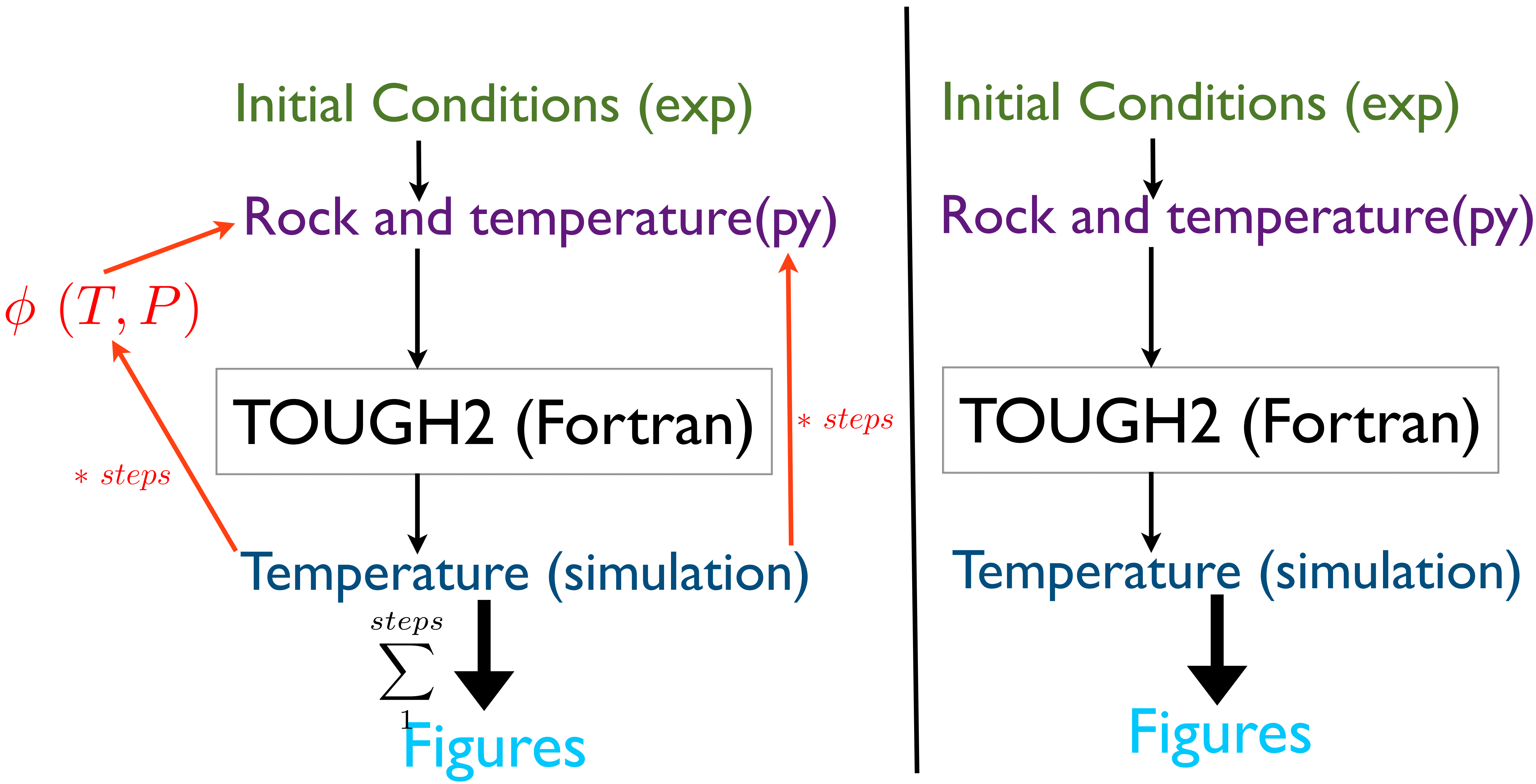
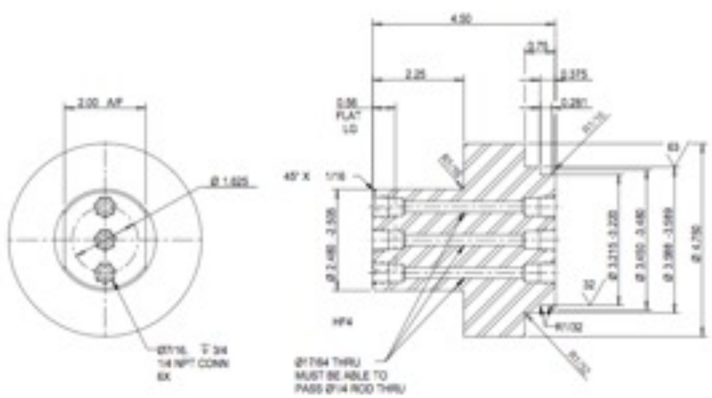
Time discretization

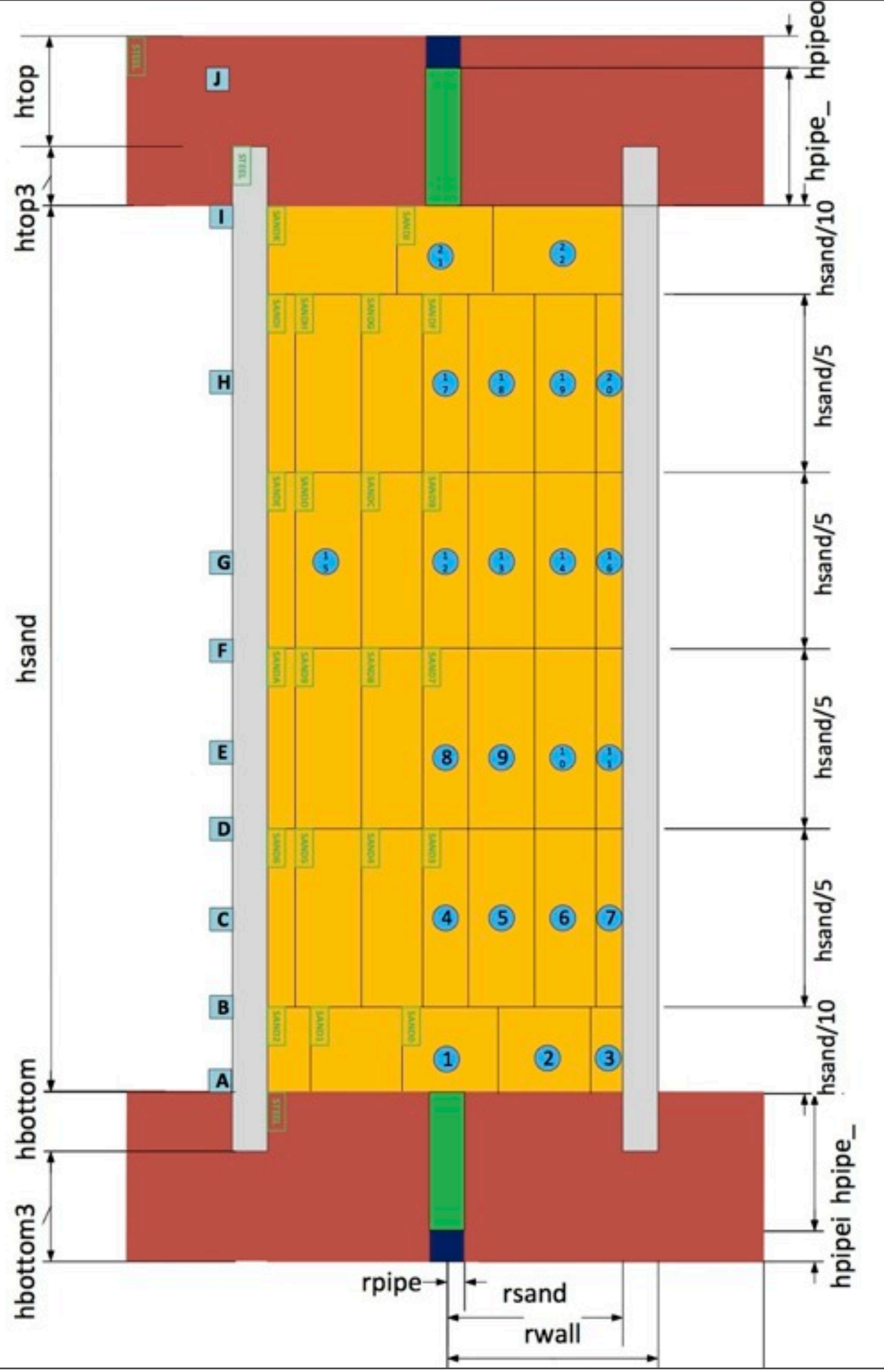


Pytough
Implementation

Spatial discretization



Mesh
Tools



- 21 types of sands
- Rings (symmetry)
- Area divided thanks to first initial conditions (thermocouples)

Post-processing

- Storage in simple structure ✓ $dictionnary[t][bloc]['T'] = ..$
- Data everywhere ✓ $findindiceblock(position) = ..$
- Figure simulation vs experiment ✓ $plot(position) = ..$
- 3D Rendering ✗ VTK

Experiment

Conclusion