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Modelling of natural gas pipe flow with rapid transients-effect of ambient model

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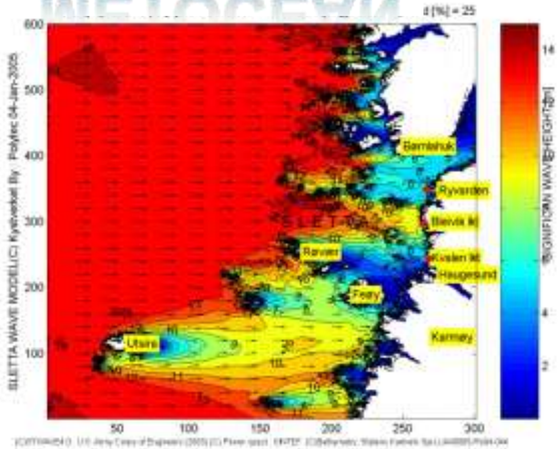
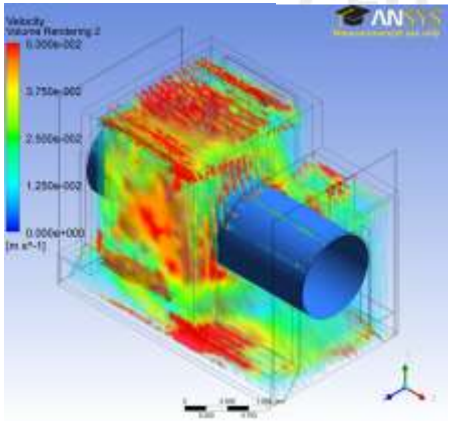


CFD



RISK & SAFETY

PROCESS & PIPELINES

Contents

- Problem description
- Models
- Results
- Conclusions

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Problem description

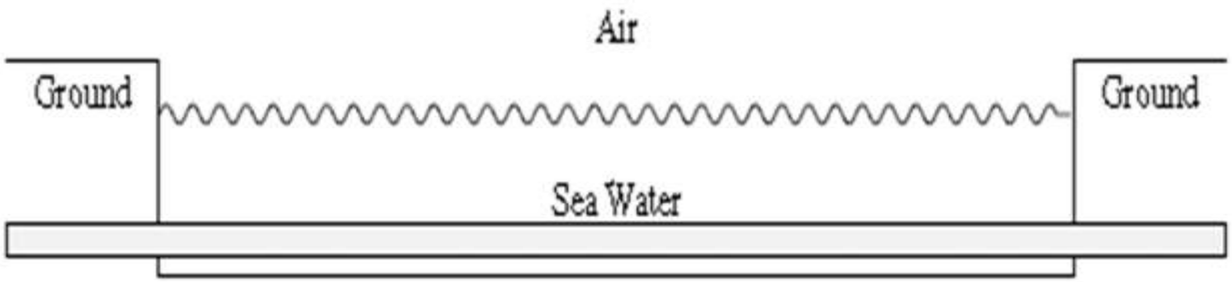
- Buried pipeline
- Unsteady, compressible, non isothermal pipe flow
- Conventional model
  - Flow is modelled in 1D
  - Heat exchange between the gas inside the pipeline and ambience is modelled through a fixed heat transfer coefficient U
  - Commercial codes have 1D unsteady, in some cases 2D representation of the ambience (soil model)
  - Requirements on calculation time for large pipeline networks neccesitate simple ambient models (i.e fixed U is commonly used, at most an 1D radial representation)

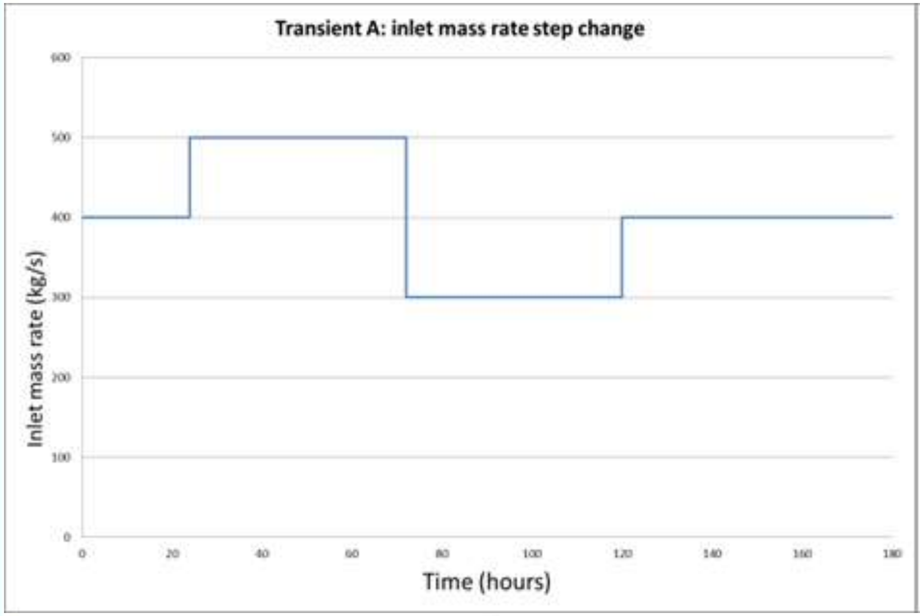
Problem description

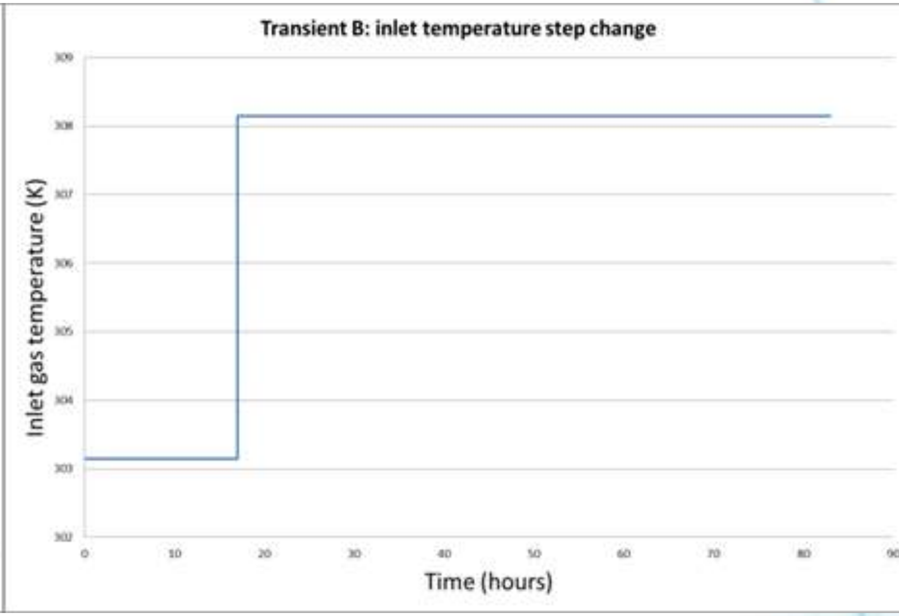
- Context: Gassco Project 'Improved flow modelling'
- Gassco online model of the gas transport network is using fixed U values
- These models are very accurate in steady flow scenarios, but show still som variation when the gas flow into the pipeline inlet is highly transient
- Earlier work in the project, and a few recent literature publications show that the ground heat storage term plays a role. These previous studies consider the buried pipeline as a one dimensional spatial problem
- In this work we study in more detail how the ambient heat exchange model influences the pipeflow response to a pipeline inlet transient.
- Question: 'how good is a 1D radial representation; what role does the 2D nature of the heat transfer play?


GASSCO

Conceptual pipeline model and flow transients







Ambient thermal models

Pipeflow energy equation (JF Helgaker 2013):

$$\rho C_v\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}\right)+u\left(\frac{\partial p}{\partial T}\right)_\rho\frac{\partial u}{\partial x}=\frac{f\rho u^3}{2D}-\frac{4U}{D}(T-T_a)$$

$$\rho C_v\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}\right)+u\left(\frac{\partial p}{\partial T}\right)_\rho\frac{\partial u}{\partial x}=\frac{f\rho u^3}{2D}-\rho q$$

- Adiabatic model
  - No heat exchange with the ambient, U=0
- Steady state, U value
  - U value based on conduction shape factor
- Unsteady
  - 1D radial, soil donut model
  - 2D, soil slices model

Ref: **Helgaker:** Modelling Transient Flow in Long Distance Offshore Pipeline. PhD thesis- 2013. NTNU, Norway.

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1D radial unsteady model

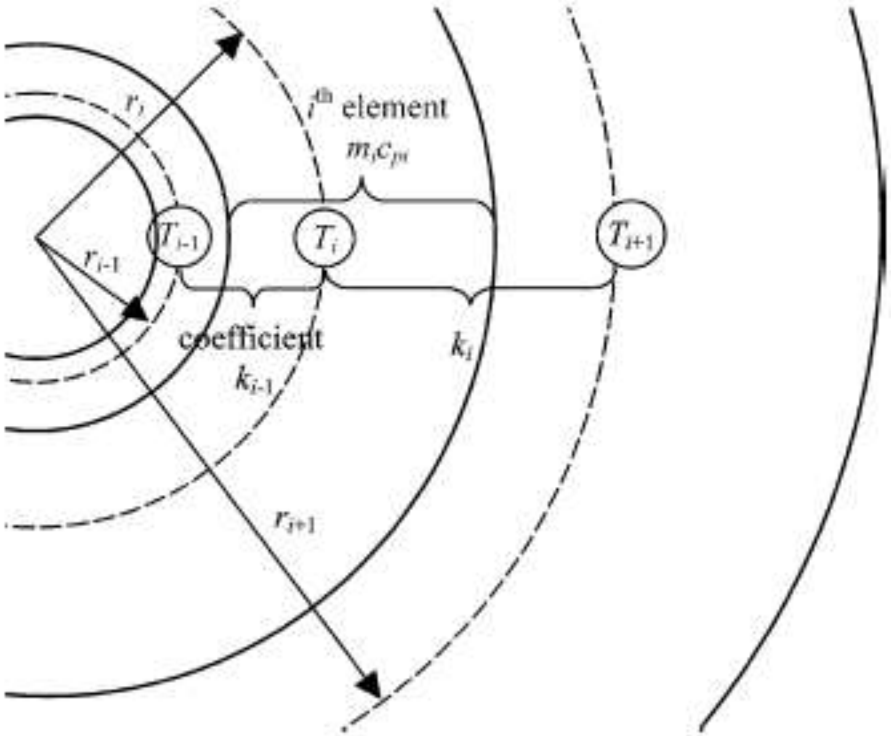
solving the 1D radial form of the unsteady heat equation

$$q\rho = -\frac{k_0}{A}(T - T_1)$$

$$\frac{m_1 C_{p1}}{dx}\frac{\partial T_1}{\partial t} = k_0(T - T_1) - k_1(T_1 - T_2)$$

$$\frac{m_2 C_{p2}}{dx}\frac{\partial T_2}{\partial t} = k_1(T_1 - T_2) - k_2(T_2 - T_3)$$

$$\frac{m_n C_{pn}}{dx}\frac{\partial T_n}{\partial t} = k_{n-1}(T_{n-1} - T_n) - k_n(T_n - T_{amb})$$



Ref: **Chaczykowski** Sensitivity of pipeline gas flow model to the selection of the equation of state. [Journal] // Chemical Engineering Research and Design. - 2009. - pp. 1596-1603.

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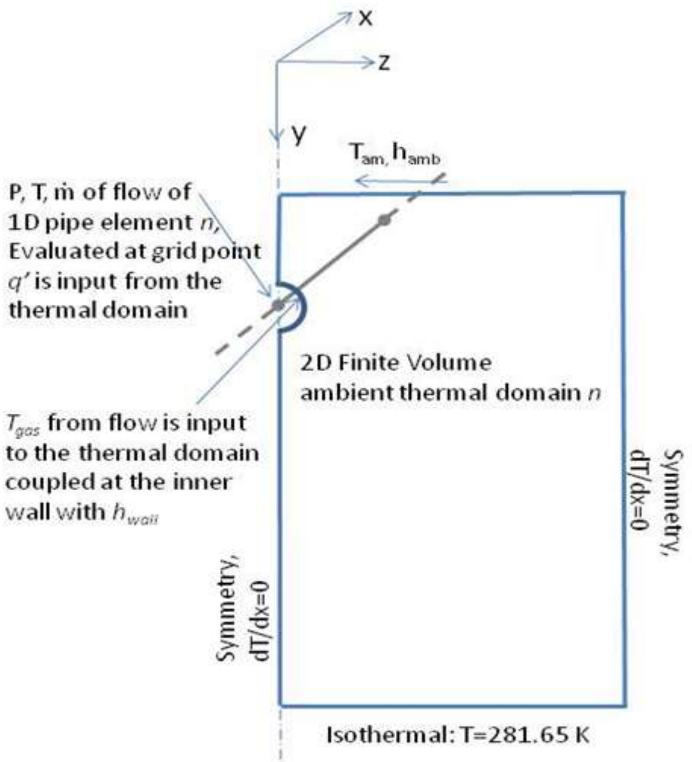
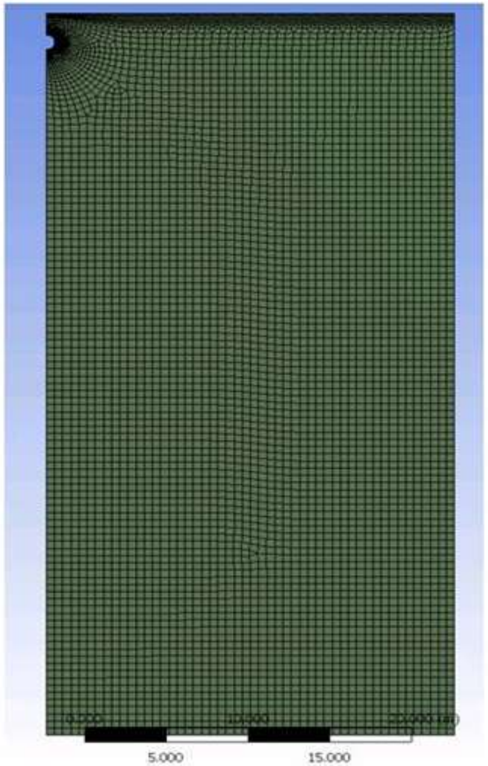
2D unsteady model





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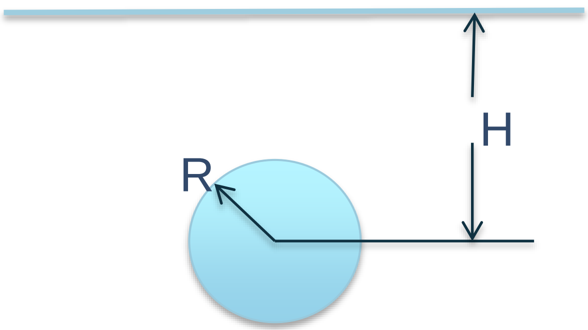
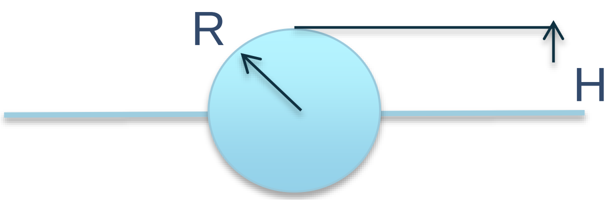
Burial configurations

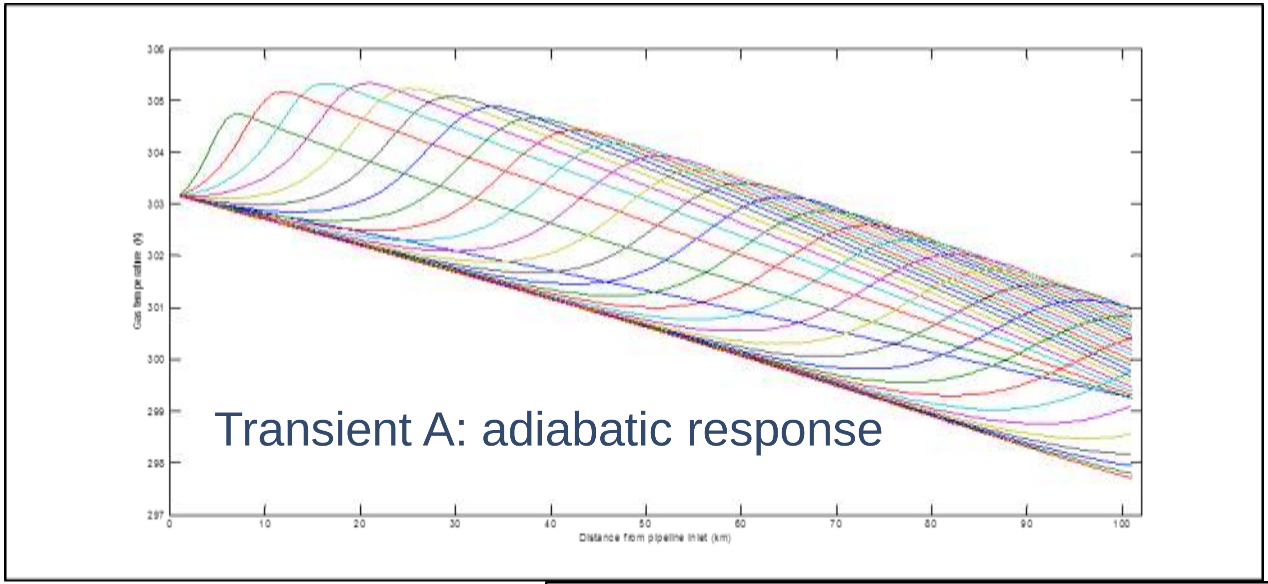


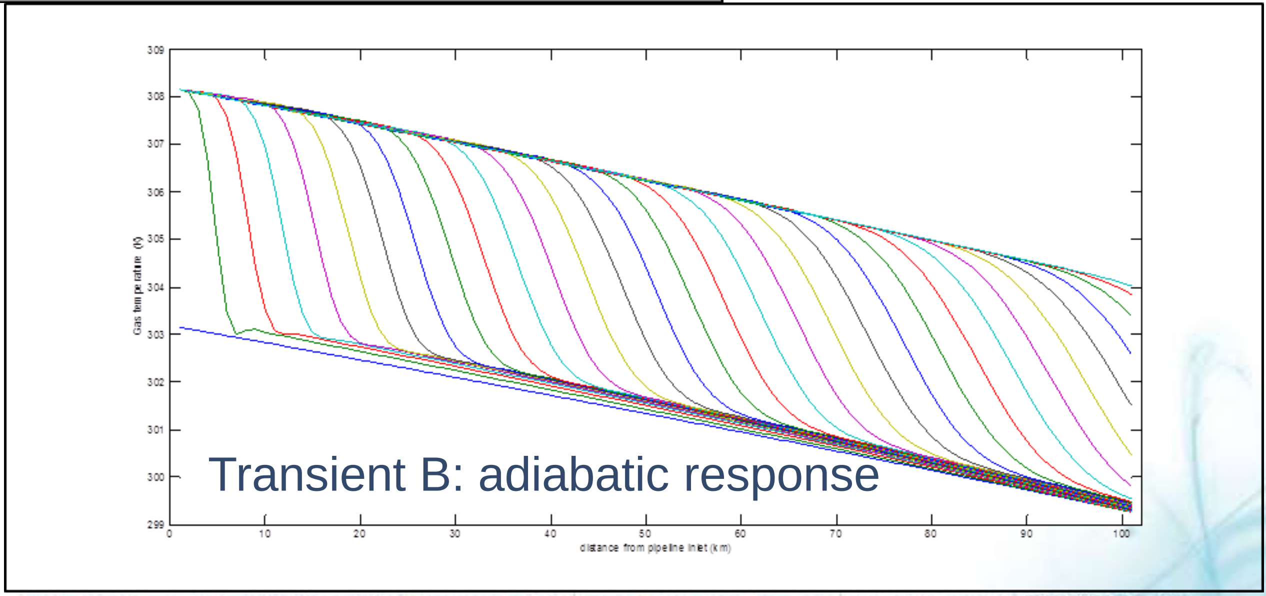
H = 0.556 m, 1 m, 2m
R = 0.555 m



H = ½ R
R = 0.555 m

Results


Transient A: adiabatic response
Gas temperature (K)
Distance from pipeline inlet (km)


Transient B: adiabatic response
Gas temperature (K)
distance from pipeline inlet (km)

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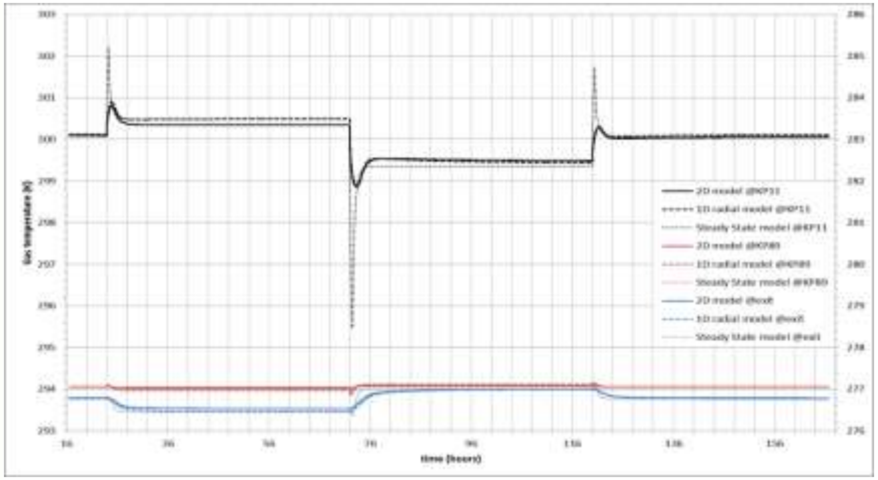
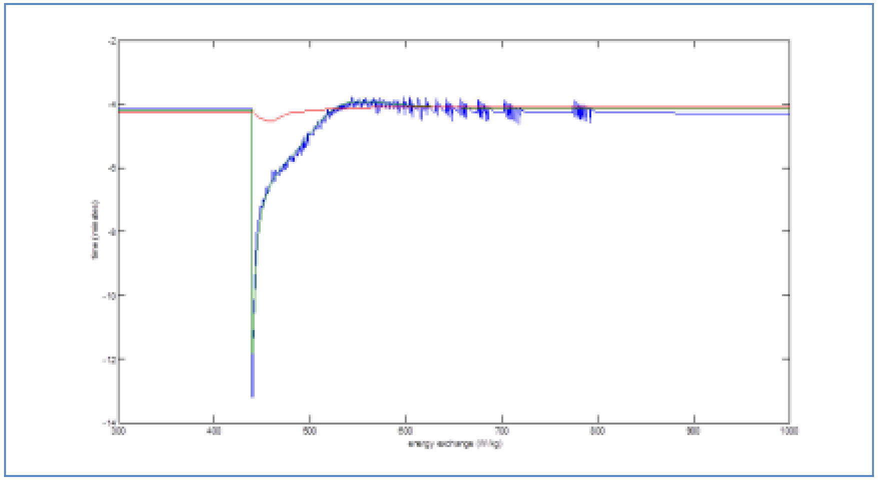
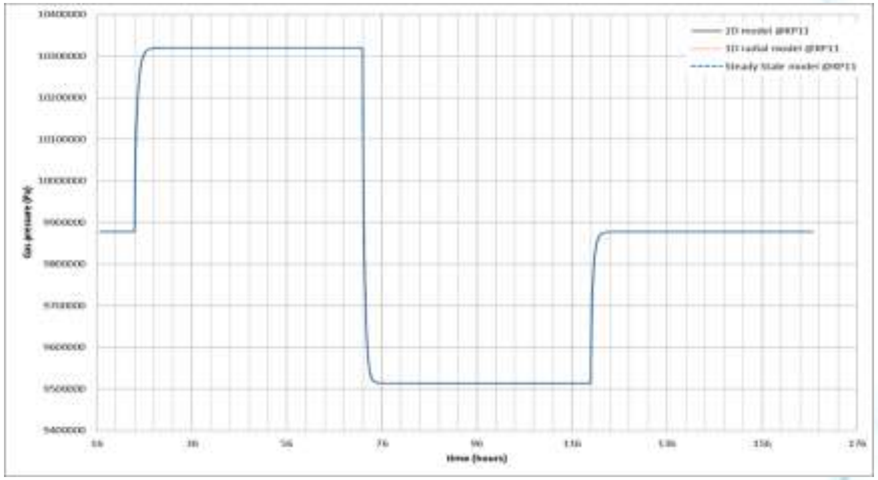
Model response transient A







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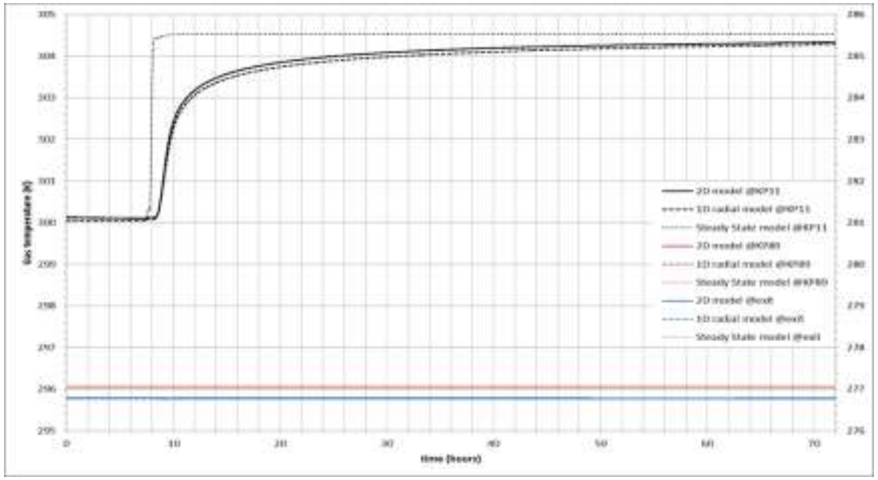
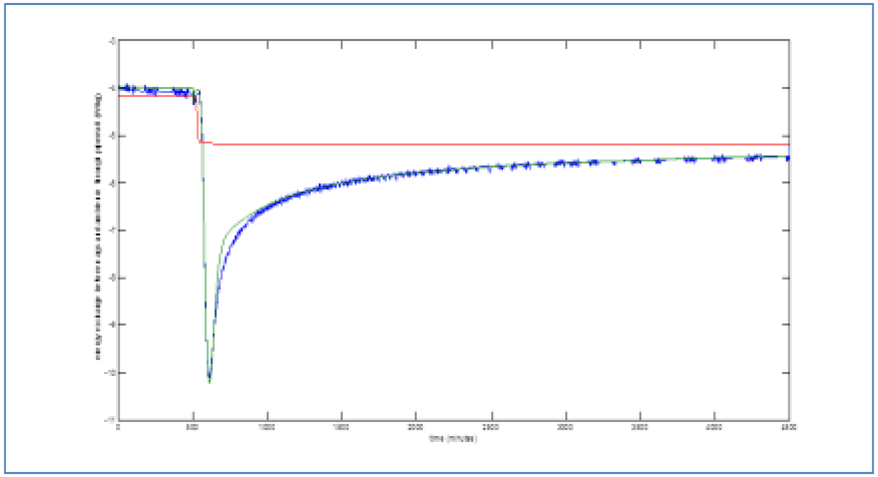
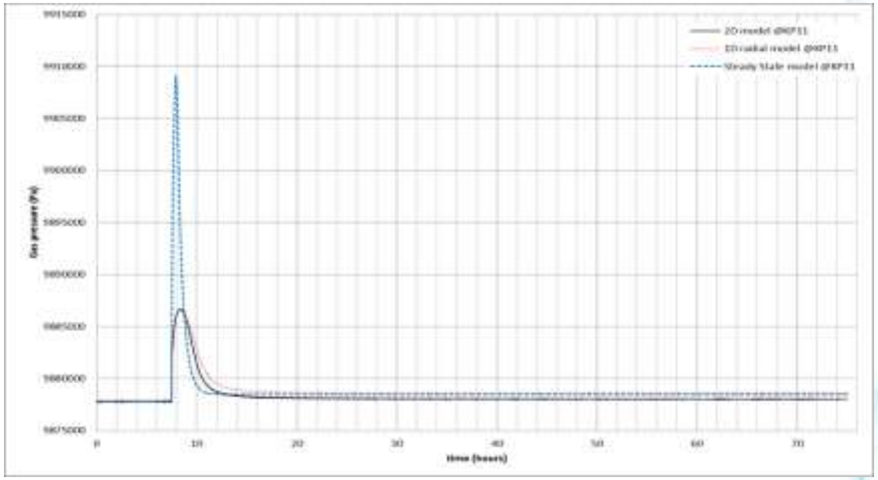
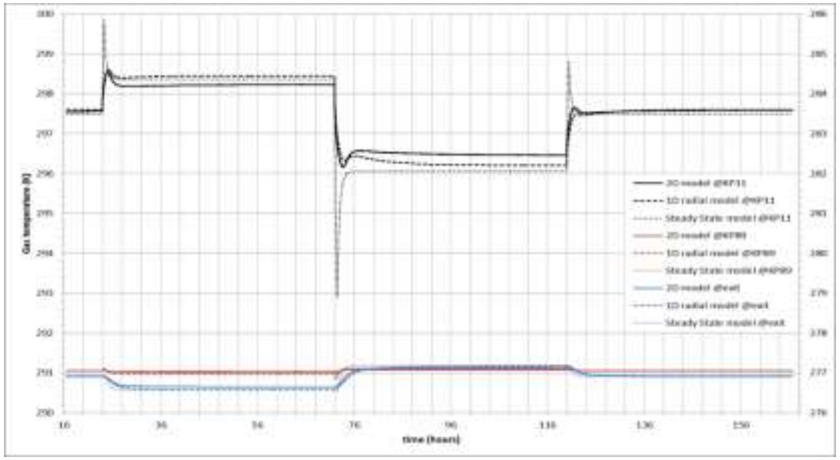
Model response transient B

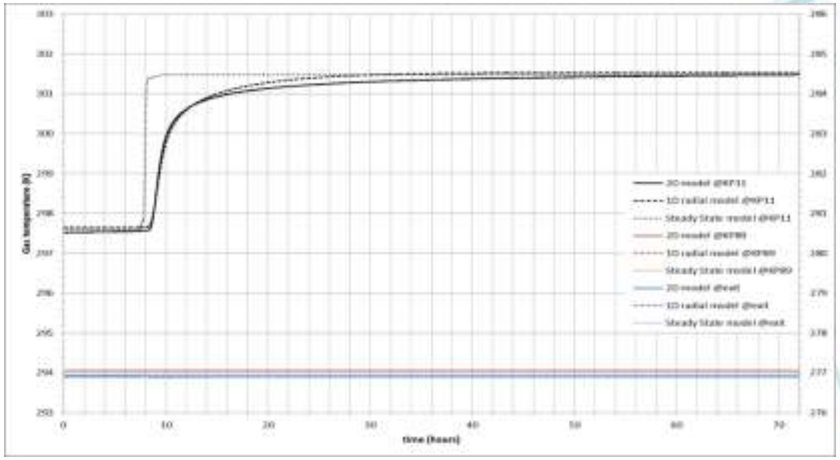


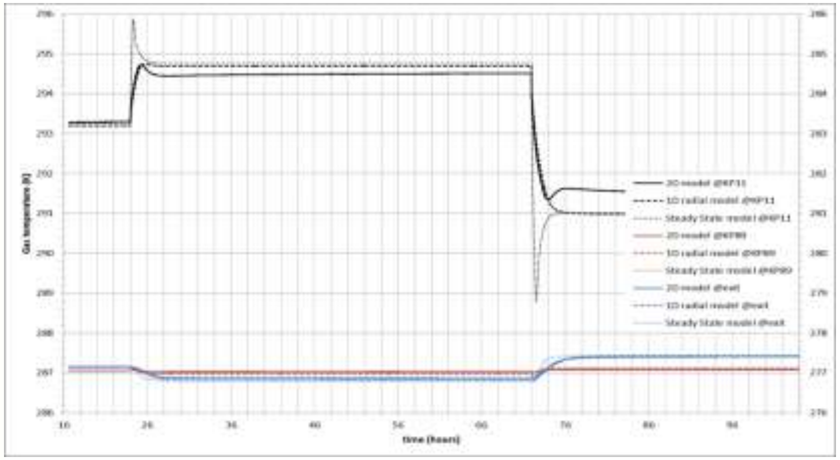


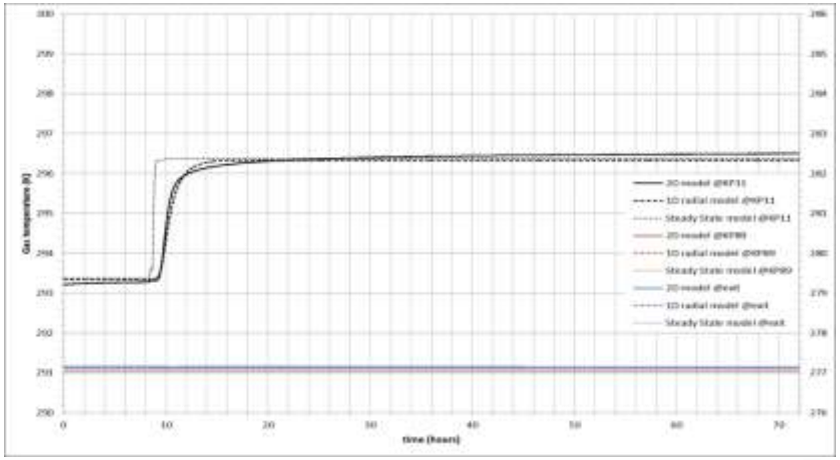


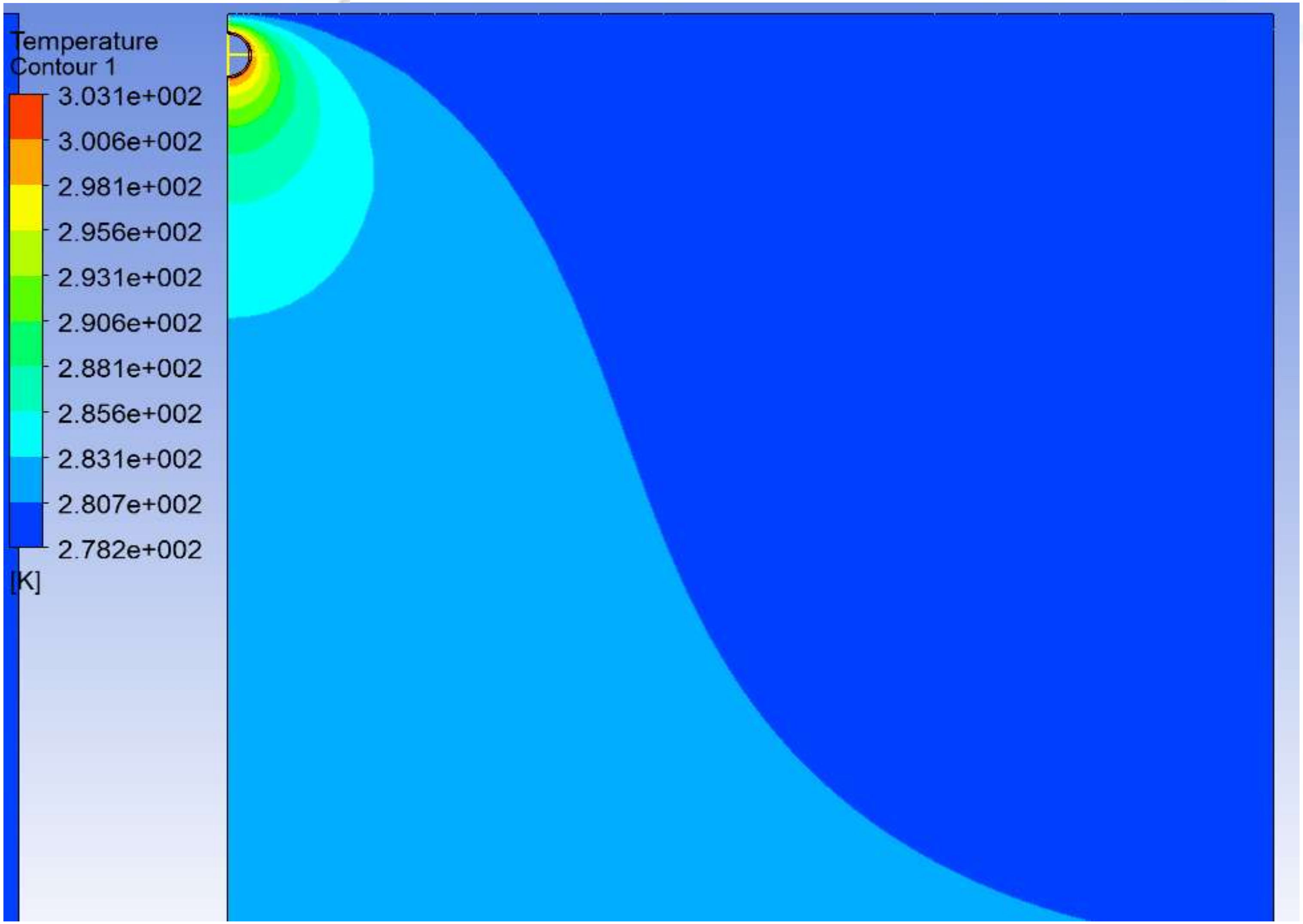
Shallow burial and exposed

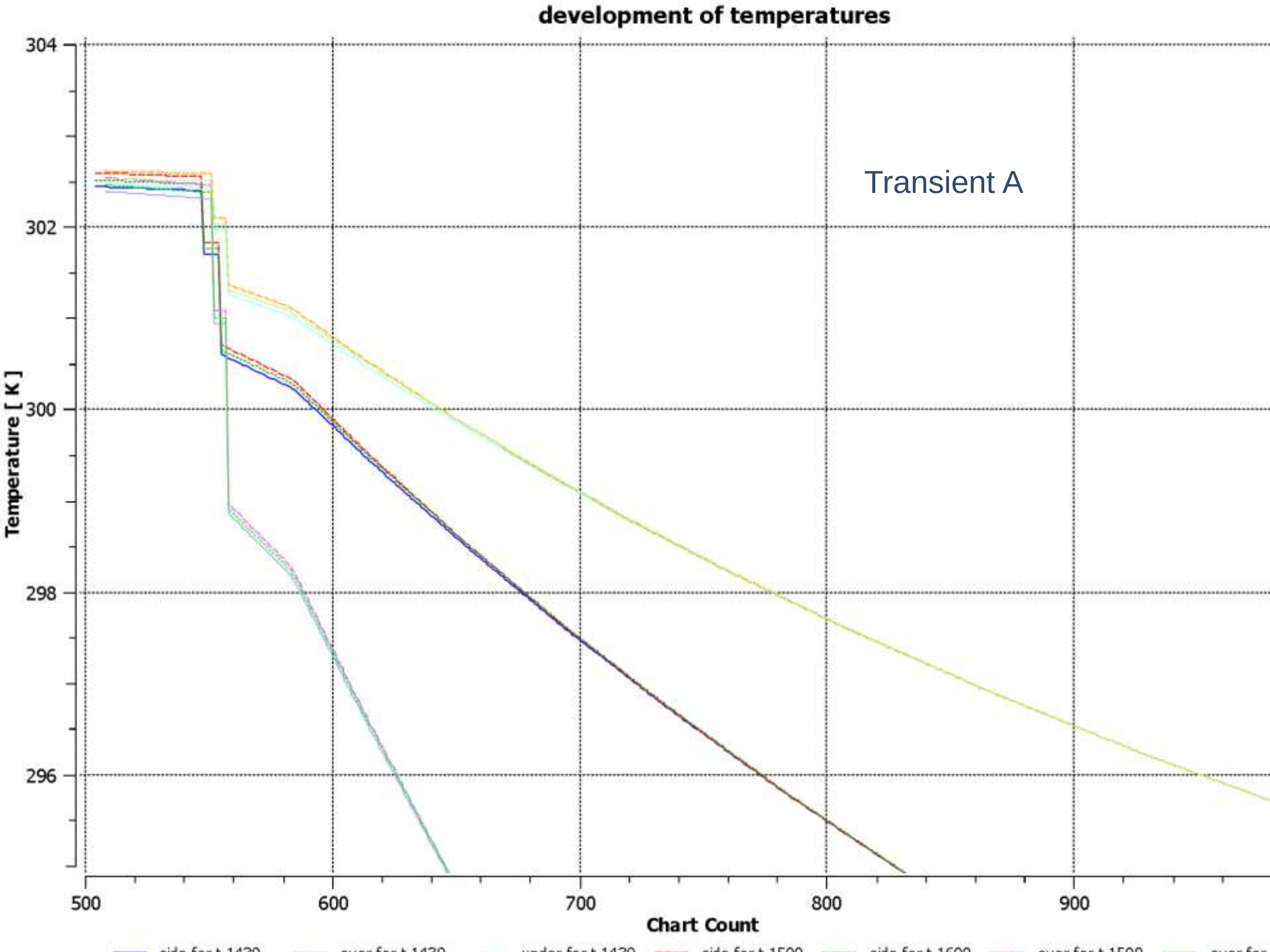









Temperature
Contour 1
3.031e+002
3.006e+002
2.981e+002
2.956e+002
2.931e+002
2.906e+002
2.881e+002
2.856e+002
2.831e+002
2.807e+002
2.782e+002
[K]


development of temperatures
Transient A
304
302
300
298
296
Temperature [K]
500
600
700
800
900
Chart Count

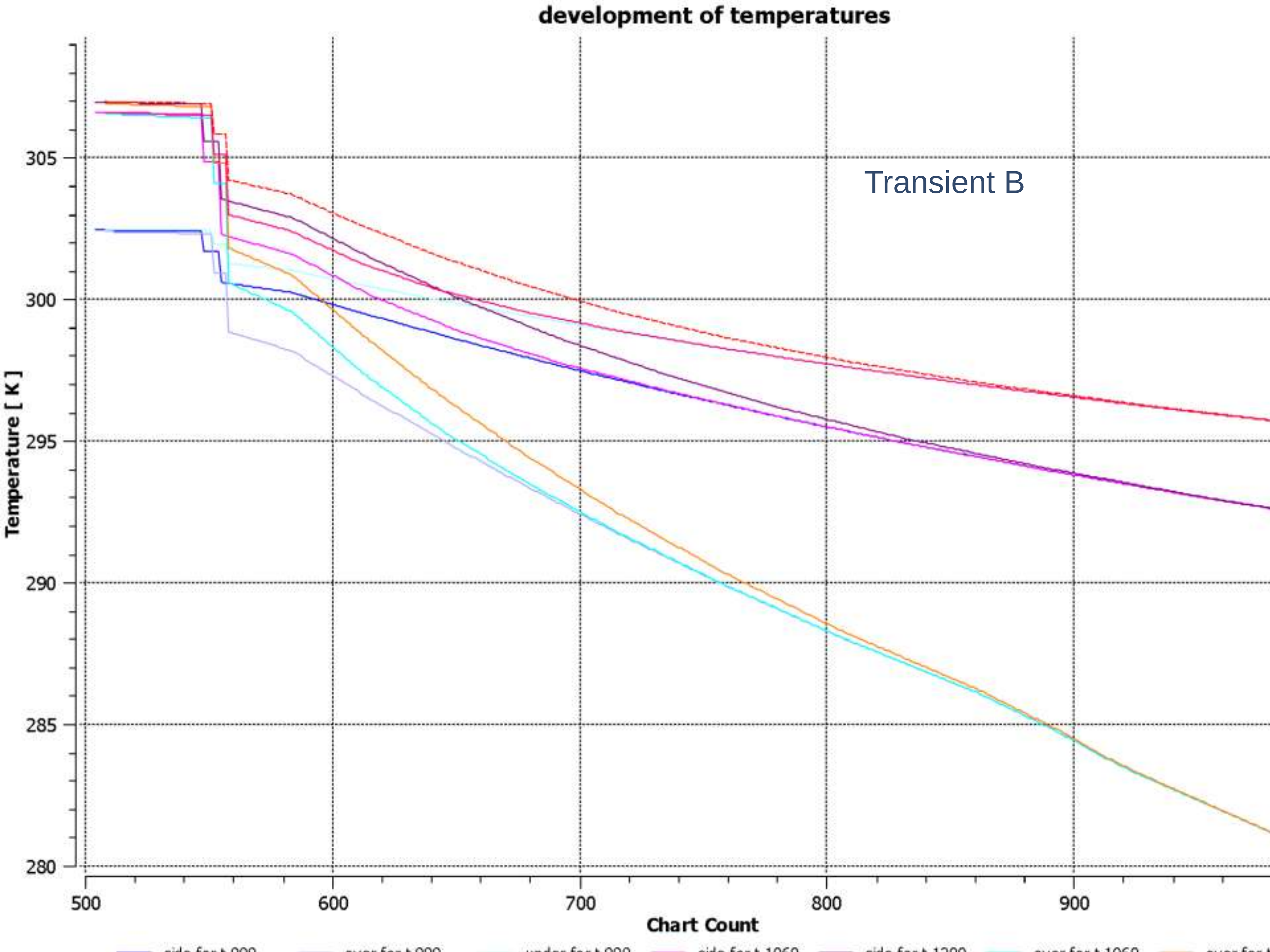

development of temperatures
Transient B
Temperature [K]
305
300
295
290
285
280
500
600
700
800
900
Chart Count

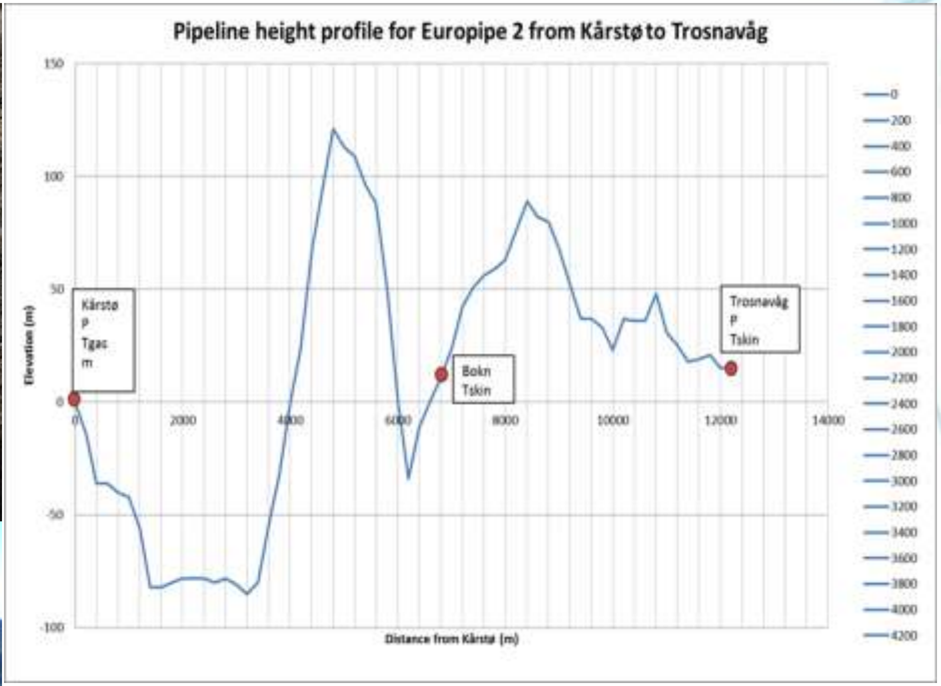
Table 1: Fourier numbers of selected pipeline burial cases.

Case	Ri (m)	Ro (m)	Fo pipe	σ=2H/D soil	l_e soil (m)	Fo soil
2 m burial depth	0.508	0.552	0.4	3.58	1.95	$1.9*10^{-5}$
1 m burial depth	0.508	0.552	0.4	1.79	1.18	$5.2*10^{-5}$
1 cm burial depth	0.508	0.552	0.4	1.02	0.2	$1.8*10^{-3}$

$$Fo = \frac{\alpha\tau}{L_e^2}$$

The time needed to achieve steady state over the distance l_e after a thermal pulse at the boundary of the system is approximately equivalent to l_e^2/α.

Real case Europipe 2



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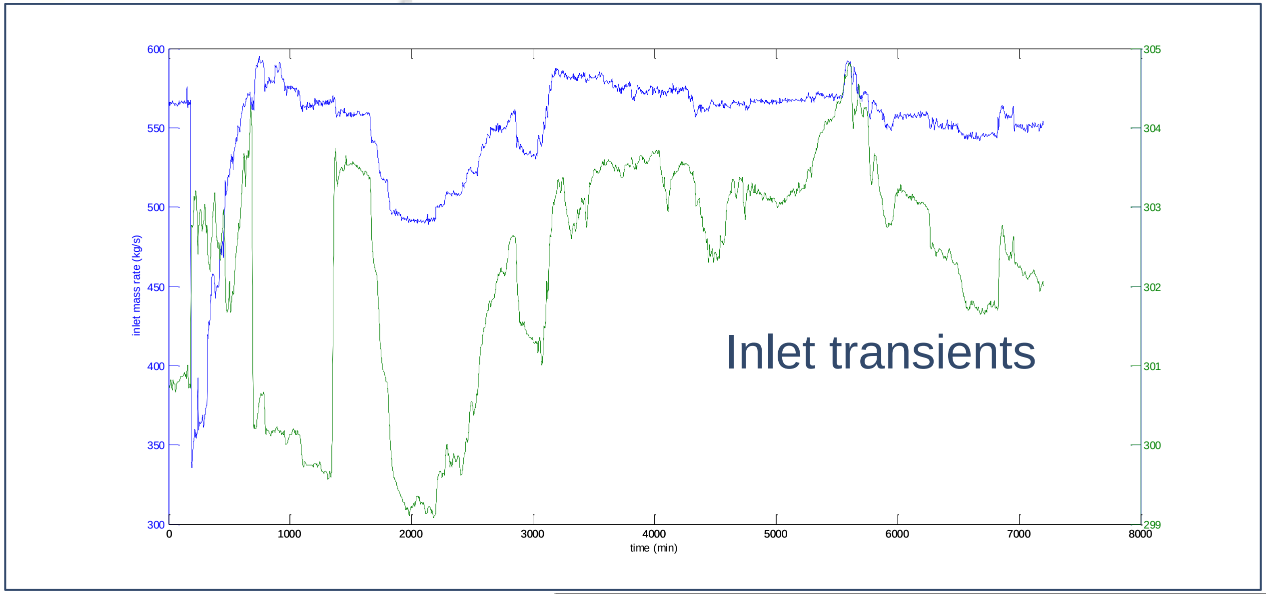

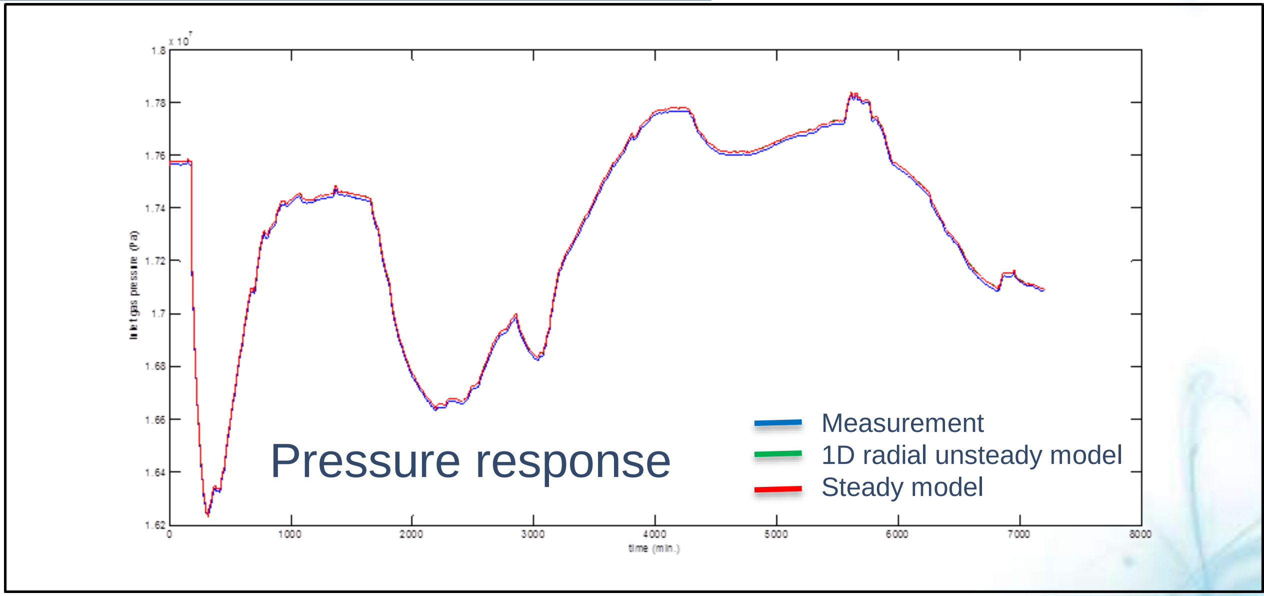

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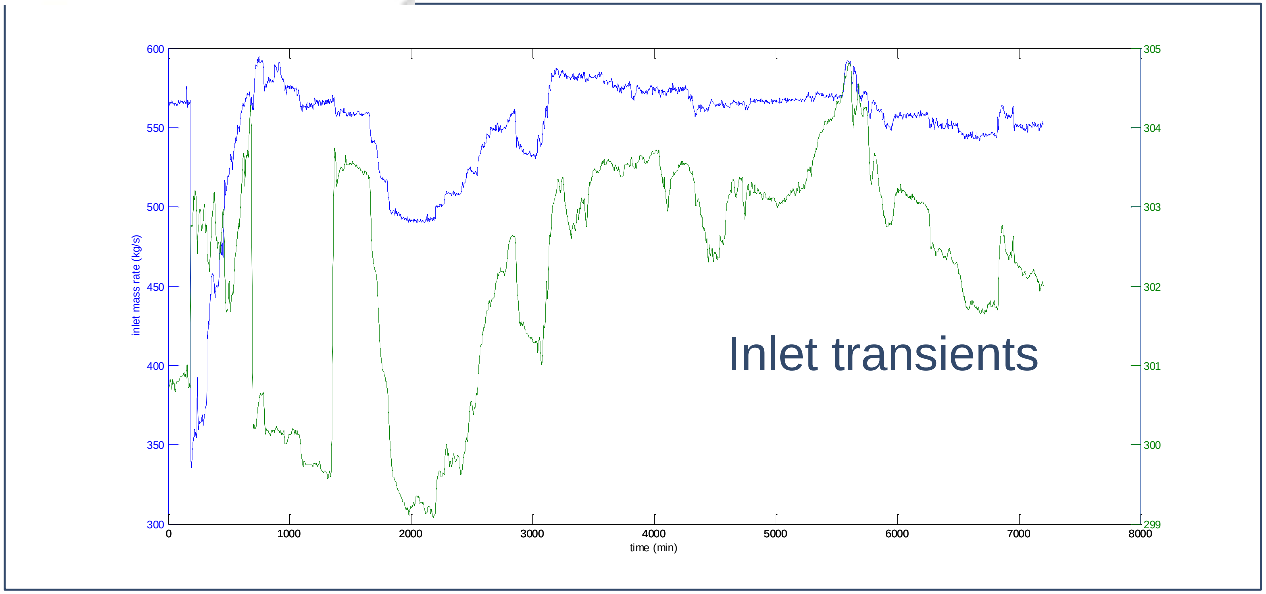
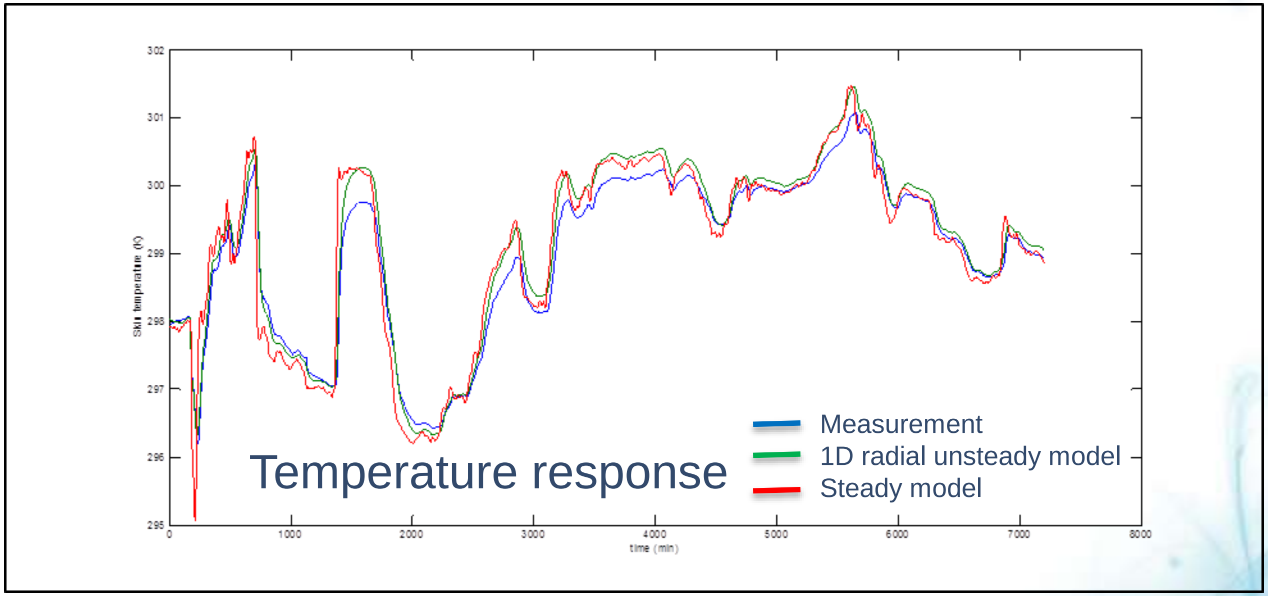

Inlet transients
inlet mass rate (kg/s)
time (min)
600
550
500
450
400
350
300
0
1000
2000
3000
4000
5000
6000
7000
8000
305
304
303
302
301
300
299


Temperature response
Measurement
1D radial unsteady model
Steady model
Skin temperature (K)
time (min)
302
301
300
299
298
297
296
295
0
1000
2000
3000
4000
5000
6000
7000
8000

Conclusions

- The response to an inlet gas mass rate transient is significantly different to that of an inlet gas temperature transient.
- Including the soil heat storage has a large influence on the response of the pipe hydraulic flow to an inlet transient.
- The use of a 1D radial model versus 2D has a much smaller impact.
- The 1D radial model shows a similar response to the transients as the 2D model when the pipeline is fully buried to one or more pipe radii.
- For the shallow burial case, the initial response to the transients is still rather similar, but some of the accuracy is lost as the 1D model approaches quicker the new steady state after the transients.
- For partially buried pipelines, heat storage still plays a role and to obtain the correct response has to be accounted for.

- Significant improvements in calculation accuracy of transient pipe flow can be achieved by implementing a 1D radial unsteady heat transfer model of the soil in case of buried pipelines instead of the currently preferred steady state model.
- The experimental verification clearly demonstrates the improvement potential the 1D radial unsteady model has compared to the steady state model. The remaining temperature deviations with the 1D radial model are over-predictions occurring at the peaks of the modulating gas temperature inside the pipe at the measurement location. Further study is needed to identify the cause(s) of this.

Acknowledgements

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