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## Gas Network Simulation and Uncertainty of Pipe Leg Surroundings Parameters

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### ABSTRACT

Users of simulation packages are interested rather in accuracy of simulated scenarios (usually, in terms of differences between calculated values and measured data known for test cases) than in precise description of heat dynamics phenomenon. Heat transfer between gas and surroundings of pipe legs can be simulated if relevant parameters of surroundings are known. The main parameters are material properties of the surrounding materials (heat conductivity, heat capacity and density), the appropriate geometry and the undisturbed (far soil) temperature.

We shall discuss impact of the surroundings' parameter values on the results that are usually considered by the users as a measure of accuracy, as the uncertainty of these parameters is usually very high. A case study will be presented, illustrating the influence of heat transfer parameters in situations mostly met in practical tasks (steady-state and transient ones). The aim is to bring reasonable engineering guidelines about how to cope with this uncertainty.

### Introduction

Thermal balance is a standard option for gas network simulators. The heat exchange between gas and surrounding environment is rather a complex phenomenon and requires good understanding by the user in order to supply the necessary input data for setting up the model as well as using it in a technically sound way.

Theoretical background of the heat exchange models was discussed in several PSIG papers in previous years (see e.g. PSIG9201) and illustrated by interesting examples, e.g. during the PSIG 2007 Showcase as the latest.

User of gas network simulators faces the need to gather the necessary inputs for his/her calculations, build the configuration (network model, scenario – task definition) for the simulator and interpret the results obtained correctly. This is not always straightforward and easy chain of tasks and still requires qualified attention; see e.g. PSIG 0309 for nice overview of common issues.

Practical experience shows that the setup of heat exchange model is a frequently asked question because of user's uncertainty of input data and the way how to handle the information available. In particular, such question is asked by typical offline users performing system planning or design simulations.

This paper aims to illustrate the impact of expectable range of input values and tries to give simple but safe guidelines.

### Heat Transfer Model and Input Data

Heat balance model has two main parts:

- Energy equation for gas coupled with continuity and momentum equations
- Heat exchange between gas and surrounding environment (soil) and it's coupling to the energy equation

It is commonly understood that the exchange gas-soil is a radial phenomena only (no longitudinal heat transfer in the soil takes role).

The coupling between gas energy equation and radial heat exchange model is done by the heat flux at the internal wall surface.

The radial heat exchange model shall describe both:

- The steady heat transfer (gas temperature and far soil temperature are constant).
- The transients: due to significant capacity of the near soil, all transients in it are typically slow – the heat flux through pipe wall significantly differs from the steady value for time substantially longer than the time scale considered for the gas simulation task. Therefore the transient behavior of radial heat transfer shall be included in many cases of gas network transient simulation!

The radial heat exchange model uses the material properties (heat conductivity & capacity, density) and the problem geometry (in terms of pipe diameter and burial depth or layer thickness) as input data.

The simplest input data for steady-state simulations can be the overall Heat Transfer Coefficient (HTC [BTU/ft<sup>2</sup>/h/°F, W/m<sup>2</sup>/K]) related to unit internal pipe surface.

The ultimate set of data for the transient heat transfer model contains detailed geometry and material data for the near environment; usually radial symmetry is assumed so the geometry is expressed by concentric layers of given material properties.

For buried pipelines, the simplified 2D idea of pipe buried in finite depth under infinite planar surface of constant temperature (this boundary condition corresponds to the far undisturbed soil) is often used. For such geometry with homogeneous soil, the analytical solution of steady heat transfer is available, see Figure 1. Here, the heat flux between cylindrical surface buried in finite depth under infinite planar surface of fixed temperature is considered. These results can be easily superimposed with multilayer radial geometry inside the cylinder (insulation, pipe wall, boundary layer etc).

## Sources of Uncertainty

As the buried pipe geometry is related to burial depth, for many cases the question of geometry has a reasonable answer for the user (assuming that pipe is laid according to the normative/project data).

The undisturbed soil temperature is usually available from tables (for usual burial depths it does not change dramatically and a guess for seasonal changes can be found) or for real pipeline systems even reliable data of soil temperatures may exist.

The main uncertainty therefore remains in material properties of the surrounding soil along the whole length of the pipeline. Looking to tables of common construction material properties for the expectable soil types gives relatively wide range of

values, see Table 1. For a given geometry of pipeline, the quick guess for steady HTC between gas and undisturbed soil can therefore vary for more than 50% (see Table 3).

## Test Cases

The test pipeline is inspired by the PSIG 2007 Showcase: ~70 miles long 20" pipeline (no elevation changes) with steel wall thickness 0.5" is laid in soil in burial depth 3 ft (measured to pipe centerline). Undisturbed soil temperature is assumed to be 50°F. At upstream end "S" (see Figure 2), the gas is supplied with constant pressure of 1000 psig with given temperature (120°F or 80°F). At downstream end "D", constant given flow is maintained (200 or 285 mmsefd). For complete summary of pipeline & gas input data see Table 2.

Regarding soil properties, 4 different soils are assumed (following Table 1): sandy soil, clay soil, wet sand, and dry sand. Following Figure 1, the equivalent soil layer of thickness is used, that results in the range of overall HTC ~0.38÷0.68 BTU/ft<sup>2</sup>/h/°F for soils or wet sand and value ~0.12 BTU/ft<sup>2</sup>/h/°F for dry sand (see Table 3).

Usually it is difficult for the user to be more specific about the soil than the information that it behaves like the above mentioned soils (sandy or clay one) or more or less wet sand; dry sand stays clearly aside due to extremely low heat conductivity and because it is not probable to meet completely dry soil.

### Steady-state simulation

Following the input data, 8 steady-state simulations were performed (2 loads of the system, 4 different HTC settings). The corresponding pressure and temperature profiles are shown on Figures 3 and 4.

The comparison to simulation done without heat exchange and using the soil temperature for gas instead (also shown in the figures) of course indicates that such approach is completely inadequate in this case (too much optimistic downstream pressure in node "D").

Interesting is the comparison of results for HTC corresponding to the two soils and wet sand – although the HTC value spans for ~50%, the difference in pressure and temperature profiles is not dramatic for low load situation. With increasing load the influence of HTC value increases on both temperature and pressure profiles.

Using HTC derived from dry sand leads to very different pressure and temperature profiles; because of extremely low HTC value the combination of heat flux and Joule-Thomson effect leads to other results.

However, the user should be aware that the different downstream pressures at node "D" may cause even more

visible effects if e.g. compression power has to be calculated based on these pressures.

### Transient simulation

The transient is induced by sudden drop of supplied gas temperature at the supply “S” down to 80°F from original 120°F, while the pressure is kept here on 1000 psig and the delivery at node “D” remains unchanged. This is, however, a classical example for illustration of the transient heat exchanges phenomena.

The transient simulations were performed for the high load cases (285 mmscdf) starting from the corresponding steady states; 1 hour after start the sudden drop of supplied gas temperature occurs. The heat exchange model was fed by the equivalent radial soil layer thickness and the soil properties for the 4 investigated cases. The simulated interval was 1 week (168 hours).

The pressure and temperature trends for the downstream end node “D” are shown at Figures 5 and 6 together with points corresponding to steady-state simulation results for the new supplied gas temperature 80°F. Note that the transient needs even more time than one week to be relaxed completely.

Some gas network simulators allow the possibility to use the simple steady heat flux model using just the overall HTC between gas and undisturbed soil. This however leads to inadequately sharp and quick temperature changes in the beginning (as the steady heat flux is calculated differently as the discharging of near soil heat capacity is neglected). See the corresponding time trends of pressure and temperature in the downstream end node “D” in Figures 7 and 8.

For the cases of two soils and wet sand, the results are closer to each other and the dry sand case shows bigger difference, again this is primarily caused by substantially different soil conductivity.

## CONCLUSIONS

The following recommendations can be formulated, extrapolating the experience demonstrated on the examples calculated above:

- For gas systems with compression and therefore non-trivial temperature profiles, the heat balance should always be taken into account. In many cases, omitting the heat balance completely makes bigger error in the pressure drop than use of any reasonable (see below), although uncertain, data for the heat exchange model.

- Reasonable input data for heat exchange model: It is advisable to check the defaults used by the particular gas network simulator against available information about geometry (diameter and burial depth) and expectable soil properties. For steady-state simulations, this approach allows to find the expectable range of the overall HTC between gas and undisturbed soil. In most cases the simulator defaults are inside or very close to such range, but such check shall not be completely by-passed.
- The user shall also be aware, that the overall HTC (per unit of internal pipe surface) depends on the pipe diameter (see Figure 1)! Using single (default) value of HTC for different pipe diameters therefore creates in fact similar effect like the change of soil conductivity discussed above.
- Especially when an increasing system load is considered, it is advisable to make a final check of the steady-state results against extreme expectable values of HTC and to stay on the safe side.
- Measured data for pipeline system operating close to steady-state can be used for hand-made tuning of the overall HTC using steady-state simulation results. Such approach is feasible, however, for sufficiently simple situations (e.g. single value to be estimated).
- For transient simulations, the heat capacity of near soil has to be taken into account, i.e. the full transient heat exchange model should be used. The above mentioned geometry and soil considerations can help to derive the reasonable data for radial layers geometry. The check of default values used by the simulator and comparison with probable range of the soil properties, and analysis the simulation results for such input data, is still the recommended practice, namely for high-load situations or rough transients.
- Parameter tuning for transient cases is always difficult and requires detailed operation data; such procedure is usually related to real-time models only.

## REFERENCES

1. Dupond, T. F., Rachford H.H: How Required Compression Depends On the Thermodynamics of Rich Gas Flow, PSIG 9201
2. Bachman, S. K., Goodreau, M.: Steady State – Is the Solution Realistic for the Piping Network?, PSIG 0309
3. Sazima, M., Kmoníček, V., Schneller, J. et al: TEPLŮ, SNTL Praha, 1989 (in Czech)

## TABLES

| Soil type  | Density $\rho_s$   |                   | Specific heat capacity $c_{ps}$ |         | Heat conductivity $\lambda_s$ |       |
|------------|--------------------|-------------------|---------------------------------|---------|-------------------------------|-------|
|            | lb/ft <sup>3</sup> | kg/m <sup>3</sup> | BTU/lb/°F                       | kJ/kg/K | BTU/ft/h/°F                   | W/m/K |
| Dry sand   | 93.6               | 1500              | 0.170                           | 0.712   | 0.187                         | 0.324 |
| Sandy soil | 93.6               | 1500              | 0.440                           | 1.842   | 0.605                         | 1.047 |
| Clay soil  | 93.6               | 1500              | 0.440                           | 1.842   | 0.874                         | 1.512 |
| Wet sand   | 112.4              | 1800              | 0.170                           | 0.712   | 1.089                         | 1.884 |

**Table 1 – Typical soil properties (taken from [3])**

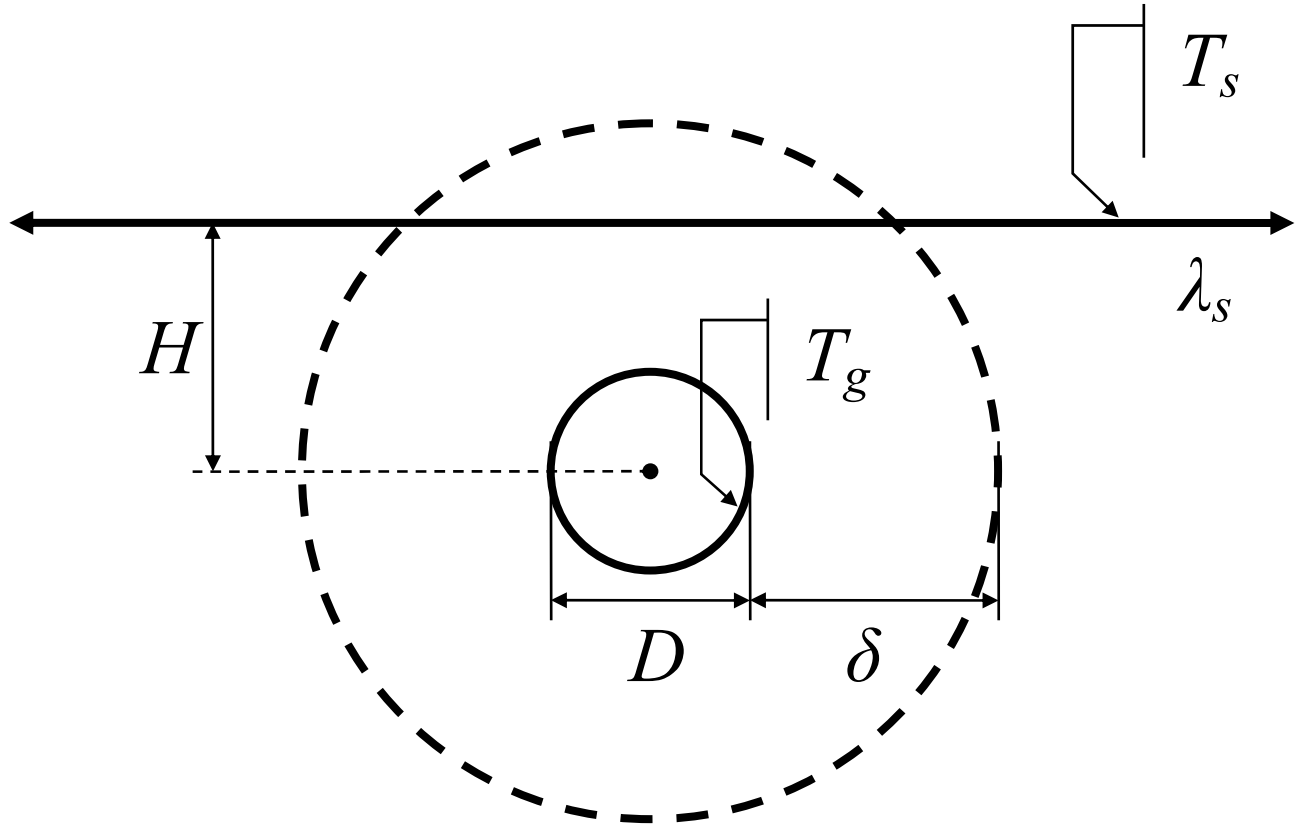
| Quantity                  |                                  | Value                  |                        |
|---------------------------|----------------------------------|------------------------|------------------------|
|                           |                                  | English units          | Metric units           |
| Pipeline data             | Lenght                           | 68.35 mi               | 110 km                 |
|                           | Inner diameter                   | 19.53 in               | 496 mm                 |
|                           | Roughness                        | 1181 $\mu$ in          | 0.03 mm                |
|                           | Wall thickness                   | 0.47 in                | 12 mm                  |
|                           | Steel density                    | 490 lb/ft <sup>3</sup> | 7849 kg/m <sup>3</sup> |
|                           | Steel heat capacity              | 0.11 BTU/lb/°F         | 0.46 kJ/kg/K           |
|                           | Steel heat conductivity          | 26 BTU/ft/h/°F         | 45 W/m/K               |
| Gas Composition<br>% mol. | CH <sub>4</sub>                  | 88.30                  |                        |
|                           | N <sub>2</sub>                   | 1.40                   |                        |
|                           | CO <sub>2</sub>                  | 0.50                   |                        |
|                           | C <sub>2</sub> H <sub>6</sub>    | 4.10                   |                        |
|                           | C <sub>3</sub> H <sub>8</sub>    | 2.40                   |                        |
|                           | i-C <sub>4</sub> H <sub>10</sub> | 1.10                   |                        |
|                           | n-C <sub>4</sub> H <sub>10</sub> | 0.90                   |                        |
|                           | n-H <sub>5</sub> H <sub>12</sub> | 1.30                   |                        |
| Calculation               | Equation of state                | AGA8 DC-92             |                        |
|                           | Friction factor formula          | Hofer                  |                        |
|                           | Viscosity                        | Lee et al. 1964        |                        |

**Table 2 – Summary data about test pipeline**

| Soil type  | HTC for test pipeline     |                     |
|------------|---------------------------|---------------------|
|            | BTU/ft <sup>2</sup> /h/°F | W/m <sup>2</sup> /K |
| dry sand   | 0.12                      | 0.673               |
| sandy soil | 0.38                      | 2.156               |
| clay soil  | 0.55                      | 3.095               |
| wet sand   | 0.68                      | 3.839               |

**Table 3 – Steady Heat Transfer Coefficient for the test pipeline and soils from Table 1**

## FIGURES



Heat flux per unit of length:  $Q = \pi D \times HTC \times (T_g - T_s)$

Heat transfer coefficient per unit of surface:  $HTC = \frac{2\lambda_s}{D \arg \cosh\left(\frac{2H}{D}\right)}$

Equivalent radial soil layer thickness:  $\delta = \frac{D}{2} \left[ \left(\frac{2H}{D}\right) - 1 + \sqrt{\left(\frac{2H}{D}\right)^2 - 1} \right]$

Figure 1 – Geometry of buried pipe and equivalent radial soil layer



Figure 2 – Test pipeline model

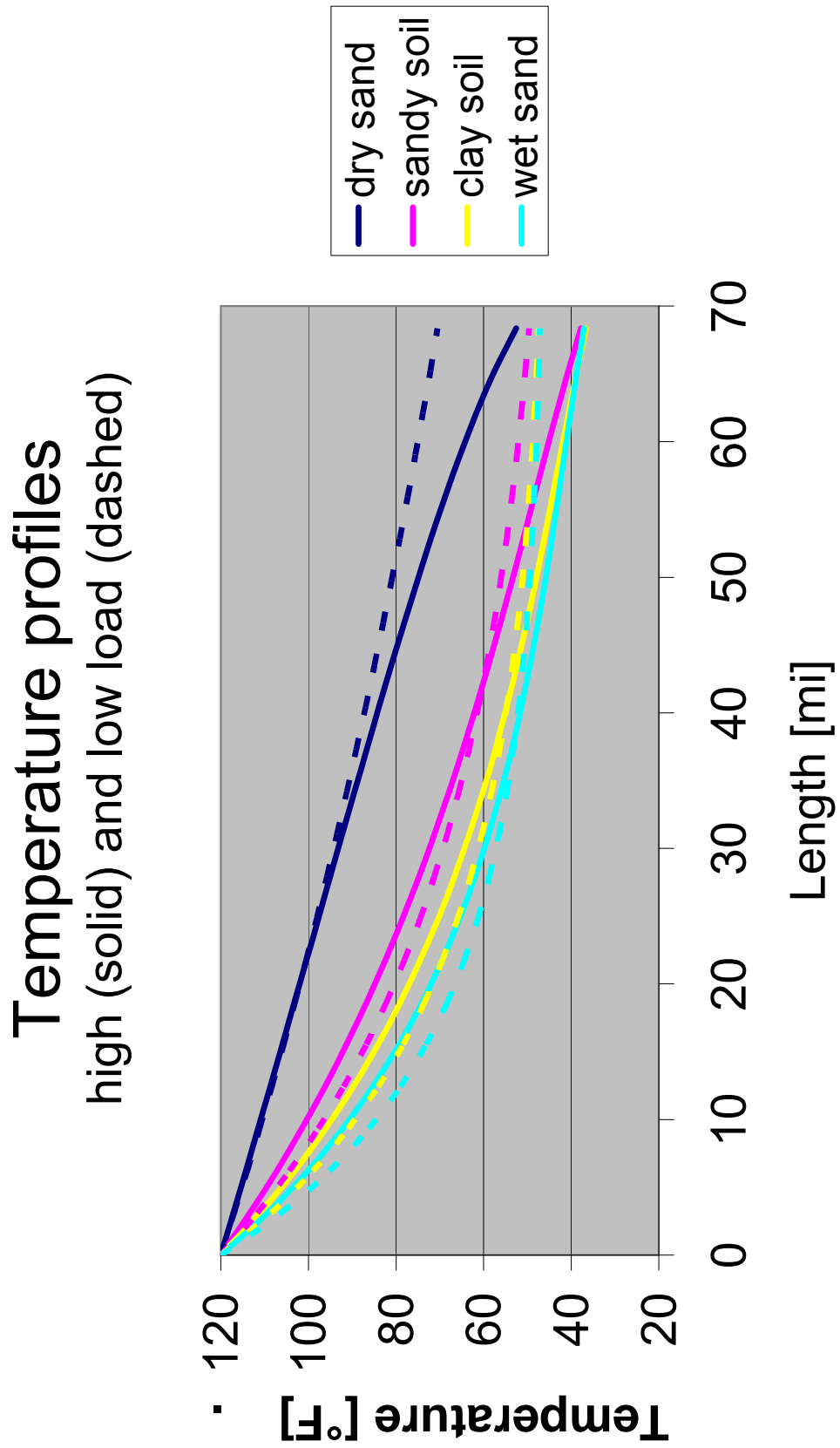


Figure 3 – Temperature profiles for steady-state calculations

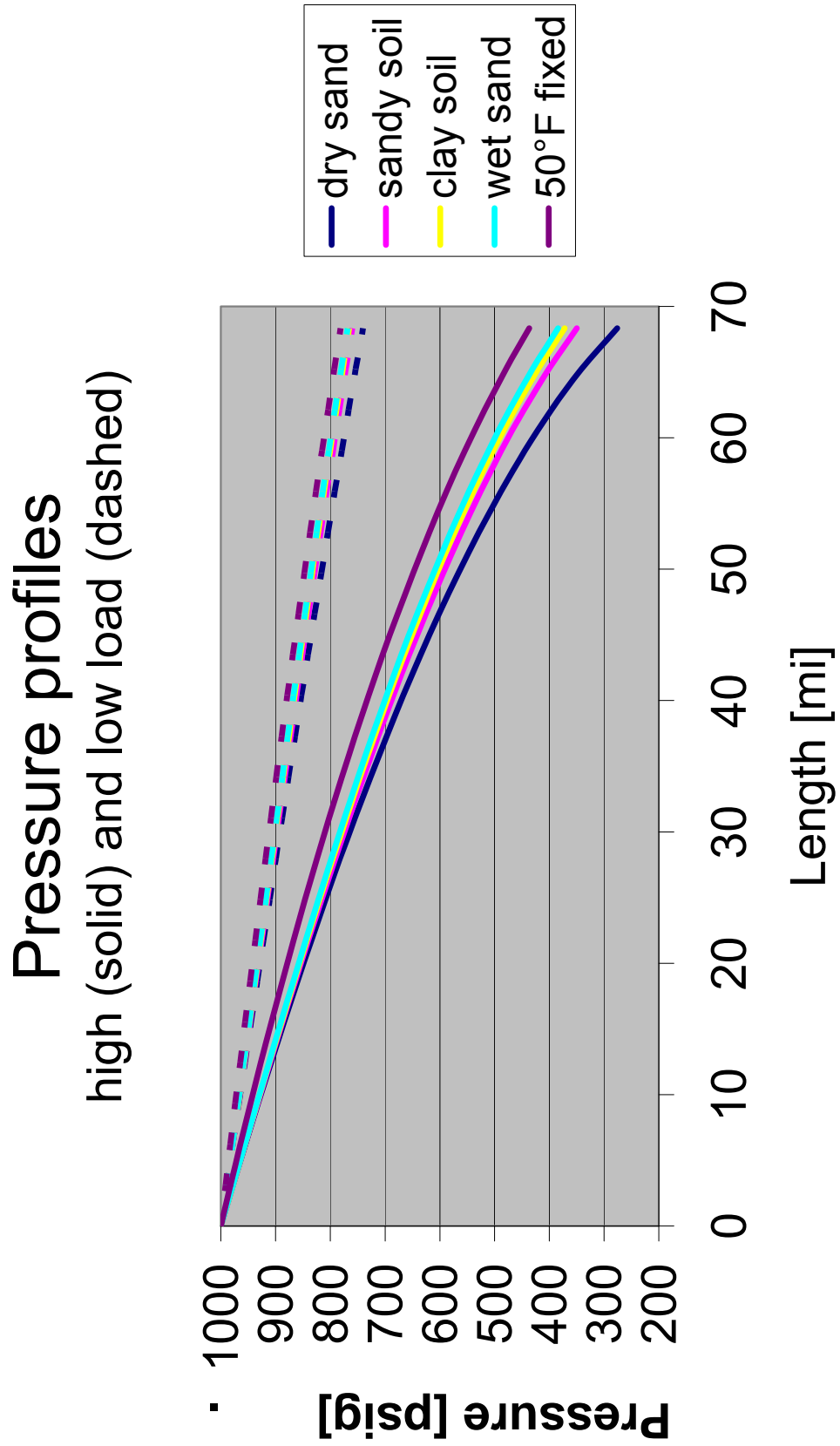


Figure 4 – Pressure profiles for steady-state calculations

# Temperature trends for node "D"

transient case, high load

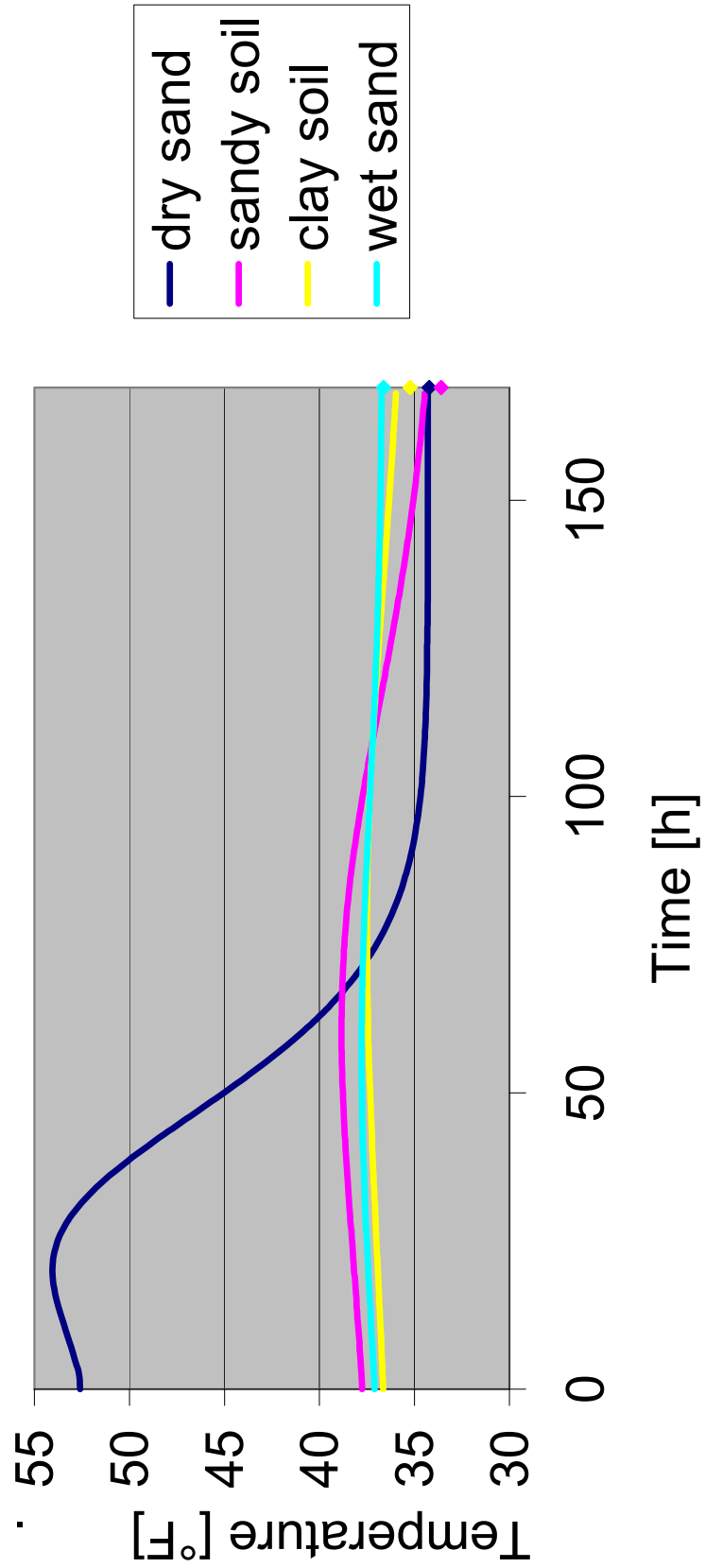


Figure 5 – Temperature trends in the downstream end node

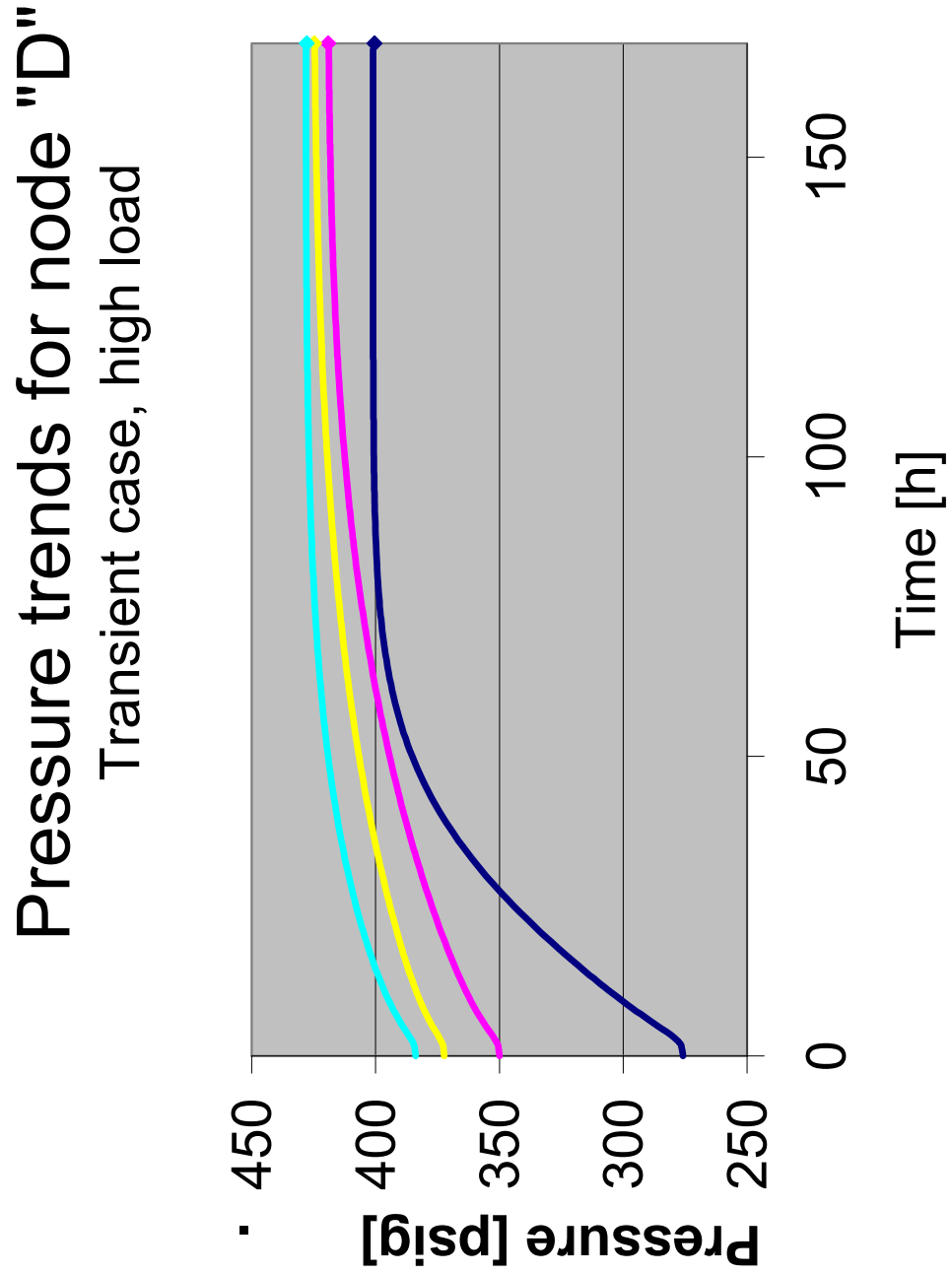


Figure 6 – Pressure trends in the downstream end node

# Simple vs. full transient heat flux

Temperature trends for node "D"

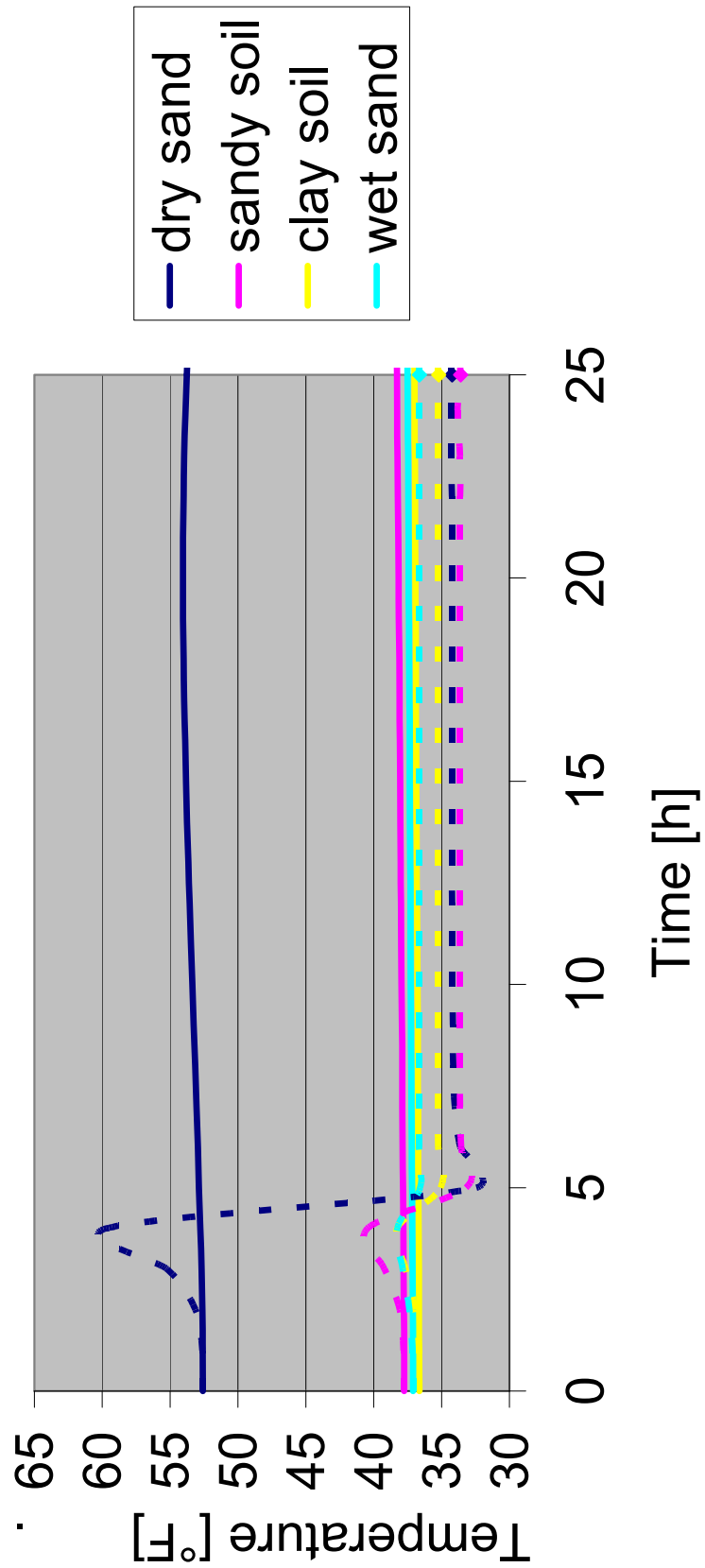


Figure 7 – Temperature trends in the downstream end node, simple steady heat flux model compared to full one

# Simple vs. full transient heat flux

Pressure trends for node "D"

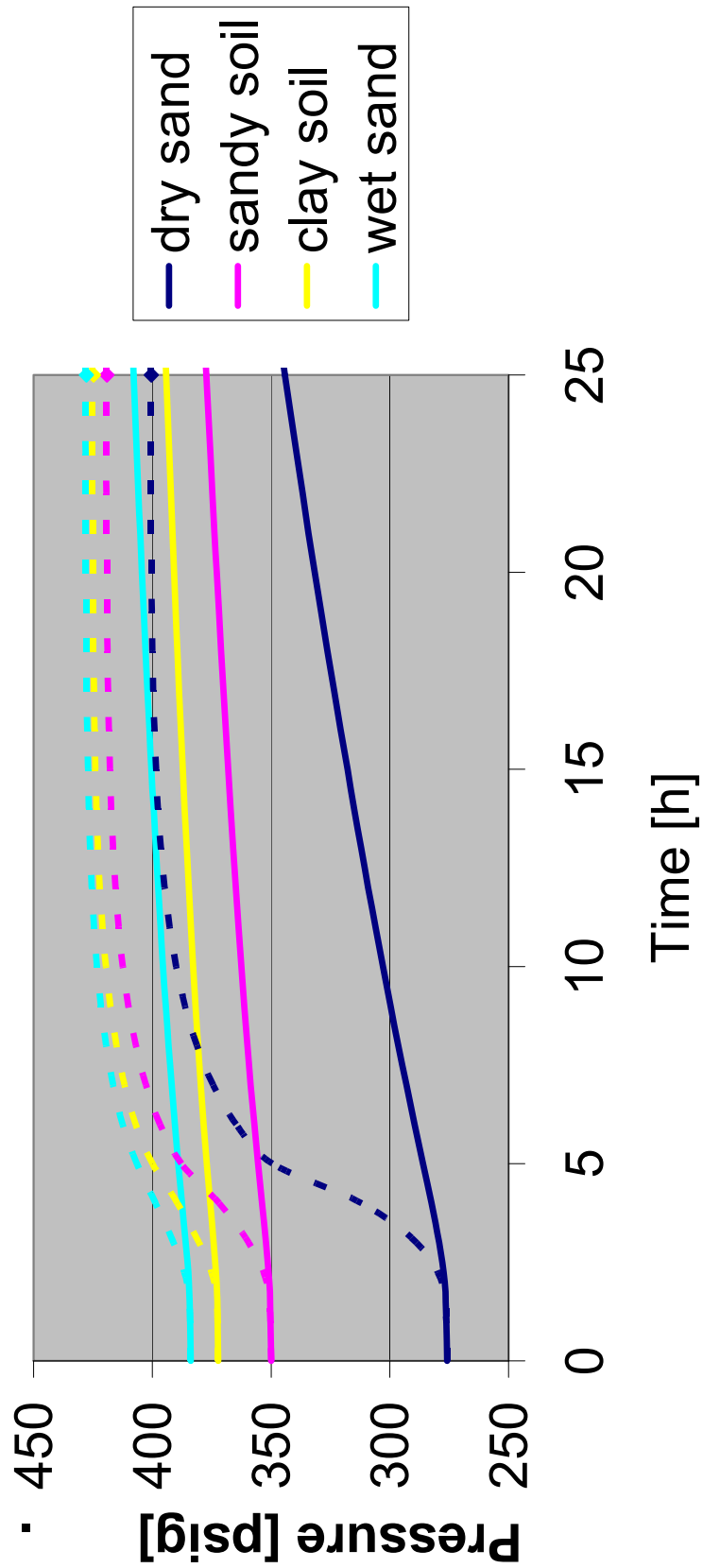


Figure 8 – Pressure trends in the downstream end node, simple steady heat flux model compared to full one