Memo

Date	**Our reference**	**Number of pages**
March 29, 2019	11201825-000-HYE-0006	39
Contact person	**Direct number**	**E-mail**
Sam van der Zwan	+31(0)88 335 8573	Sam.vanderZwan@deltares.nl

Subject
Wanda simulations

This memo describes the method and results of the Wanda simulation performed to determine the temperature rise of drinking water due to parallel district heating pipelines or electrical power cables which are in the proximity of the drinking water distribution pipes. This is a continuation of the work reported in 11201825-000-HYE-0004-m-WP2. In the previous work 2D simulations have been performed to calculate the soil temperature for different parameters. The goal of the results presented here is to get an insight in the effect of these different parameters on the drinking water temperature in a distribution network.

1   Model description

To investigate the effect on the drinking water temperature a Wanda model (1D pipeline simulation software developed by Deltares) has been built of a single pipeline. The pipeline has a length of 1 km. The inner diameter, flow rate and temperature at the upstream side are varied. Also, the surrounding soil temperature and soil properties are varied; this will be based on the results of Plaxis simulations reported in 11201825-000-HYE-0004-m-WP2. Upstream a flow boundary will be implemented, which is set to acquire the correct velocity in the pipe. Downstream a pressure boundary at 2 bar has been implemented, which does not affect the applicability of the results for other network pressures. How the coupling between the Wanda model and the Plaxis result is done is explained in chapter 2.

2   Coupling of Wanda to Plaxis results

2.1   WANDA Heat component

In Wanda a new pipe component in the heat domain has been implemented. The subsurface around the pipe can be subdivided in sections for which the heat transfer and storage are calculated based on the soil properties (see Figure 2.1). The pipe is divided in element along its length. For every element the soil temperatures as shown in Figure 2.1 are calculated. The temperature at the outside layer ($T_{ambient}$) is set by the user. A detailed description is available in appendix A.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
2 of 39

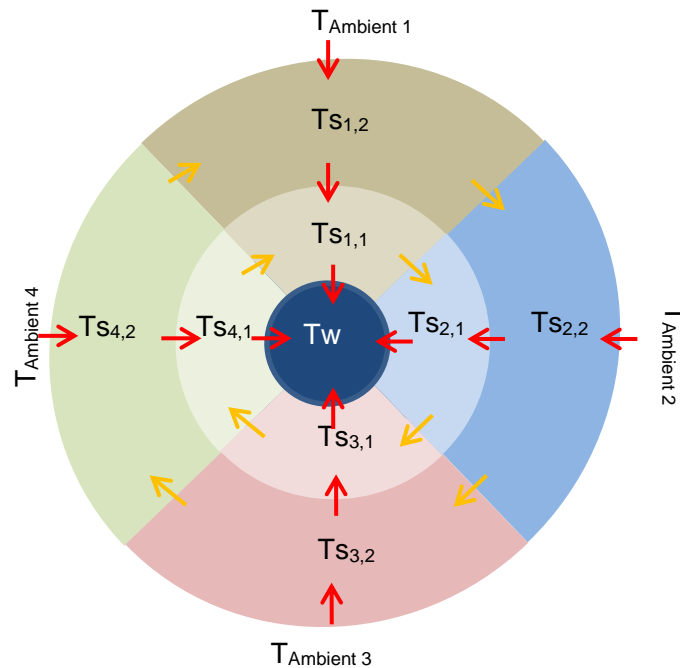*Figure 2.1: Overview of the division in sections and layers of the subsoil around the pipe Ts are soil temperatures, Tambient are soil temperatures at the boundary of the domain used in Wanda. T w is the temperature of the water. This is the cross section of one element in the Wanda pipe.*

2.2 Plaxis results as WANDA boundary condition

This section explains how the results of Plaxis are coupled to Wanda. Temperature boundary conditions are extracted from the 2D Plaxis model and used in the WANDA model. The time at which the results are coupled is chosen at the moment that the circumference average temperature is maximum. This will result in the highest drinking water temperature and thus the most conservative approach. For the coupling the following questions need to be answered:

1. At what distance from the drinking water pipe line the Plaxis results are coupled to the Wanda model?
2. In how many sections does the subsoil need to be divided to make a sufficiently accurate coupling?

The question in how many layers the soil needs to be divided is relevant for the transient simulations and will be answered in the corresponding section (3.2.10)

2.2.1 Distance from the drinking water pipeline.

Figure 2.2 to Figure 2.5 show the mean soil temperature vs the rotation angle around the drinking water pipeline for different constant drinking water temperatures. Figure 2.6 shows the orientation of the angle used in the calculations. These are results of the simulations with Plaxis. Table 2.1 shows the properties of the case shown here. First, it can be seen from Figure 2.2 that the temperature at the wall of the drinking water pipeline is almost constant, there is no radial

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
3 of 39

distribution, while at a certain distance from the pipeline the temperature is not constant. Furthermore, the figures show that the temperature in the subsoil depend upon the drinking water temperature in a linear fashion. Figure 2.7 shows the simulated points and a linearization based on the minimum and maximum drinking water temperature. There is no difference between the linearization and the points from the 2D simulations. This is logical since the heat transfer process is modelled with linear conduction equations for a fixed drinking water temperature. This observation is included in the new Wanda heat pipe which linearly interpolates and extrapolates between the two boundary values given in the temperature table. Therefore, from this point of view it does not matter at which distance the models are coupled. Figure 2.8 shows a comparison of the drinking water temperature along a 1000 m long drinking water pipeline for a coupling at 0.2 m and at 0.5 m. There is hardly any difference for this stationary simulation.

The distance of coupling might matter for transient simulations, this will be investigated when the transient results are presented.

Table 2.1: Properties of the simulated case

| Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Saturated
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m^3, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	Yes
	Outer diameter	63 mm
	Temperature	Supply 70°C, return 40°C
	Distance from drinking water pipe	1 m between SP and DWP centrelines
	Order	Supply-Return-Drinking water pipe
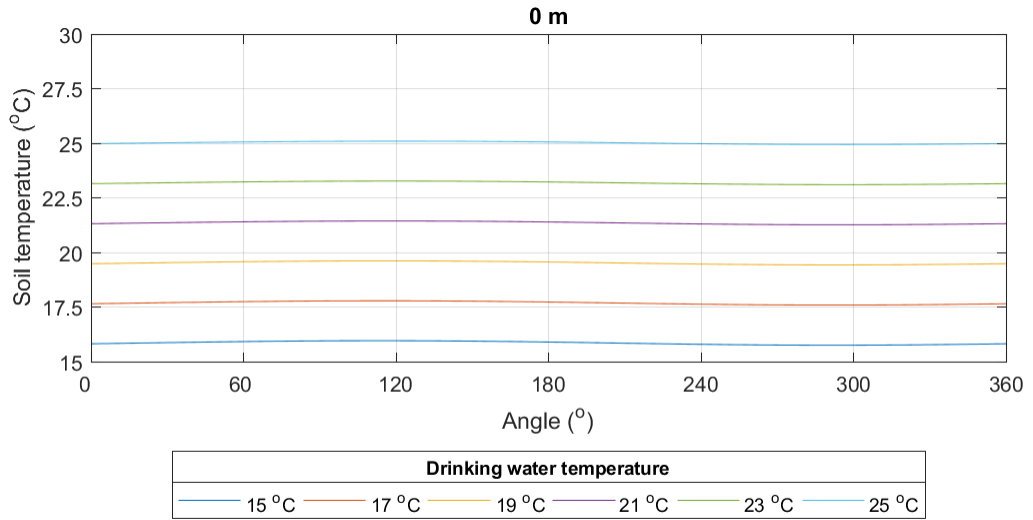
Figure 2.2: Ground temperature at a distance of 0 m from the drinking water pipeline for different drinking water temperatures
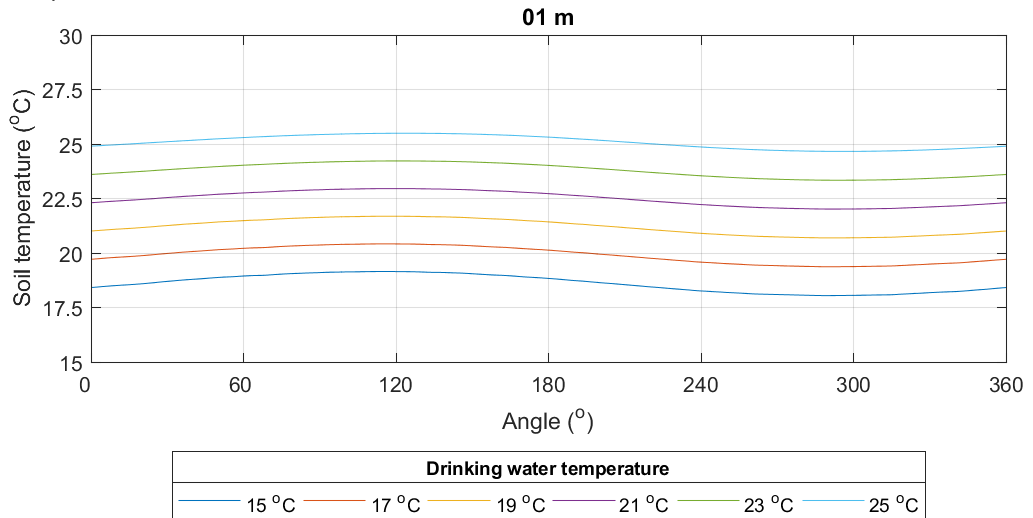

Figure 2.3: Ground temperature at a distance of 0.1 m from the drinking water pipeline for different drinking water temperatures

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
5 of 39

02 m

Figure 2.4: Ground temperature at a distance of 0.2 m from the drinking water pipeline for different drinking water temperatures

05m

Figure 2.5: Ground temperature at a distance of 0.5 m from the drinking water pipeline for different drinking water temperatures

Date
March 29, 2019

Our reference
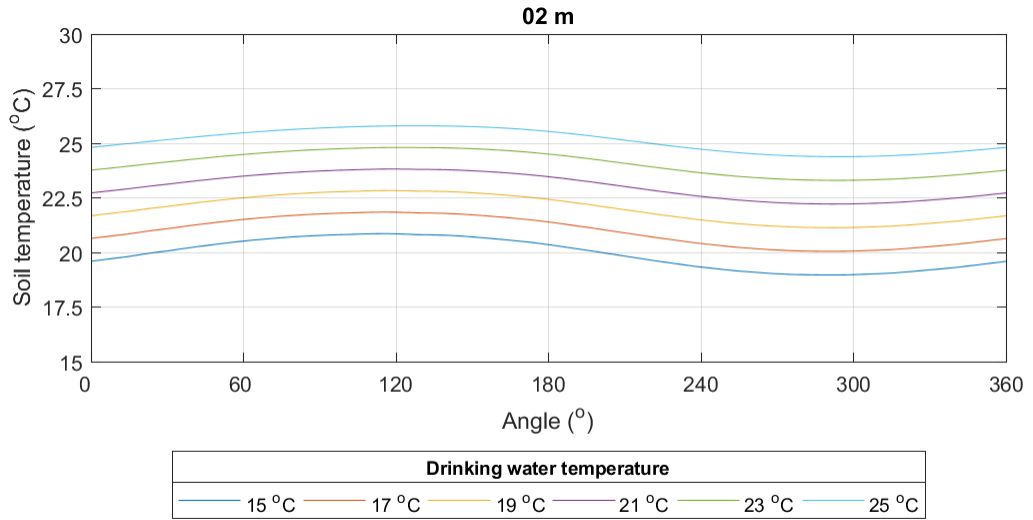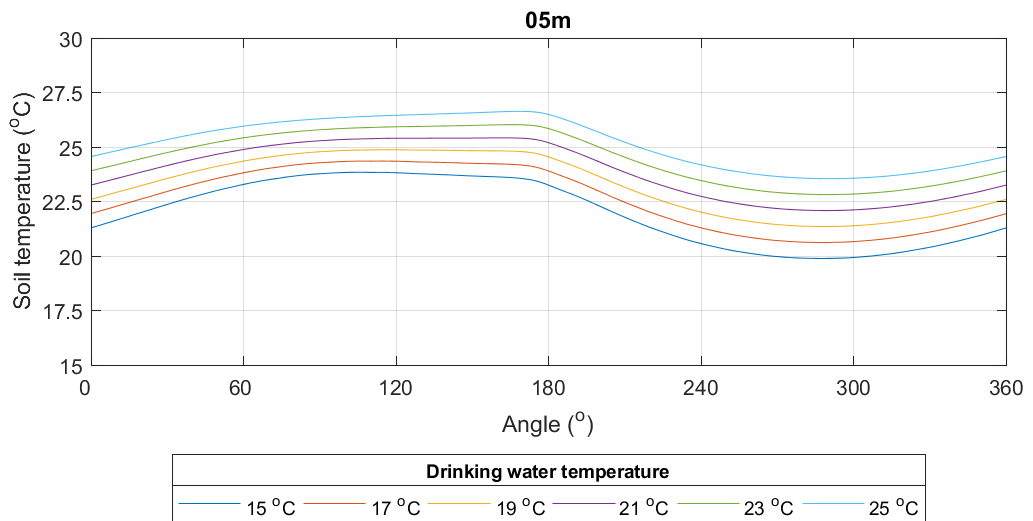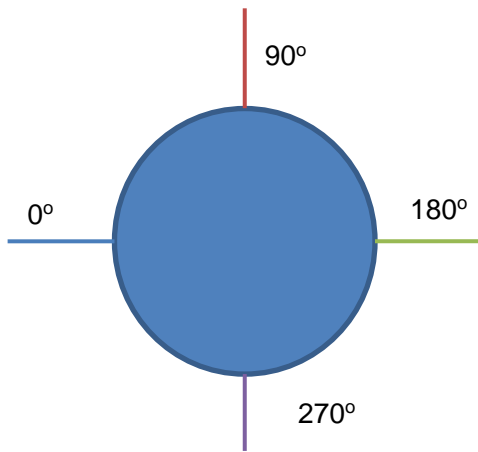11201825-000-HYE-0006

Page
6 of 39

Figure 2.6, Overview of the angles used in Figure 2.2 to Figure 2.5.
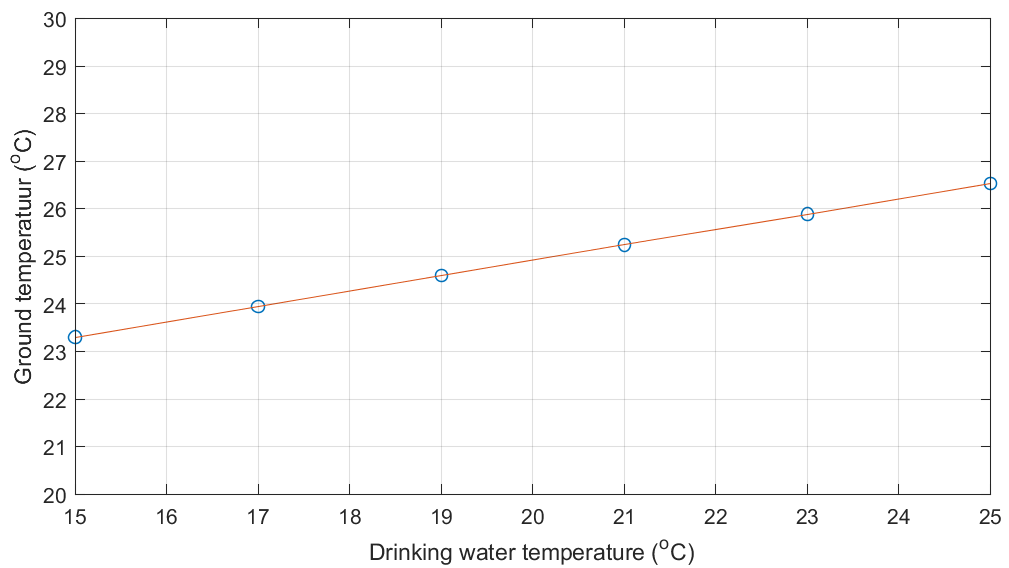

Figure 2.7: Linearization of the ground temperature boundary condition at 0.2m from the drinking water pipe wall for varying drinking water temperatures.
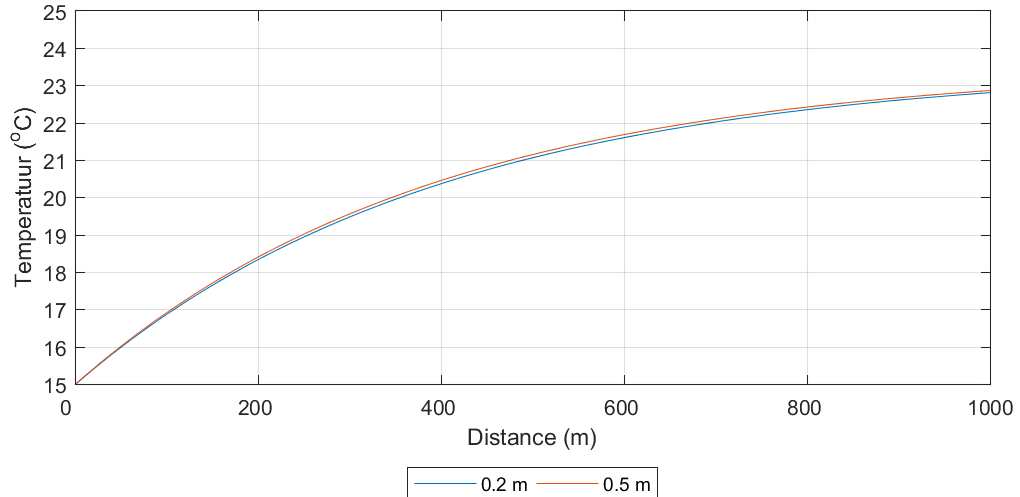
Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
7 of 39

Figure 2.8: Comparison of the drinking water temperature with the boundary at 0.2 m and 0.5 m at a drinking water velocity of 0.012 m/s

2.2.2 Discretisation of the circumference around the drinking water pipeline.
Table 2.2 shows the mean, standard deviation, minimum and maximum root mean square error Plaxis and discretisation in a number of sections This has been calculated for Plaxis results at a distance of 0.2 m from the drinking water pipeline and a drinking water temperature of 19°C. More sections lead to a better discretisation and thus a lower RMS value see Table 2.2. It has been chosen to split the circumference in 8 sections; this will yield a good enough accuracy in the discretisation while still maintaining computational efficiency.

Table 2.2 Overview of the RMS value for different number of sections of the surrounding subsoil

Number of sections	Mean RMSE (°C)	Min RMSE (°C)	Max RMSE (°C)
2	0.39	0.38	0.40
4	0.29	0.16	0.42
8	0.14	0.02	0.24
16	0.0728	0.0143	0.1194

Date
March 29, 2019

Our reference
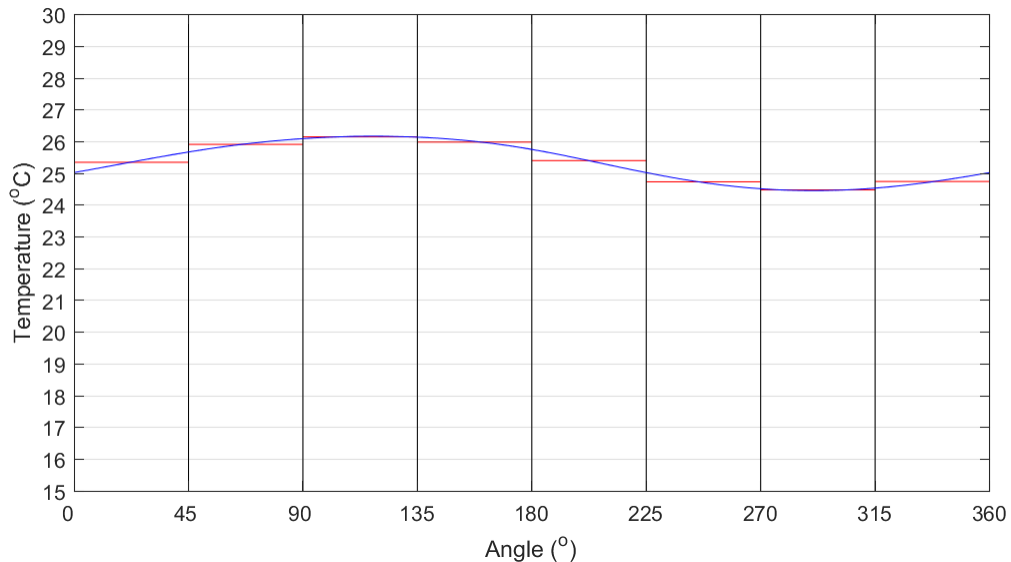11201825-000-HYE-0006

Page
8 of 39

Figure 2.9: Mean temperature in time at a distance of 0.2 m from the drinking water pipeline for a division in 8 sections. Red lines are the average values per sections

3 Results and discussion

The chapter discussed the results on the drinking water temperature for different parameters. To study the effect steady state simulations are performed. In this steady state simulation, we have determined for different residence times of the drinking water what the change in drinking water temperature is going to be. First the results of one simulation is discussed in detail, followed by an overview of the results for the other scenarios. The results are then discussed, and some conclusions are drawn. For all cases the soil temperature at the boundary is chosen at the moment that the average circumference temperature of the soil is at is maximum based on the time simulations of Plaxis. Please note that the results are based upon the summer of 2016.

3.1 Basic case

The base case includes no electric cable nor a district heating pipeline next to the drinking water pipeline. Table 3.1 shows the properties of the case. Figure 3.1 shows the temperature along the pipeline for this scenario. The rate of change in temperature along the line decreases due to the decreasing temperature difference. The temperature at the end of the pipeline is 22.8°C. If the pipeline length is doubled and the velocity is doubled, the end temperature is still 22.8 °C. This shows that the observed length and velocity of the pipeline are not of importance, but the residence time drives the temperature at the end of the line.

Figure 3.2 shows the temperature along the pipeline for different residence times in the pipeline. As expect, the longer the residence time the higher the outflow temperature. Figure 3.3 shows the drinking water temperature as a function of the residence time. This figure shows that without any district heating pipe or electric cable in the vicinity the temperature could already rise to approximately 23°C when the drinking water is more than 24 hours in the system for the summer

of 2016. This is already close to the limit of 25°C. Furthermore, it shows that flushing of the pipelines to reduce the residence time can significantly limit the temperature rise.

Table 3.1: Properties of the simulated case

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Saturated
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m^3, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	No
	Outer diameter	n/a
	Temperature	n/a
	Distance from drinking water pipe	n/a

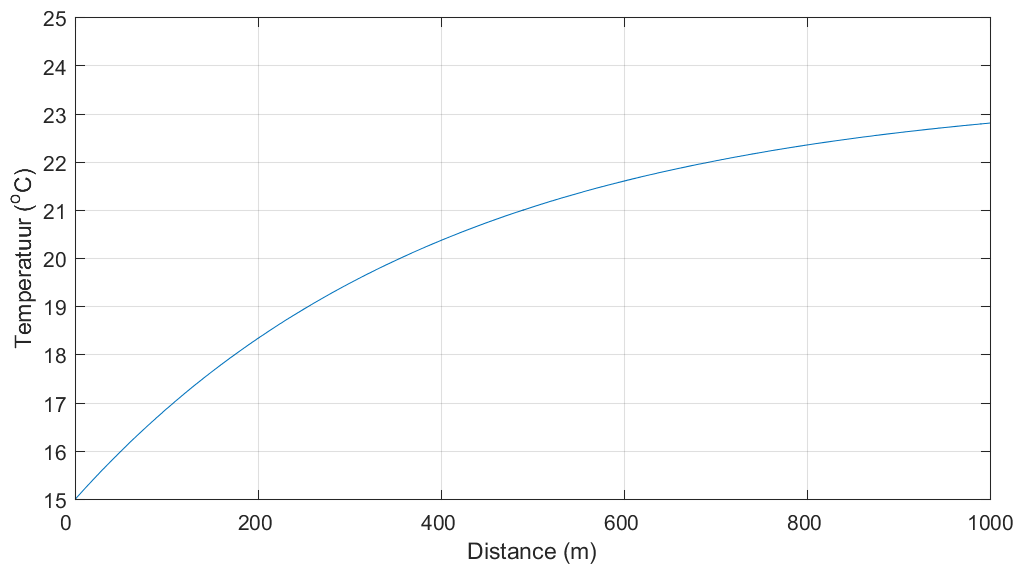*Figure 3.1: Soil Temperature along the pipeline without any adjacent district heating pipes, with a residence time of 24 hrs.*

Date
March 29, 2019

Our reference
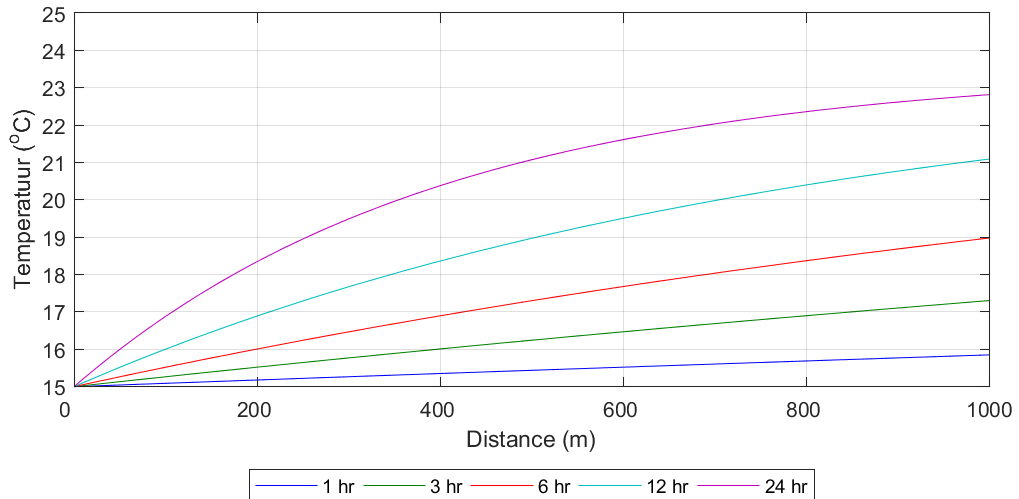11201825-000-HYE-0006

Page
10 of 39

Figure 3.2: Soil Temperature along the pipeline without any adjacent district heating pipes for different residence times.
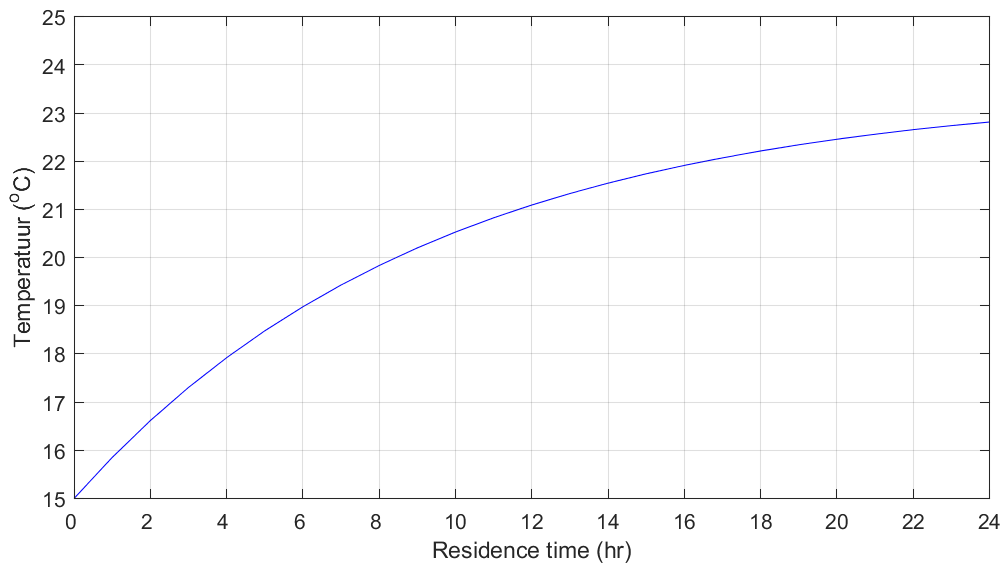
Figure 3.3: Drinking water temperature as function of the residence time

3.2 Parameter variation

3.2.1 Inflow temperature

Figure 3.4 shows the drinking water temperature as function of the residence time for different inflow temperatures of the drinking water. The first observation is that, the longer the water is in the pipeline the less influence there is from the inflow temperature. After about one day of residence inside the drinking water pipeline the influence of the inflow temperature can be neglected. Furthermore, it is interesting to note that for an inflow temperature of 24°C, the drinking water temperature decreases, since the ground is cooler than the drinking water. Concluding the drinking water temperature cannot rise above 25°C in this scenario.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
11 of 39

Table 3.2: Properties of the simulated case

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Saturated
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m^3, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	No
	Outer diameter	n/a
	Temperature	n/a
	Distance from drinking water pipe	n/a

Figure 3.4: Drinking water temperature as function of the residence time for different start temperatures of the drinking water

3.2.2 Effect of district heating pipe

Table 3.3 shows the properties used for a simulation with a district heating pipe in the subsurface. Figure 3.5 shows the results for these scenarios for different drinking water inflow temperatures. The temperature again converged to the same temperature after long residence times. Furthermore, it can also be seen that the temperature does not come above 25°C unless the inflow temperature is above 25°C, in that case the temperature decreases towards 25°C, so concluding for this case the temperature of the drinking water cannot rise above 25°C for this scenario.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
12 of 39

Figure 3.6 shows a comparison of the drinking water temperature vs. the residence time for the case with and without a district heating pipe in the neighbourhood of the drinking water pipeline. The difference increases for longer residence times. For a residence time of 24 hours, the difference is 1°C.

Table 3.3: Properties of the simulated case

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Saturated
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m^3, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	Yes
	Outer diameter	63 mm
	Temperature	Supply 70°C, return 40°C
	Distance from drinking water pipe	1 m between Supply and Drinking water pipe centrelines
	Order	Supply-Return-Drinking water pipe

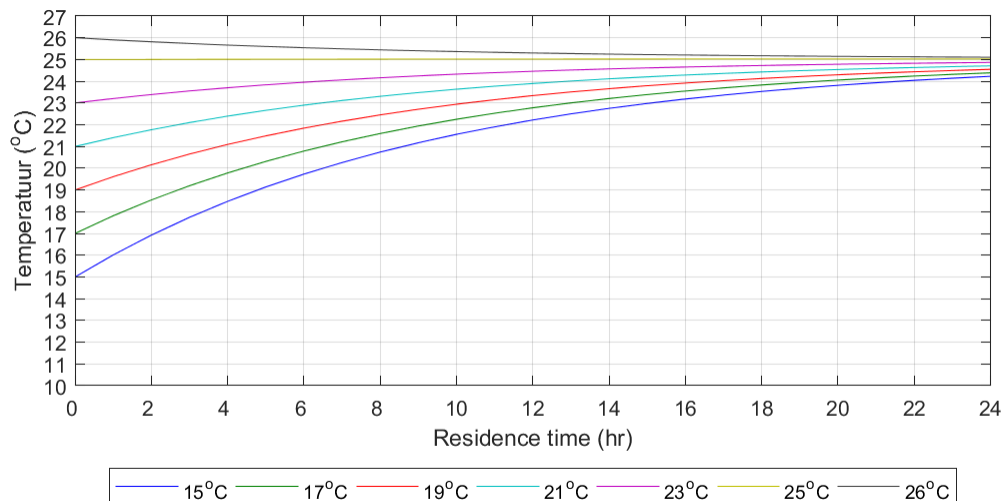*Figure 3.5: Results for the drinking water temperature vs. the residence time for different inflow temperatures of the water for the scenario parameters as given in Table 3.3.*

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
13 of 39

Figure 3.6: Comparisons of the drinking water temperature vs. the residence time for the scenario with (green) and without (blue) a district heating pipe next to the drinking water pipeline.

3.2.3   Effect of electrical cable

Table 3.4 shows the properties used for the simulation with an electric cable at 1 m of the drinking water pipeline. Figure 3.7 shows the effect for different drinking water temperatures.

Again, the asymptotic behaviour, as observed in the previous section can be seen and it can be concluded that the drinking water temperature will not rise above 25°C for this scenario. Figure 3.8 shows a comparison for the scenario without any heat source in the subsurface, with a district heating pipe and the scenario with an electrical cable. The electrical cable has less effect on the drinking water temperature than a district heating pipe, but the difference is only 0.4°C. (24.2°C vs. 23.8°C). Since the district heating pipe results in the highest drinking water temperature, this case is studied in the remainder of this chapter.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
14 of 39

Table 3.4, Properties of the simulated case

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m³, C_p = 920 J/kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Saturated
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m³, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	No
	Outer diameter	n/a
	Temperature	n/a
	Distance from drinking water pipe	n/a
	Order	n/a
Electric cable	Yes/No	Yes
	Distance from drinking water pipe	1 m
	Heat produced	4.5 W/m

Figure 3.7: Results for the drinking water temperature vs. the residence time for different inflow temperatures of the water for the scenario parameters as given in Table 3.4.
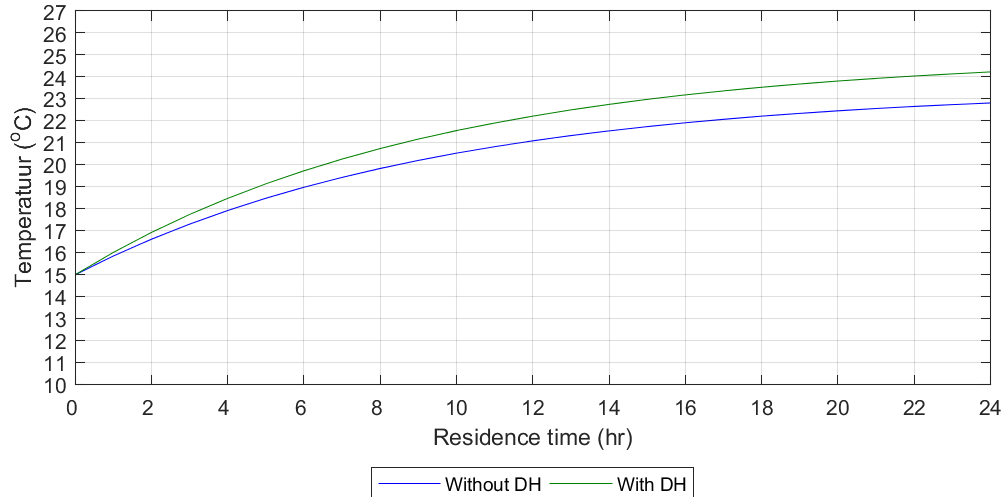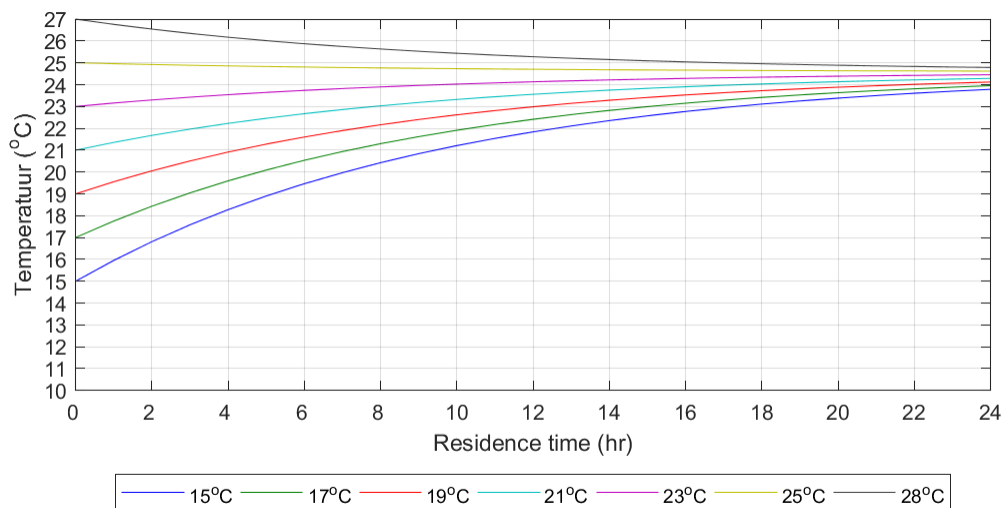
Date
March 29, 2019

Our reference
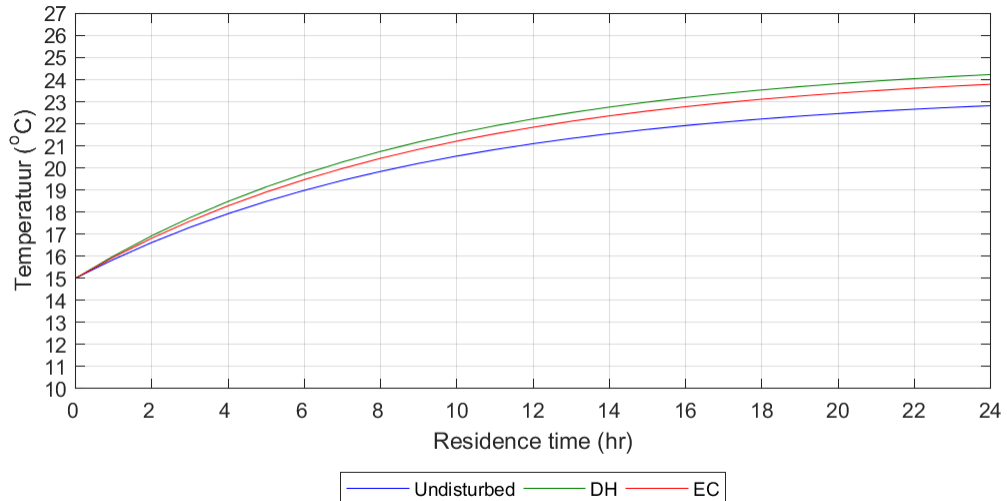11201825-000-HYE-0006

Page
15 of 39

Figure 3.8: Comparisons of the drinking water temperature vs. the residence time for the scenario without any heat source, the scenario with a district heating pipe (DH) and the scenario with an electric cable (EC) next to the drinking water pipeline.

3.2.4 Effect of above-ground material

Table 3.5 shows the properties of the simulated case. Figure 3.9 shows a comparison between the drinking water temperature vs. the residence time for a case where the ground top layer is tiles or grass. A grass layer significantly decreases the temperature (about 3^oC after 24 hrs). Concluding, the type of ground coverage has a significant impact on the results. This big difference is caused by the rate of evaporation which is much higher with grass then with tiles on the surface. This results in a lower surface temperature and thus a lower drinking water temperature.

Table 3.5, Properties of the simulated case

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Saturated
	Top layer	Tiles/Grass
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m^3, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	Yes
	Outer diameter	63 mm
	Temperature	Supply 70°C, return 40°C
	Distance from drinking water pipe	1 m between Supply and Drinking water pipe centrelines
	Order	Supply-Return-Drinking water pipe

Date
March 29, 2019

Our reference
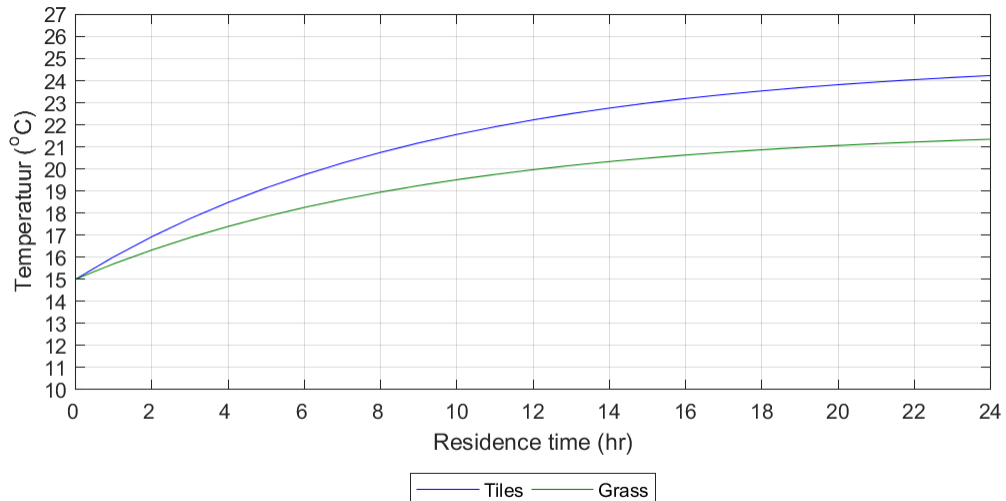11201825-000-HYE-0006

Page
16 of 39

Figure 3.9, Comparisons of the drinking water temperature vs. the residence time for the scenarios with different type of top layers.

3.2.5 Effect of the soil

Figure 3.10 shows a comparison for the scenarios with different soil properties, Table 3.6 shows the properties used for the simulation. The scenario with dry sand results in the highest temperature, since this sand has the highest thermal conductivity coefficient, which is only of importance since we are only simulating steady state cases.

Table 3.6, Properties of the simulated case

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/(kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Dry, Saturated, Wet, Clay
	Material	See Table 3.7
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	Yes
	Outer diameter	63 mm
	Temperature	Supply 70°C, return 40°C
	Distance from drinking water pipe	1 m between Supply and Drinking water pipe centrelines
	Order	Supply-Return-Drinking water pipe

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
17 of 39

Table 3.7, Overview of the properties for the different soil types

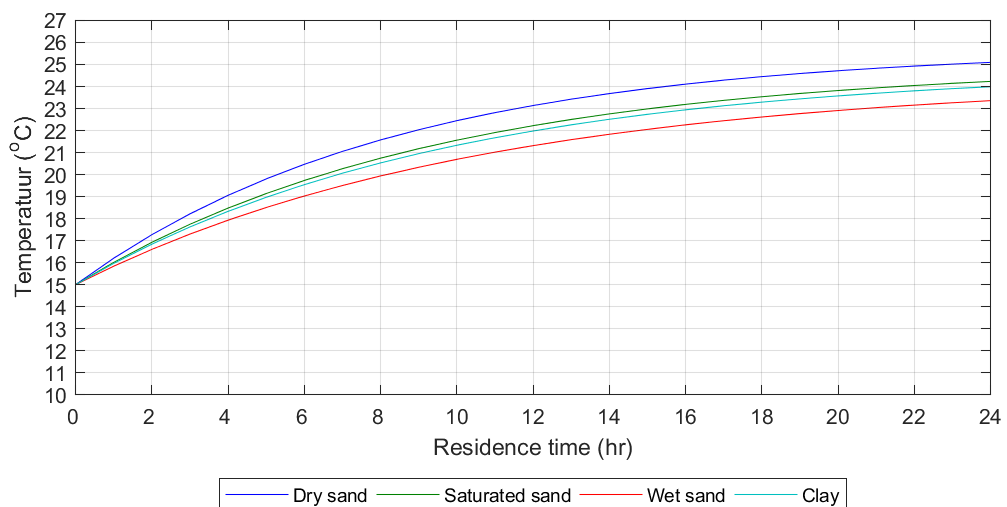| Saturation	Density (kg/m³)	Heat capacity (J/kg/K)	Thermal conductivity coefficient (W/mK)
Dry	1,600	800	1.6
Saturated	1,700	1,000	1.4
Wet	1,800	1,200	1.2
Clay	1,600	1,350	1.35

Figure 3.10: Comparisons of the drinking water temperature vs. the residence time for the scenarios with different type of soil properties.

3.2.6 Effect of drinking water pipe material and diameter

Figure 3.12 shows a comparison of the results for the different diameter of the drinking water pipelines, Table 3.8 shows the properties of the simulated cases. The diameter of the district heating pipes has also been varied with the size of the drinking water pipeline to simulate the difference between a transport system and a distribution system.

As expected, the smaller the diameter the higher the drinking water temperature. A smaller diameter pipe contains less water and therefore is more influenced by the surroundings. However, for this case a relatively large diameter district heating pipeline has been used resulting in a large heat source.

Furthermore, there is a negligible influence of the material of the drinking water pipeline. The effect that can be seen is caused by the larger diameter of the drinking water pipeline, since the heat transfer coefficient is in the same order of magnitude. The coefficient for the ductile iron pipeline is determined by the cement lining.

For the case with the DN160 pipe the subsurface temperature is higher than the drinking water temperature resulting in a constant increase of the temperature and no limitation. However, the conditions of this cases are to simulate a transport system, which has low residence times and it is not expected that this will result in a drinking water temperature higher than 25⁰C for this scenario.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
18 of 39

Table 3.8: Properties of the simulated cases

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/kg/K)) DI ((λ = 0.323 W/(mK), ρ = 7300 kg/m^3, C_p = 506 J/kg/K)))
	Outer diameter	110 mm, 63 mm, 160 mm, 121.6 mm (DI)
	Wall thickness	2.7 mm, 2 mm, 4 mm, 11.8 mm
Ground	Saturation	Saturated
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m^3, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	Yes
	Outer diameter	63 mm, 140 mm, 280 mm, 140 mm
	Temperature	Supply 70ºC, return 40ºC
	Distance from drinking water pipe	1 m between Supply and Drinking water pipe centrelines
	Order	Supply-Return-Drinking water pipe

Figure 3.11: Comparisons of the drinking water temperature vs. the residence time for the scenarios with different type of diameters of drinking water pipes.

3.2.7 Effect of distance between drinking water pipe and district heating pipes

Table 3.9 shows the properties of the simulated scenario for which the distance between the district heating pipes and the drinking water pipe are varied. The given distance is the distance between the centerline of the drinking water pipe and the supply pipe of the district heating system. Figure 3.12 shows the drinking water temperature drops at increasing distance from the

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
19 of 39

DH-pipe. However, increasing the distance above 1.5 m will not significantly increase the drinking water temperature.

Table 3.9: Properties of the simulated case

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Saturated
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m^3, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	Yes
	Outer diameter	63 mm
	Temperature	Supply 70ºC, return 40ºC
	Distance from drinking water pipe	0.75m, 1 m, 1.5 m and 2 m between Supply and Drinking water pipe centrelines
	Order	Supply-Return-Drinking water pipe

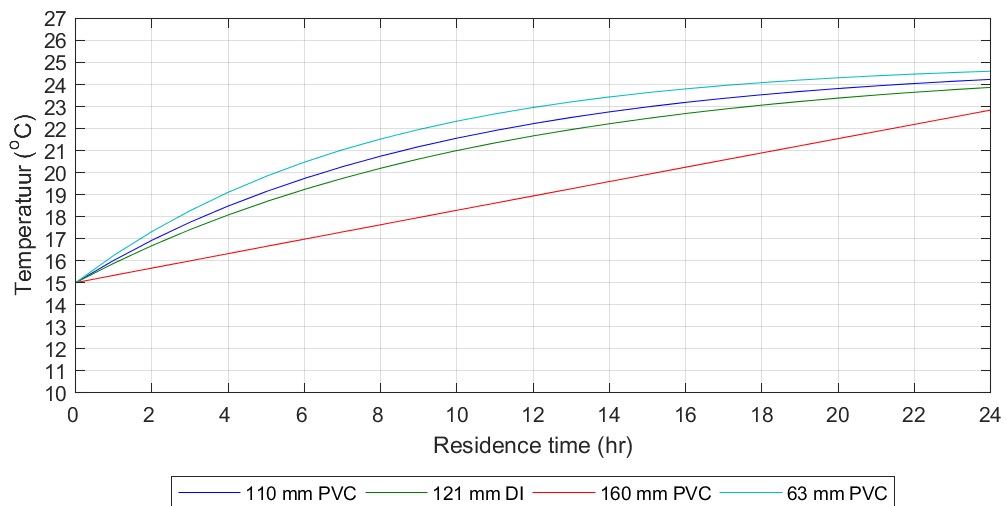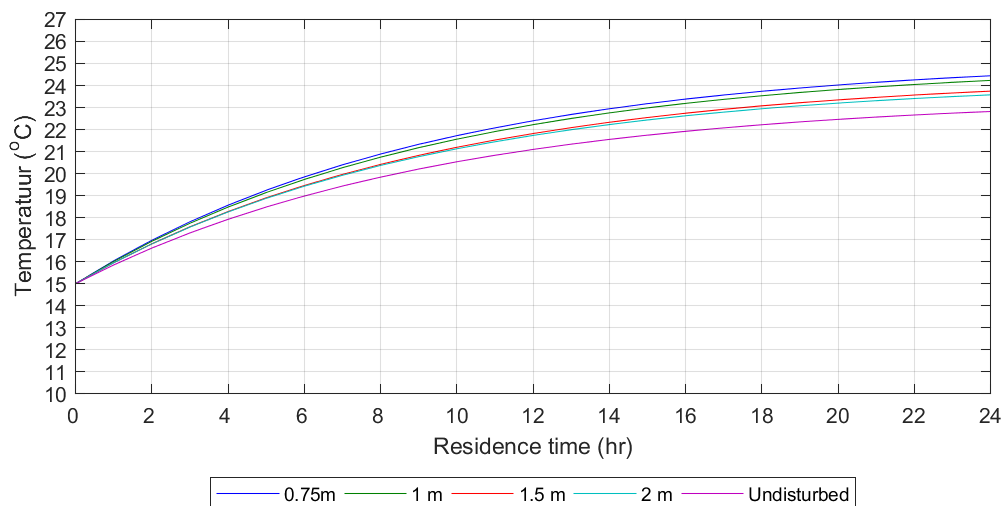*Figure 3.12: Comparisons of the drinking water temperature vs. the residence time for the scenarios with different distance between the district heating pipe and the drinking water pipes*
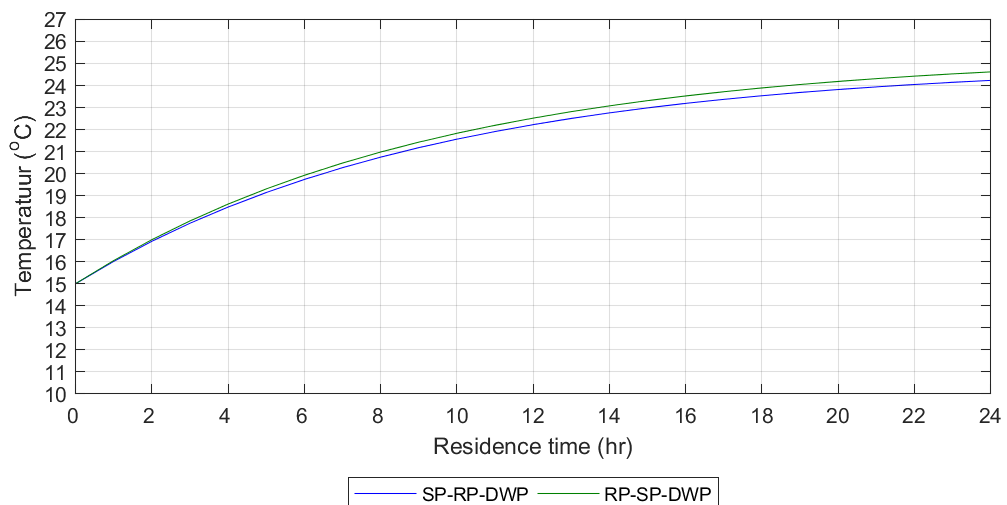
3.2.8   Effect of order of district heating pipes
Table 3.10 shows the properties of the simulated scenario for which the distance between the district heating pipes and the drinking water pipe are varied. Figure 3.13 shows the results.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
20 of 39

There is almost no effect when the order of the supply pipe and return pipe are changed. However, it should be noted that since the distance between the supply pipe and the drinking water pipe is kept the same, the distance between the district heating pipes and the drinking water pipes changes. Therefore, it is recommended for the smallest distance between the district heating pipes and the drinking water pipe to have the return pipe the closest to the drinking water pipe. The presence of the return pipe in between the supply pipe and DW pipe has a small cooling effect on the drinking water temperature (0.4 °C)

Table 3.10: Properties of the simulated case

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Saturated
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m^3, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	Yes
	Outer diameter	63 mm
	Temperature	Supply 70°C, return 40°C
	Distance between supply pipe and drinking water pipe	1 m between Supply and Drinking water pipe centrelines
	Order	Supply-Return-Drinking water pipe/ Return-Supply-Drinking water pipe

Figure 3.13: Comparisons of the drinking water temperature vs. the residence time for the scenarios with different order of the district heating pipes

3.2.9 Effect of the ground coverage

Table 3.11 shows the properties of the simulated scenario for which the distance from the surface is varied. Figure 3.14 shows that the temperature of the drinking water increases at smaller ground coverage since the highest subsoil temperature is between the district heating pipe and the top layer. Therefore, if the drinking water pipe is put at a higher level, the ambient ground temperature around the pipe will increase resulting in a higher drinking water temperature.

Table 3.11: Properties of the simulated case

Item	Property	Value
Drinking water pipeline	Material	PVC (λ = 0.16 W/(mK), ρ = 1380 kg/m^3, C_p = 920 J/kg/K))
	Outer diameter	110 mm
	Wall thickness	2.7 mm
Ground	Saturation	Saturated
	Material	Sand (λ = 1.4 W/(mK), ρ = 1700 kg/m^3, C_p = 1000 J/kg/K)
	Above ground material	Tiles
	Building level	Medium
District heating pipes	Yes/no	Yes
	Outer diameter	63 mm
	Temperature	Supply 70ºC, return 40ºC
	Distance from drinking water pipe	1 m between Supply and Drinking water pipe centrelines
	Order	Supply-Return-Drinking water pipe

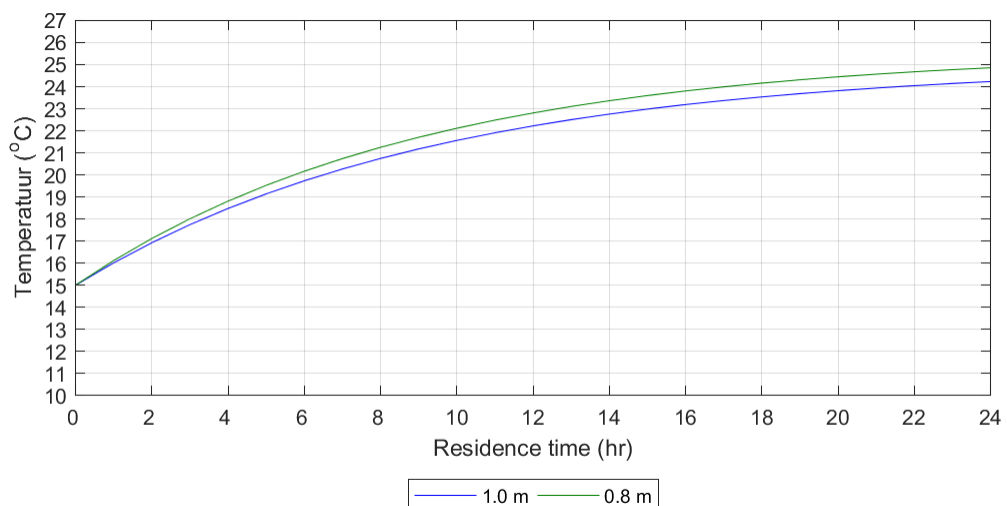*Figure 3.14: Comparisons of the drinking water temperature vs. the residence time for the scenarios with different ground coverages.*

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
22 of 39

3.2.10 Variation in time

The results in the previous sections were obtained with stationary simulations. However, a drinking water distribution system is a dynamic system. To assess the effect of time variation of the drinking water velocity simulations were performed with variable flow in time. The drinking water inflow temperature is kept constant at 15°C. The flow is then varied on a diurnal pattern basis. For the temperature in the soil at the boundary there are two options:

1   Keep the soil boundary temperature constant (the same as the steady state result)
2   Vary the soil boundary temperature with the drinking water temperature (i.e. each drinking water temperature has its specific soil boundary temperature).

Both options have limitations. It is expected that after about 1.5 hours of a (new) drinking water temperature through the drinking water pipe there is an influence on the outer boundary, at 0.2 m. This is calculated based on the penetration time in the soil. This means option 1 is not valid, because it assumes no influence. Also, option 2 is not valid because it assumes an instantaneous reaction. So, the truth will be somewhere in between. For a more exact approach a fully coupled model would need to be developed.

Figure 3.15 shows the drinking water temperature at the end of a 1 km pipe over time when the flow varies according a diurnal pattern. This figure shows that when the demand increases (and thus residence times in the pipe decreases) the temperature drops sharply (in effect the temperature rise over the 1 km pipe is less during higher demands). The temperature increases when the demand decreases again. Please note that the flushing flow is set very high, this result in a low residence time. Since we are interested in the residence time, the fact that the flow has been set to a high value is not of importance.

Figure 3.16 shows the temperature vs. the residence time for the variable flow simulation for both option 1 (blue) and 2 (red) compared to the stationary simulation (orange). The residence time is calculated from the (time varying) flow velocity. The points which are far off the blue and red lines (around residence times 0 and 6-7 hours) are due to the discretisation of the pipeline into elements.

The steady state simulations were done with a constant flow rate, and a variable soil boundary temperature over the length of the pipe, depending on the drinking water temperature. This means that the full range of 24 hours was calculated. However, for the variable flow rate simulations, the initial soil boundary temperature was set according to the initial drinking water temperature, which was for a residence time of 2.4 hours. For option 1 this temperature is kept constant. For option 2 it changes instantaneously with the increasing drinking water temperatures which results in this case in a higher drinking water temperature at the end of the 1 km pipe.

As said, we expect the truth to be somewhere between the results of option 1 and option 2. The result of the steady state simulations is partly in between and therefor might be a good approach. This needs to be verified with measurements.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
23 of 39
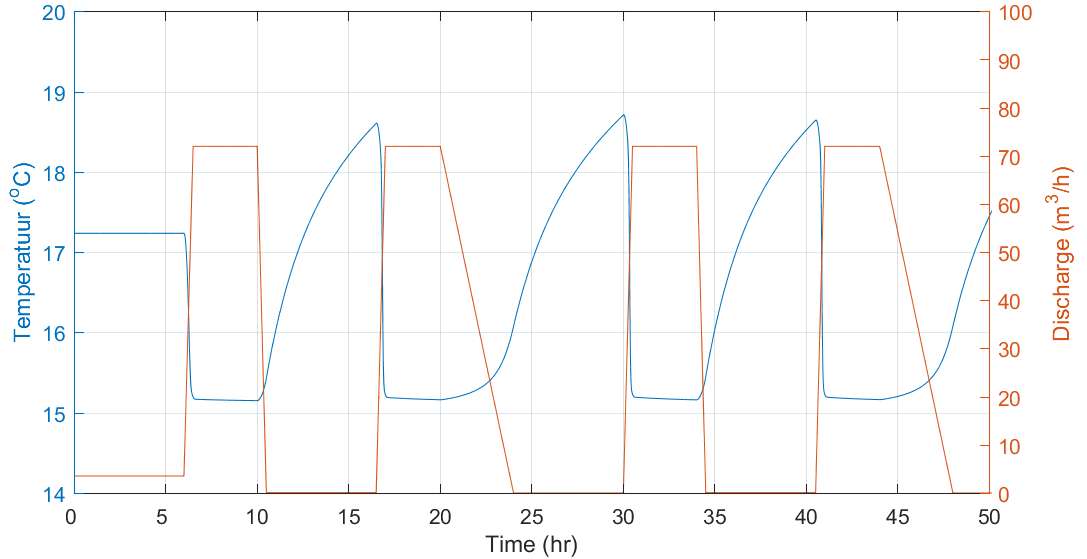
Figure 3.15: Drinking water temperature over time when the flow follows a diurnal pattern. Inflow temperature is 15ºC, length is 1 km, inner diameter is 104.6 mm, PVC, dry sand soil.
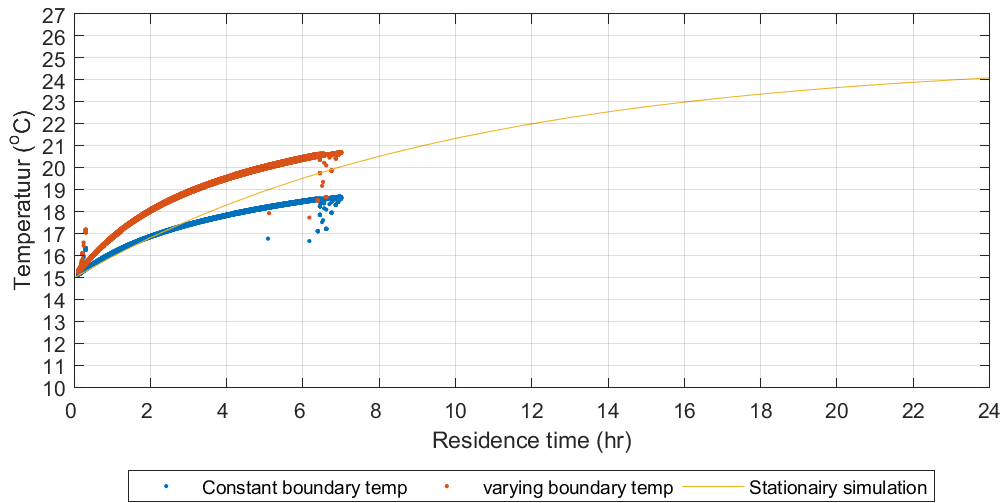
Figure 3.16: Temperature vs. residence time for the transient simulations compared to the results of the steady state simulations. The results of the steady state simulations are in yellow, the results of the varying flow simulations with a varying soil temperature at the boundary are in red, with a constant soil temperature at the boundary are in blue.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
24 of 39

4 Conclusions

This study has been done with climate data of the year 2016, therefore the conclusions in absolute values are only valid for this year. However, conclusions of the effect of the various parameters are also valid for other climate years. The following conclusions are drawn:
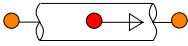
1. The maximum temperature the drinking water can reach is limited by the soil temperature at -1 meter, which for the year 2016 is in most simulations lower than 25°C.
2. The residence time is the major factor which influences the drinking water temperature compared to the other factors studied here.
3. An electrical cable results in a smaller temperature increase of the drinking water than a district heating pipe adjacent to the drinking water pipeline.
4. Grass coverage results in a significant lower drinking water temperature.
5. The dryer the sand the higher the drinking water temperature. The difference between wet sand and dry sand is about 2°C for a residence time of 24 hours for 2016.
6. Installing the drinking water pipes deeper will result in a lower drinking water temperature.
7. A steady state simulation might be used to determine the drinking water temperature if the residence time is known. This needs to be verified with measurements.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
25 of 39

Appendix A Wanda heat manual

1.1 Pipe with heat storage in surrounding

Type label	Symbol	Description	Active
Heat pipe		Pressurised pipe with heat transfer and storage in a surrounding annulus around the pipe.	Yes

1.1.1 Mathematical model

In the default heat pipe in Wanda the heat transfer between the pipe and an ambient condition at a certain distance from the pipe wall is modelled in a quasi-steady way, which implies that the internal thermal energy storage in the surrounding annulus around the pipe is neglected. If the ambient temperature varies over time, then the corresponding heat exchange with the fluid inside the pipe occurs instantaneously in a quasi- steady way. This heat pipe includes a more complete heat transfer model of the surrounding of the pipe by taking into account a layer discretisation and internal energy storage in these layers. Furthermore, this model accounts for specification of multiple sections (at most 10) to specify different ambient temperatures at different positions around the heat pipe; e.g. a higher soil temperature above the pipe during a heat wave.

1.1.1.1 Fluid equations

The PIPE can be considered the primary component in Wanda to simulate the pressure wave propagation during transient simulations. In Wanda Heat, the PIPE is also used to simulate transfer of heat in the system.

In steady state $dQ/dt = 0$. The PIPE is considered as a fall type, in which the head loss is modelled by the following equations:

$$\left(p_2 - p_1\right) + \rho g \left(y_2 - y_1\right) + f \frac{1}{32\pi^2} \frac{L}{D^5} \frac{\dot{m}|\dot{m}|}{\rho} = 0 \tag{1}$$

$$\dot{m}_1 - \dot{m}_2 = 0$$

in which:

$p_1 - p_2$	=	pressure loss from H-node 1 to H-node 2	[N/m^2]
$\dot{m}$	=	mass flow through the pipe	[kg/s]
f	=	friction factor	[-]
D	=	inner diameter	[m]
y_2-y_1	=	height difference between Heat node1 and Heat node 2	[m]
ρ	=	density	[kg/m^3]
g	=	gravitational acceleration	[m/s^2]

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
26 of 39

| L | = | pipe length | [m] |
| D | = | inner diameter | [m] |

WANDA calculates the friction factor, *f*, iteratively using the Darcy-Weisbach wall roughness, *k*. In Transient Mode the friction factor is recalculated each time step using a quasi-steady approach.

The wave propagation speed is calculated based on pipe and fluid properties (analogous to the Liquid pipe with "calculation mode" set to "waterhammer"). Details about the wave propagation and the equations involved are discussed in Theory on waterhammer pipes in Chapter 3. The water hammer equations are given:

Momentum:

$$\frac{1}{A_f}\frac{\partial Q}{\partial t} + g\frac{\partial H}{\partial s} + \frac{fQ|Q|}{2DA_f^2} = 0 \tag{2}$$

Continuity:

$$\frac{1}{c_f^2}\frac{\partial H}{\partial t} + \frac{1}{gA_F}\frac{\partial Q}{\partial s} = 0 \tag{3}$$

Note: only a circular cross section is supported in WANDA Heat.

1.1.1.2 Heat equations

The heat transfer in the pipe is included by dividing the pipe in elements, see Figure 4.1. Per element the temperature is calculated based on the following energy balance:

$$\frac{\rho_i c_{pi} V T_i^{t+\Delta t} - \rho_i c_{pi} V T_i^t}{\Delta t} = \left(c_p \dot{m} T\right)_{i-1}^t - \left(c_p \dot{m} T\right)_i^t - Q_{loss} + fr\left(\frac{\xi}{L} + \frac{f}{D}\right)\frac{\dot{m}_i^2 |\dot{m}_i|}{2\rho_i^2 A^2}ds \tag{4}$$

In which:

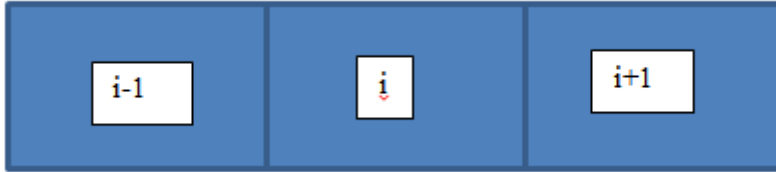| ρ | = | Density | [kg/m³] |
c_p	=	Specific heat	[J/kg/K]
V	=	Volume of the observed element	[m³]
T	=	Temperature	[K]
$\dot{m}$	=	Mass flow rate	[kg/s]
Q_{loss}	=	Heat loss	[W]
ξ	=	Local loss coefficient	[-]
L	=	Length of the entire pipe	[m]
f	=	Friction coefficient	[-]
A	=	Area of the pipe	[m²]
fr	=	Fraction friction loss to heat	[-]
ds	=	Element length	[m]

Figure 4.1 subdivision of pipe in elements for the temperature calculations

The division of the pipes in elements depends upon the type of pipe. For water hammer pipes the the water hammer grid is used. In a rigid column pipe a grid is created based on the advection velocity, which is defined by the user. The size of the grid is calculated from:

$$ds = \frac{L}{n} \tag{5}$$

n　=　number of internal grid cells　　　　[-]

The number of grid cells is calculated from:

$$n = Integer \left\lfloor \frac{L}{v_{adv}dt} \right\rfloor \tag{6}$$

v_{adv}　=　Maximum advection velocity　　　[m/s]
dt　=　Time step　　　　　　　　　　[s]

The maximum advection velocity is set by the user and should be greater than the flow velocity in the pipe for numerical stability. By increasing the time step the number of grid cells can be reduced. To ensure that steep temperature fronts are correctly conserved a flux limiter scheme is implemented. In Wanda the super bee limiter scheme is implemented see [3].

To increase the stability an additional robust check is built in when a pipe only contains one element. This can occur when the model consists of long and short pipes. In this case it is checked whether the actual advection velocity (L/dt), which can be lower than the advection velocity specified by the user, is lower than the flow velocity. When his occurs, the entire volume of water in the pipe is refreshed during on time step. If there are no heat losses in this pipe the inflow temperature is equal to the outflow temperature. If there is a heat loss the outflow temperature is calculated with:

$$T_{out} = T_{in} - \frac{Q_{loss}dx}{v} \tag{7}$$

By using this equation only the heat loss is used for the time the fluid is in the pipe. If this is not done the heat loss would be too high.

The heat loss in equation (4) includes all the heat losses to the surrounding. The heat is transported from the fluid through the pipe wall into the surrounding subsoil. All these effects should be taken into account. In the following section these effects are discussed.

Heat transfer from the surroundings
Heat transfer from the surroundings (conduction only) to the fluid is included at the pipe element discretisation. This is included by modelling different layer. Every layer can be subdivided in several sections, which can have different properties see Figure 4.2. To calculate the heat transferred to the fluid for each section of each layer the following equation is solved:

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
28 of 39

$$\frac{\partial V \rho c_p T}{\partial T} = Q_{lo} + Q_{li} + Q_{lr} + Q_{ll} \tag{8}$$

In which:

Q_{lo}	=	Heat flow on the outer edge between two layers, red arrows figure ..	[kW]
Q_{li}	=	Heat flow on the inner edge between two layers, red arrows figure ..	[kW]
Q_{lr}	=	Heat flow on the right edge between two adjacent sections, orange arrows figure ..	[kW]
Q_{ll}	=	Heat flow on the left edge between two adjacent sections, orange arrows figure ..	[kW]

Equation (8) models the heat transfer and transient energy storage in the discretised surrounding of the heat pipe. Equation (8) assumes that the heat transfer between adjacent elements in the surroundings can be neglected; therefore the right-hand side of equation (8) includes 4 terms instead of 6.
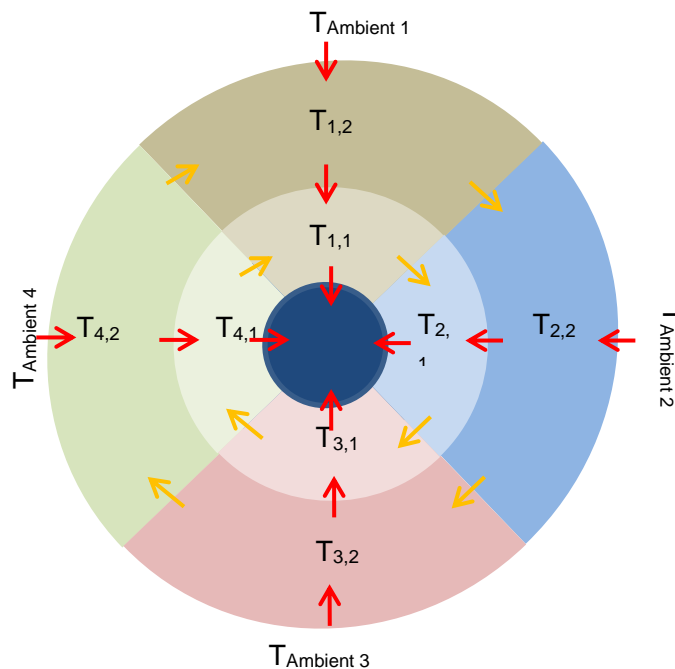

Figure 4.2 Overview of the heat transfer model with the surroundings. It consists of 4 sections and 2 layers. Arrows represent the heat flows that are taken into account.

These heat loss terms can be calculated from:

$$Q_{l*} = hA_{side}\Delta T \tag{9}$$

In which:

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
29 of 39

A$_{side}$ = Area through which the heat flows, based on the fluid   [m^2]
element length and the discretisation of the
surrounding materials (soil, isolation, etc)

For the inner and outer edge of a partial circular annulus, red arrows in Figure 4.2, the heat
transfer coefficient through a layer of material can be calculated from:

$$h = \frac{2\lambda}{D_2 ln \frac{D_2}{D_1}} \tag{10}$$

In which:

D$_2$ = Outer diameter   [m]
D$_1$ = Inner diameter   [m]

The heat transfer coefficient through the left and right side, orange arrows in Figure 4.2 can be
calculated from:

$$h = \frac{\lambda}{y} \tag{11}$$

In which:

$$y = \frac{2 \cdot \pi \cdot r}{n} \tag{12}$$

y = The length corresponding to the circumference at radius r [m]
from the pipe centerline divided by the number of sections
n

The final step is the heat transfer from the wall into the fluid. The heat transport in the fluid is
determined by the flow regime (laminar or turbulent). For laminar flow the following applies [2]
and [3]:

$$Nu = 3.66 \quad if \quad Gz > 0.1$$
$$Nu = 1.62 Gz^{-\frac{1}{3}} \quad if \quad Gz < 0.05 \tag{13}$$

In which
Nu = Nusselt number   [-]
Gz = Greatz number   [-]

The Greatz-number is given by:

$$Gz = \frac{a}{Dv} \tag{14}$$

in which
a = Thermal diffusion coefficient   [m^2/s]
D = Diameter of the pipe   [m]
v = Velocity of the fluid   [m/s]

The heat transfer coefficient can be calculated from:

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
30 of 39

$$h = \frac{Nu\lambda}{D} \tag{15}$$

In which:

h	=	Heat transfer coefficient	[W/m²/K]
λ	=	Heat conductivity coefficient	[W/m/K]

For turbulent flow, the following formula can be used [5]:

$$Nu = 0.027 Re^{0.8} Pr^{0.33} \quad if \quad Re > 10^4; Pr \geq 0.7 \tag{16}$$

In which

Pr	=	Prandtl-number	[-]

The Prandtl-number is given by:

$$Pr = \frac{\nu}{a} \tag{17}$$

In which

ν	=	Kinematic viscosity	[m²/s]

These above equations can be used to calculate the heat transfer coefficient from the wall into the fluid. This can be used the calculated the heat loss for every section and the sum of this is the total heat loss which can be used in equation(4). These equations together can be used to calculate the new temperature in every section and every layer and in the fluid based upon the temperature at the previous time step.

1.1.1.3   Thermal boundary conditions

The thermal boundary conditions at the up- and downstream side of the pipe are determined by the Wanda solver. The steady state version of equations (4) and the set of heat conduction equations in the surrounding soil are appended to the thermo-hydraulic steady state solver of Wanda Heat. In Transient mode, the complete sets of equations (4) and (8) are included in the thermos-hydraulic solver. The other boundary condition is specified by the user as the ambient temperature at all sections of the outer annulus of the pipe surrounding. This ambient temperature may be specified as a constant or time-varying temperature in each section.

1.1.1.4   Additional frictional losses

If several local losses (like bends, Tee's etc) exist in a pipe section, you can combine them in the pipe model (neglecting the exact position). Combining them can be done in 3 different ways, using either:

- the ξ-annotation (e.g. for one elbow ξ$_{elbow}$ is about 0.2, hence for 5 elbows the combined ξ-value is 1.0)
- the equivalent length annotation (for an elbow L$_{eq}$ is about 15 D)
- a percentage relative to the calculated loss in the pipe itself

1.1.1.5   Geometry

Each PIPE must have a length input and height location. This so-called profile can be defined in several ways:

- Scalar value for length (interpolating height from Heat nodes)
- Length-height profile
- Isometric layout specified with absolute XYZ co-ordinates
- Isometric layout specified with differential XYZ co-ordinates.

Each type of profile input is translated to a longitudinal profile (x-H profile). In case of a scalar value the height of the beginning and the end of the pipe is derived directly from the adjacent Heat nodes.

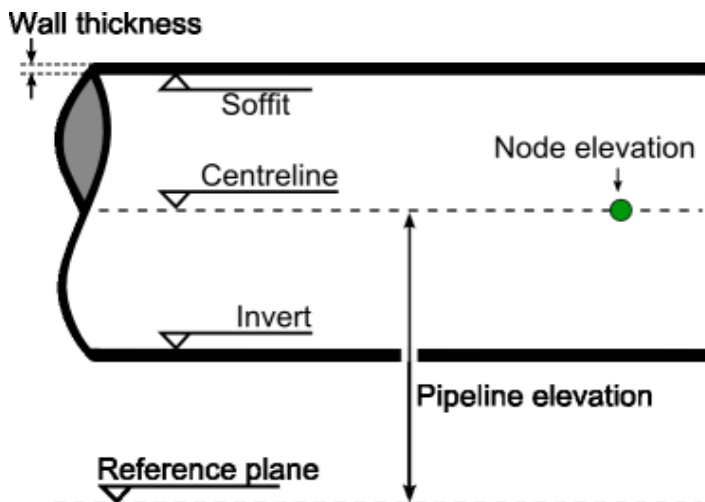The input height is the height of the centreline of the pipe (see figure 4 below).

Figure 4.3: Definition of the height of the pipe and the node elevation.

WANDA compares the input of the beginning and end of the Pipe with the connecting Heat node heights. If there is a difference of more than half the pipe diameter, a warning is displayed in the property field "H-node height check". Otherwise, "OK" is displayed.

Below an example of differential XYZ input based on the given isometric is given.

Date
March 29, 2019

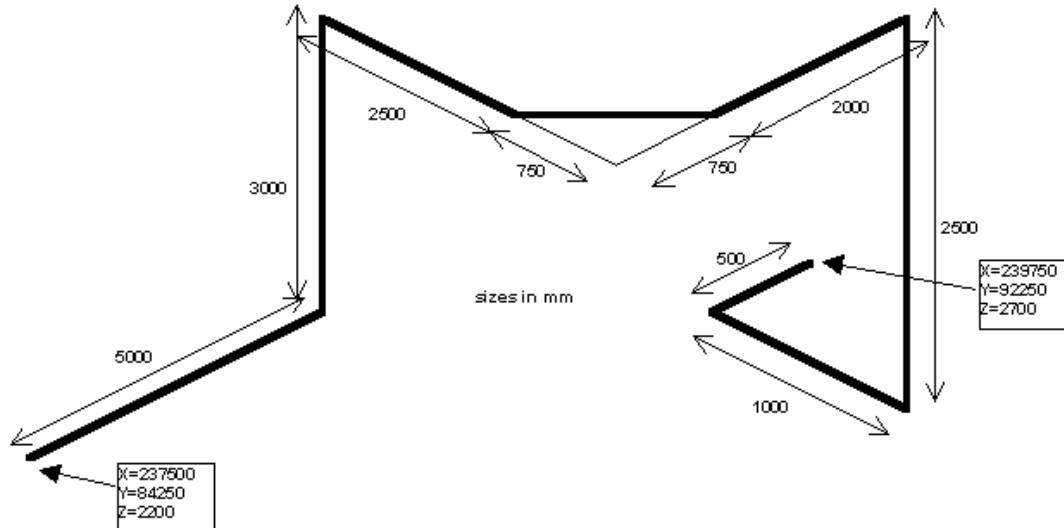**Our reference**
11201825-000-HYE-0006

Page
32 of 39

Figure 4.4: PIPE isometric with differential input.

	x-distance (m)	height (m)	X-abs (m)	Y-abs (m)	Z-abs (m)	X-diff (m)	Y-diff (m)	Z-diff (m)
1	0.0000	2.20000	237.5000	84.25000	2.200000	237.5000	84.25000	2.200000
2	5.0000	2.20000	237.5000	89.25000	2.200000	0.000000	5.000000	0.000000
3	5.0000	5.20000	237.5000	89.25000	5.200000	0.000000	0.000000	3.000000
4	7.5000	5.20000	240.0000	89.25000	5.200000	2.500000	0.000000	0.000000
5	8.5607	5.20000	240.7500	90.00000	5.200000	0.7500000	0.7500000	0.000000
6	10.561	5.20000	240.7500	92.00000	5.200000	0.000000	2.000000	0.000000
7	10.561	2.70000	240.7500	92.00000	2.700000	0.000000	0.000000	-2.500000
8	11.561	2.70000	239.7500	92.00000	2.700000	-1.000000	0.000000	0.000000
9	12.061	2.70000	239.7500	92.50000	2.700000	0.000000	0.5000000	0.000000

Please note the first row starts with the absolute XYZ coordinates followed by the differential coordinates.

The input is translated to real XYZ values and subsequently to a x-H profile. This x-H profile is shown in the location charts.
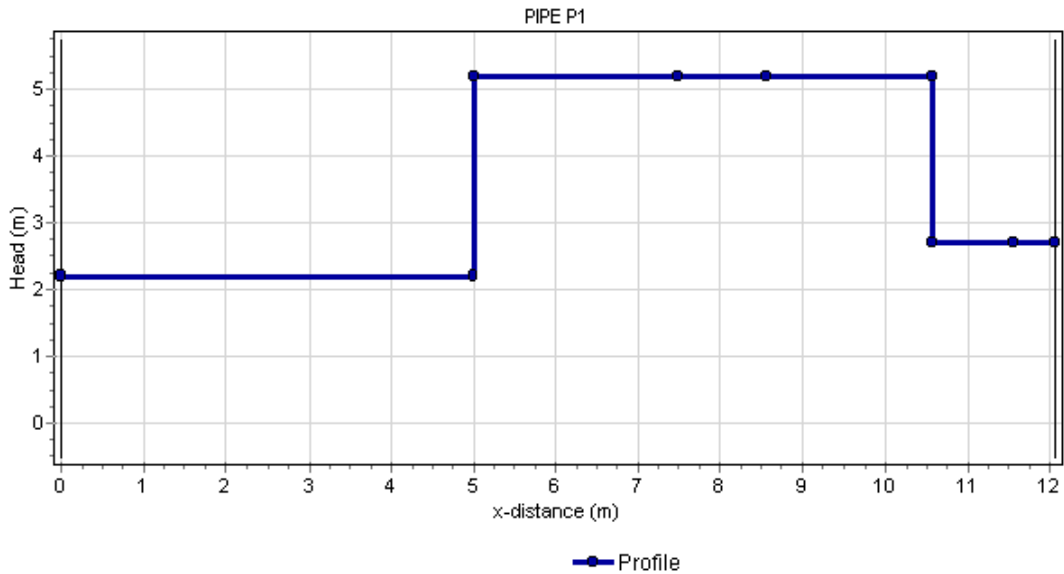
Longitudinal profile of 3d-scheme

Figure 4.5: result of XYZ diff specified profile translated to x-H profile

It is not necessary that the pipe profile start with zero. Any positive value is possible. If you split a pipe into two parts, you only have to copy the pipe and delete the unnecessary rows.

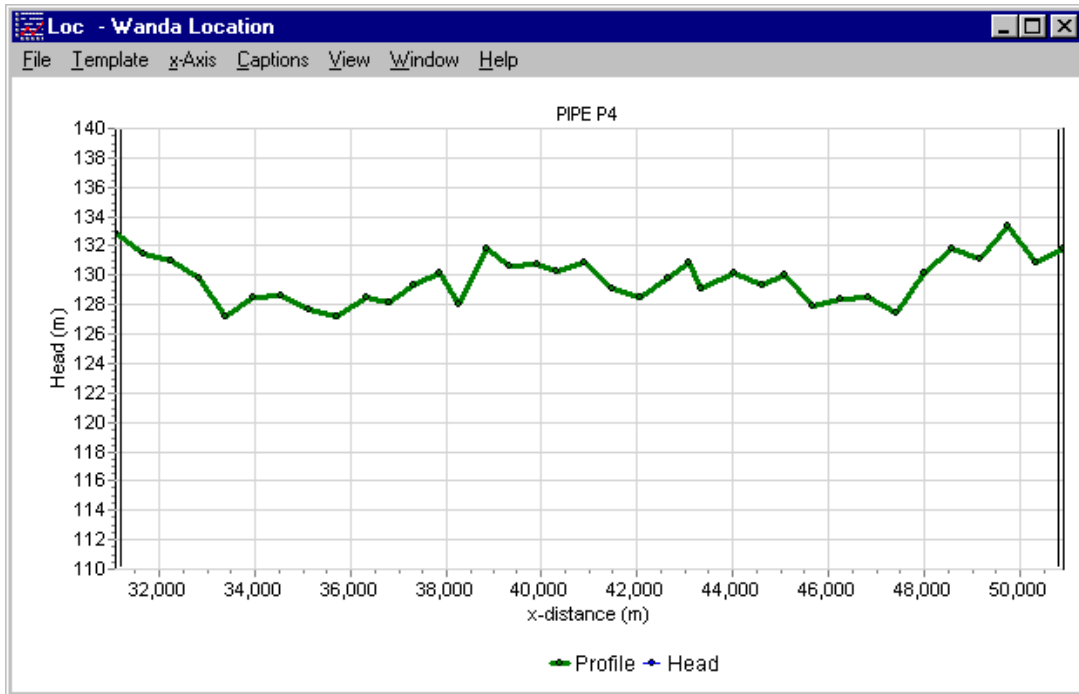The location chart (route) starts with the value specified in the first row of the table.

Figure 4.6: Pipe profile starting with a non-zero begin location

1.1.1.6   Reference

[1]   Mills, A.F., *Basic heat and mass transfer*. second ed. 1999: Prentice Hall, Inc.

[2]   Incropera, F.P. and D.P. De Witt, *Fundamentals of heat and mass transfer*. 2 ed. 1985: John Wiley & Sons inc.

[3]   Dullemond C.P. and Wang A.A. , Lecture Numerical Fluid Dynamics, Course given at Heidelberg University, (http://www.mpia.de/homes/dullemon/lectures/fluiddynamics/)

1.1.2   Heat pipe

1.1.2.1   Hydraulic specifications

Input properties

Description	Input	SI-units	Remarks
Calculation mode	Waterhammer Rigid column		Only in transient mode, default = Waterhammer
Inner diameter	real	[m]	
Wall roughness	real	[mm]	
Wall thickness	real	[m]	Only in transient mode and with calculation mode Waterhammer
Young's modulus	real	[N/m^2]	Only in transient mode and with calculation mode Waterhammer
Advection velocity	real	[m/s]	Only in transient mode and with calculation mode Rigid column

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
35 of 39

Description	Input	SI-units	Remarks
Geometry input	Length l-h xyz xyz diff	[-]	Default = Length
Length	real	[m]	if Geometry input = Length
Profile	table		if Geometry input = L-h, xyz or xyz diff
Upper limit pressure	real	[N/m²]	Only for post processing, not needed for calculation
Lower limit pressure	real	[N/m²]	Only for post processing, not needed for calculation
Additional losses	None Xi Length Percentage	[-]	Default = None
Additional length	real	[m]	If Additional losses = Length
Local losses coeff	real	[-]	If Additional losses = Xi
Add. loss percentage	real	[%]	If Additional losses = Percentage
Fraction gen. heat to fluid	real	[%]	
Properties of surrounding	Table		See remarks
Fluid temp for table 1	Real	[ºC]	See remarks
Ambient temp. time table 1	Table		See remarks
Fluid temp for table 1	Real	[ºC]	See remarks
Ambient temp. time table 1	Table		See remarks
GIS	No Yes	[-]	Default = No
Gis table	Table		If GIS = Yes Table with GIS coordinates of the pipeline not used in the calculations
Location	real	[m]	If empty, chart button creates a location series If filled in, chart button creates a time series for nearest internal calculation node

Remarks

The location charts of "Pressure" and "Head" show the specified limits only if they are filled in. It is possible to specify these values after the simulation. If these fields are not visible, first check the "Upper/Lower limits in pipes" fields in the Mode & option window. You may change

these values without re-calculating the case. In the heat domain, the change in the maximum head criterion due to changing density is not taken into account.
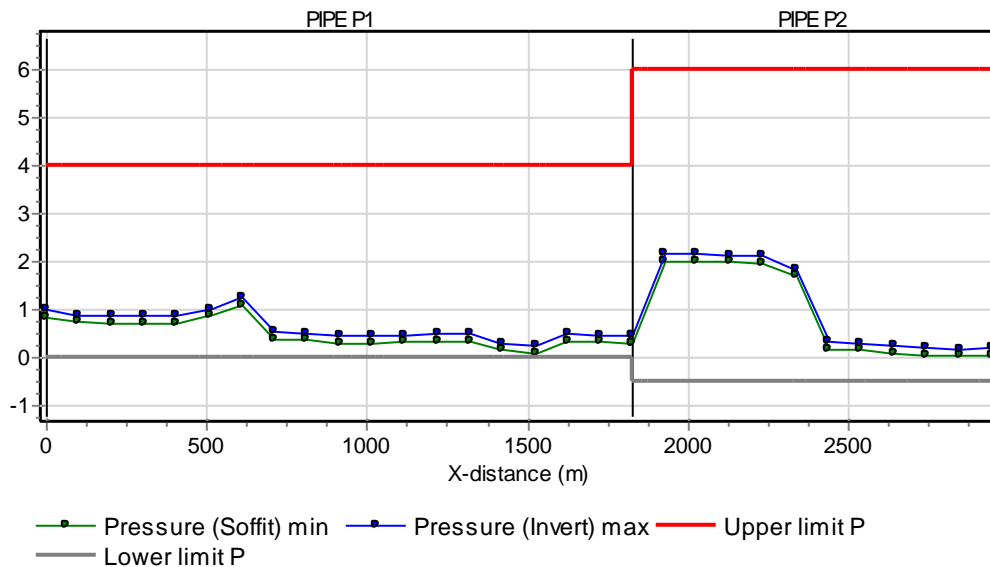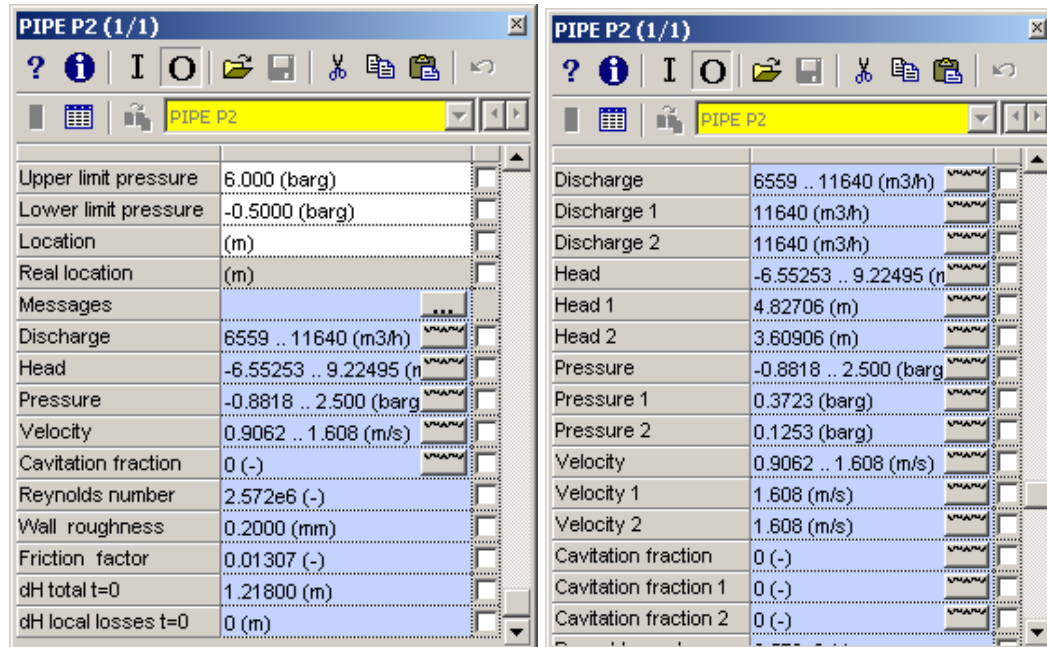

Figure 4.7: Pressure location chart with additional pressure rating series

Note that the reference for the pressure output (centre line / soffit (top) / invert (bottom) is defined in the Mode & options window.

The main output properties like "Discharge" and "Pressure" contains vector based output (output values in each calculation node or element in the pipe). That means that the chart button automatically creates a location chart. If you want a time chart in a particular pipe node you have to specify the location in the "Location" field.

To have direct access to the first and last node of the pipe (corresponding with the left and right H-node) you may extend the output property list with these points by checking the field "Connect point output in pipes" in "Modes & Options" (ctrl-m). Pressing the chart button in these additional fields automatically generates a time series chart.

Date
March 29, 2019

Our reference
11201825-000-HYE-0006

Page
37 of 39

Figure 4.8: Two appearances of output properties window depending on Mode & Options setting "Connect point output in pipes".

Property of surroundings table

This table is used to specify input on the different sections; it consists of 7 columns:

1. Layer, to which layer number does this section belong. The lowest number is the closest to the water. The maximum number of layers is 10.

2. Section, the number of this section, this should be between 1 and 10, since the maximum number of section in a layer is 10

3. Thickness of the particular layer

4. Density of the soil or material in the element

5. Heat transfer of the soil in the element

6. Heat capacity of the soil in the element

7. Outer diameter of the section

It should be checked that:

- The number of sections into which the different layers are divided is the same.

- The section in one layer have the same thickness

- The maximum number of sections in a layer is 10

- The maximum number of layers is 10

The ground properties can vary per element.

	Layer (-)	Section	Thickness (mm)	Density (kg/m3)	Specific heat (J/kg.K)	Ther Cond coef. (W/m.K)	Diameter (mm)
1	1	1	100.000	1200.0	50.000	50.000	900.0
2	1	2	100.000	1200.0	50.000	50.000	900.0
3	1	3	100.000	1200.0	50.000	50.000	900.0
4	1	4	100.000	1200.0	50.000	50.000	900.0
5	2	1	100.000	1200.0	50.000	50.000	700.0
6	2	2	100.000	1200.0	50.000	50.000	700.0
7	2	3	100.000	1200.0	50.000	50.000	700.0
8	2	4	100.000	1200.0	50.000	50.000	700.0

Figure 4.9: example table of the properties of the surroundings table. This example consists of 2 layers which all have 4 sections, see Figure 4.2)

Ambient surroundings temperature table

The user needs to specify 2 Ambient temperature tables, which corresponding drinking water temperature. Figure 4.10 shows an example of the ambient surroundings temperature table. The table consists of 11 columns. The first is the time the other ten are the temperature at the boundary of the different sections. Please note the following:

1. The first row of the ambient temperature table should always be filled even if there is no variation in time. The first value is used to set the initial temperature at the outside layer.

2. All cells in the table should have a value even if that section number does not exist. These values are neglected in the calculations.

In steady state the ambient temperature is based upon the drinking water temperature and is interpolated and extrapolated based upon the values given in the table by the user.

	Time (s)	Temp. section 1 (°C)	Temp. section 2 (°C)	Temp. section 3 (°C)	Temp. section 4 (°C)	Temp. section 5 (°C)	Temp. section 6 (°C)	Temp. section 7 (°C)	Temp. section 8 (°C)	Temp. section 9 (°C)	Temp. section 10 (°C)
1	1.00000	2.0000	3.0000	4.0000	5.0000	6.0000	8.0000	9.0000	10.000	12.000	10.000
2	100.000	4.0000	5.0000	3.0000	4.0000	7.0000	9.0000	10.000	11.000	15.000	12.000

Figure 4.10: example of ambient temperature table for the different sections.

7.1.1.1 Component specific output

Output	Description
Wave speed [m/s]	Wave propagation speed based on fluid properties and pipe properties
Pipe element count [-]	Amount of elements of same length in which pipe is divided.
Adapted wave speed [m/s]	Wave speed is adapted in such way that a integer number of elements (minimal 1) fit in the total length
Deviation adapted [%]	Ratio between wave speed and adapted wave speed. Must be less than 25% for a valid computation

H-node height check	Input validation between H-node height with corresponding pipe node elevation.
	OK means the difference is less than 0,5 D, otherwise "Warning" is displayed.
Real location [m]	If a location is specified the nearest (internal) calculation node will be selected. The real location is the location of this calculation node.
Cavitation fraction [-]	Ratio between cavitation volume and element volume
	Must be less than 20% for valid range of cavitation algorithm
Generated heat flux [W]	The generated heat due to friction with the pipe wall
Heat flux out [W]	Heat radiated to the surroundings through the pipe wall
Total heat flux [W]	Nett heat flux including effect of 'fraction generated heat to fluid' parameter (heat actually absorbed by the fluid)
Ambient temperature [°C]	The friction factor is used in the calculation of the head loss. This factor is calculated iteratively based on the wall roughness.
Friction factor [-]	The friction factor is used in the calculation of the head loss. This factor is calculated iteratively based on the wall roughness.
Kinematic viscosity [m^2/s]	The kinematic viscosity.