Neofit lining of lead pipes - Effect on Flow capacity

Report

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Summary

In order to determine the effect on lining lead pipes with the Neofit® system, flow capacity calculations are carried out, using Colebrook-White's theory, taking into account the reduction in internal diameter as well as the improvement of bore smoothness.

From this it was learned that:

- The flow capacity is only marginally influenced by the lining with Neofit®
- The bigger the expansion allowed by the host pipe the higher the capacity after lining
- With the regular expansion rate of 2.0, the capacity increases up to 2.2%
- With optimal installation conditions and a rate of 2.4, capacity increases up to 5.3% are possible

1. Introduction

For the rehabilitation of lead drinking water service pipes, the Neofit® system, developed by Wavin, is frequently applied. The system provides the internal of the lead pipes with a thin wall PET lining/barrier against lead contamination of the drinking water.
Like with any lining technology, the bore of the service pipe is reduced to some extent.

This report presents the calculation procedure and the results of calculations for the whole range of Neofit® linings when installed in lead services.

2. Calculation Method

The following formulae apply for calculating the flow in pipelines and have been adopted by international standards, such as EN 805 [1]). These formulae are used in this study too.   .

The General flow relationship is expressed by :
<u>the Continuity equation</u>:

$$Q = v \cdot \pi/4 \cdot Di^2 \qquad (1)$$

where:
- Q = flow quantity (m^3/s)
- v = flow velocity (m/s)
- Di = internal pipe diameter (m)

The fluid characteristics are expressed by:
<u>Reynolds' Number</u>:

$$Re = v \cdot Di / \mu \qquad (2)$$

where:
- μ = kinematic viscosity of the fluid (m^2/s)

The pressure loss (head loss) is given by:

<u>Darcy / Weisbach</u>:

$$\Delta p = \lambda * L/Di * v^2/2g \qquad (3)$$

where:
- Δp = pressure loss per metre (m/m),
- L = length of pipeline (m) , set as 1 to get the head loss i in (m/m)
- λ = friction coefficient (-)
- g = gravitational constant (m/s^2)

The friction coefficient is determined by:

<u>Colebrook / White</u>:

$$1/\sqrt{\lambda} = -2 \log [2.51 / (Re\sqrt{\lambda}) + ((k / Di) / 3.71)]$$

or:

$$\lambda = [1 / \{ -2 \log (2.51 / Re\sqrt{\lambda}) + k /(3.71. Di) \}]^2 \qquad (4)$$

where:
- k = pipe wall roughness (m)
- k / Di = relative roughness (-)

From a flow capacity point of view, a with Neofit® lined pipe can be considered as a small diameter plastics pipe, with excellent performance because of its smoothness of bore.
For new lead and new plastics pipes of small diameter a k-value of 0,01mm would apply.

The independent Netherlands Waterworks testing and research institute KIWA performed an initial analysis of PET lining (now Neofit®), incl. capacity considerations [2]), in which KIWA adopted operational k-values for lead pipes and for with-Neofit®-lined lead pipes of 0,10mm and 0,05mm respectively, reflecting PET's lesser potential for biofilm formation, which was demonstrated in their report with for PET a conservative value. Other tests revealed that a 'slimed k-value' of 0,02mm for PET is more realistic.
These k-values (0,10 and 0,02mm) are considered fair for lead and PET and adopted in this study too.

[1]): EN 805, "Water supply – requirements for systems and components outside buildings", 2000

[2]): KIWA, "Applicability of PET-lining for the renovation of lead service pipes", 1995

Note 1:
Realising that the existing lead pipelines often have seriously misaligned joints and Neofit® provides a smooth, joint less liner, the respective k-values for the existing pipelines even could have been taken substantially higher. Hence, the values used, can be considered as conservative, safe values for the sake of comparison

Note 2:
Other materials than lead applied for water supply service lines, generally have even higher operational k-values, because they tend to corrode next to the occurrence of sliming. These encrustations should be reflected by higher k-values, e.g. for lightly corroded copper k = 0.5mm and for corroded galvanised iron k = 2mm. This means that Neofit® lining of these types of pipes will achieve substantial % flow capacity increase, higher than that achieved when lining a lead host pipe with comparable ID

3. Input values

The calculations were carried out making use of an Excel spread sheet programme.

Flow capacity calculations were carried out on the existing (lead) situation and on the with-Neofit®-lined pipes.

Neofit® tubes can be expanded with different expansion ratio's, varying from 1.6 to 2.2 and with optimal installation conditions even up to 2.4. Obviously, expansion causes thinning of the wall thickness.

Following geometric values at five different expansion rates, 1.6, 1.8, 2.0, 2.2 and 2.4, apply for Neofit® and for the corresponding lead pipes. Annex 1 provides the background.

Manuf. Dim.		**Installed dimensions Neofit**				
Nom.dim.		inside diameter				
d_n (mm)	e_n (mm)	$d_{i1,6}$ (mm)	$d_{i1,8}$ (mm)	$d_{i2,0}$ (mm)	$d_{i2,2}$ (mm)	$d_{i2,4}$ (mm)
7	0,60	10,49	11,97	13,44	14,89	16,34
10	0,83	15,02	17,13	19,22	21,30	23,36
15	1,25	22,52	25,70	28,83	31,94	35,03
20	1,66	30,04	34,27	38,45	42,59	46,71

	corresp. ID lead pipe (mm)				
d_n (mm)	$ID_{1,6}$	$ID_{1,8}$	$ID_{2,0}$	$ID_{2,2}$	$ID_{2,4}$
7	11,20	12,60	14,00	15,40	16,80
10	16,00	18,00	20,00	22,00	24,00
15	24,00	27,00	30,00	33,00	36,00
20	32,00	36,00	40,00	44,00	48,00

where:
d_n = nominal diameter (manufactured outside diameter) of Neofit® tube (mm)
e_n = nominal wall thickness (manufactured wall thickness) of Neofit® tube (mm)
di = inside diameter of expanded Neofit® lining (mm)
ID = inside diameter of lead pipe (mm)

Further input: $k_{\text{lead pipe}}$ = 0,10 mm k_{Neofit} = 0,02 mm (operational conditions)
v = 1,5 m/s no gradient (pipes presumed installed horizontally)
μ = 1,31. 10^{-6} m^2/sec

In order to calculate the effect on the flow capacity (Q), the pressure loss (Δp) is kept constant. The influence of the smaller inside diameter (ID -> d_i) , the smoother wall (k), and the somewhat increased flow velocity (v) then was taken into account.

The increase in flow velocity to arrive at the same pressure loss was determined using trial-and-error.

Annex 2 sets out the different steps of the calculation.

4. Results & Conclusions

The actual calculation results are presented in the Annex to this report.

In summary these findings are presented for an expansion rate (X) of 2,0: in the table below:

d_n (mm)	ID (mm)	di (mm)	v_{lead} (m/s)	Δp (m/m)	v_{Neofit} (m/s)	Q_{lead} (m^3/h)	Q_{Neofit} (m^3/h)	$Q_{relative}$ (%)
7	14,0	13,44	1,50	0,3115	1,664	0,8313	0,8496	**102,2%**
10	20,0	19,22	1,50	0,1949	1,649	1,6965	1,7230	**101,6%**
15	30,0	28,83	1,50	0,1152	1,633	3,8170	3,8380	**100,6%**
20	40,0	38,45	1,50	0,0797	1,623	6,7858	6,7847	**100,0%**

For all four Neofit® dimensions and five different expansion rates the relative flow quantity is given in the next table:

	rel. flow quantity (%)				
d_n (mm)	$Q_{1,6}$	$Q_{1,8}$	$Q_{2,0}$	$Q_{2,2}$	$Q_{2,4}$
7	**96,2%**	**99,7%**	**102,2%**	**104,0%**	**105,3%**
10	**95,8%**	**99,2%**	**101,6%**	**103,3%**	**104,5%**
15	**94,8%**	**98,2%**	**100,6%**	**102,3%**	**103,6%**
20	**94,3%**	**97,6%**	**100,0%**	**101,7%**	**103,0%**

From this, following conclusions can be drawn:

- The flow capacity is only marginally influenced by the lining with Neofit®
- The bigger the expansion allowed by the host pipe the higher the capacity after lining
- With the regular expansion rate of 2.0, the capacity increases up to 2.2%
- With optimal installation conditions and a rate of 2.4, capacity increases up to 5.3% are possible

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Neofit® installed internal diameter at different expansion rates

Calculation formulae:

liner wall area: $\mathbf{A} = \pi/4.\ (OD^2\text{-}ID^2) = \pi/4.\ (d_n^2\text{-}(d_n\text{-}2.e_n)^2) = \pi/4.\ (d_n^2\text{-}(d_n^2\text{-}4.d_n.e_n + (2.e_n)^2)$

$$\mathbf{A = \pi\ .\ e_n\ .\ (d_n - e_n)}$$

expanded wall thickness: $\mathbf{e_{exp} = A / \{ \pi\ .(d_n\ .\ x - e_{exp}) \}}$ (iterative process)

where: x = expansion ratio

Results:

Manuf. Dimensions			**Installed dimensions**									
Nom.dim.		wall	x = 1,6		x = 1,8		x = 2,0		x = 2,2		x = 2,4	
d_n (mm)	e_n (mm)	area A (mm^2)	d_{exp} (mm)	e_{exp} (mm)	d_{exp} (mm)	e_{exp} (mm)	d_{exp} (mm)	e_{exp} (mm)	d_{exp} (mm)	e_{exp} (mm)	d_{exp} (mm)	e_{exp} (mm)
7	0,60	12,06	11,2	0,354	12,6	0,313	14,0	0,280	15,4	0,254	16,8	0,232
10	0,83	23,91	16,0	0,491	18,0	0,433	20,0	0,388	22,0	0,352	24,0	0,321
15	1,25	54,00	24,0	0,739	27,0	0,652	30,0	0,584	33,0	0,529	36,0	0,484
20	1,66	95,64	32,0	0,981	36,0	0,867	40,0	0,776	44,0	0,703	48,0	0,643

Manuf. Dim.		**Installed dimensions Neofit**				
Nom.dim.		inside diameter				
d_n (mm)	e_n (mm)	$d_{i1,6}$ (mm)	$d_{i1,8}$ (mm)	$d_{i2,0}$ (mm)	$d_{i2,2}$ (mm)	$d_{i2,4}$ (mm)
7	0,60	10,49	11,97	13,44	14,89	16,34
10	0,83	15,02	17,13	19,22	21,30	23,36
15	1,25	22,52	25,70	28,83	31,94	35,03
20	1,66	30,04	34,27	38,45	42,59	46,71

	corresp. ID lead pipe (mm)				
d_n (mm)	$ID_{1,6}$	$ID_{1,8}$	$ID_{2,0}$	$ID_{2,2}$	$ID_{2,4}$
7	11,20	12,60	14,00	15,40	16,80
10	16,00	18,00	20,00	22,00	24,00
15	24,00	27,00	30,00	33,00	36,00
20	32,00	36,00	40,00	44,00	48,00

Flow calculations Neofit® lining at different expansion rates

1. Flow in lead pipe

a. Pressure (head) loss :

	friction coefficient λ (-)				
d_n (mm)	$\lambda_{1,6}$	$\lambda_{1,8}$	$\lambda_{2,0}$	$\lambda_{2,2}$	$\lambda_{2,4}$
7	0,04092	0,03935	0,03802	0,03688	0,03588
10	0,03644	0,03512	0,03400	0,03303	0,03218
15	0,03218	0,03108	0,03015	0,02934	0,02863
20	0,02960	0,02863	0,02780	0,02708	0,02645

	head loss Δp (m/m)				
d_n (mm)	$\Delta p_{1,6}$	$\Delta p_{1,8}$	$\Delta p_{2,0}$	$\Delta p_{2,2}$	$\Delta p_{2,4}$
7	0,4190	0,3582	0,3115	0,2746	0,2449
10	0,2612	0,2237	0,1949	0,1722	0,1538
15	0,1538	0,1320	0,1152	0,1020	0,0912
20	0,1061	0,0912	0,0797	0,0706	0,0632

b. Flow quantity :

	flow quantity Q (m^3/h)				
d_n (mm)	$Q_{1,6}$	$Q_{1,8}$	$Q_{2,0}$	$Q_{2,2}$	$Q_{2,4}$
7	0,5320	0,6733	0,8313	1,0058	1,1970
10	1,0857	1,3741	1,6965	2,0527	2,4429
15	2,4429	3,0918	3,8170	4,6186	5,4965
20	4,3429	5,4965	6,7858	8,2109	9,7716

2. Flow in Neofit®-lined pipe

a. Velocity at equal pressure loss :

	new velocity				
d_n (mm)	$v_{1,6}$	$v_{1,8}$	$v_{2,0}$	$v_{2,2}$	$v_{2,4}$
7	1,645	1,656	1,664	1,667	1,670
10	1,631	1,642	1,649	1,653	1,655
15	1,615	1,626	1,633	1,638	1,641
20	1,605	1,616	1,623	1,628	1,631

	friction coefficient λ (-)				
d_n (mm)	$\lambda_{1,6}$	$\lambda_{1,8}$	$\lambda_{2,0}$	$\lambda_{2,2}$	$\lambda_{2,4}$
7	0,03186	0,03067	0,02970	0,02887	0,02816
10	0,02892	0,02789	0,02704	0,02633	0,02571
15	0,02606	0,02517	0,02444	0,02382	0,02328
20	0,02427	0,02347	0,02281	0,02225	0,02176

	head loss Δp lined pipe (m/m)				
d_n (mm)	$\Delta p_{1,6}$	$\Delta p_{1,8}$	$\Delta p_{2,0}$	$\Delta p_{2,2}$	$\Delta p_{2,4}$
7	0,4189	0,3580	0,3116	0,2747	0,2450
10	0,2611	0,2237	0,1950	0,1722	0,1537
15	0,1538	0,1320	0,1152	0,1020	0,0912
20	0,1061	0,0912	0,0797	0,0706	0,0632

b. Flow quantity :

	flow quantity Q (m^3/h)				
d_n (mm)	$Q_{1,6}$	$Q_{1,8}$	$Q_{2,0}$	$Q_{2,2}$	$Q_{2,4}$
7	0,5120	0,6714	0,8496	1,0456	1,2602
10	1,0402	1,3629	1,7230	2,1198	2,5533
15	2,3163	3,0354	3,8380	4,7251	5,6925
20	4,0943	5,3648	6,7847	8,3510	10,0634

	rel. flow quantity (%)				
d_n (mm)	$Q_{1,6}$	$Q_{1,8}$	$Q_{2,0}$	$Q_{2,2}$	$Q_{2,4}$
7	96,2%	99,7%	102,2%	104,0%	105,3%
10	95,8%	99,2%	101,6%	103,3%	104,5%
15	94,8%	98,2%	100,6%	102,3%	103,6%
20	94,3%	97,6%	100,0%	101,7%	103,0%