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Deliverable D4.4
Report on technologies available for a non-interrupted maintenance of tunnels drainage pipes

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1. Executive Summary

The purpose of Deliverable 4.4 is to give a more detailed insight on technologies and devices available for non-interrupted maintenance of (tunnel) drainage pipes already partially described in Deliverable 4.1, "A review report on technologies and devices available for intervention measures for railway bridges and tunnels".

Based on research and experience, Chapter 5 "Removal of incrustations from long drainage pipes" reviews technologies available for solving of the problems of drainage clogging.

Chapter 6 "Comparative analysis of non-interrupting drainage pipe cleaning systems" shows a comparison between those technologies.

2. Abbreviations and acronyms

Abbreviation / Acronyms	Description
A4R	*Assets4Rail, GA No. 826250*
D	*Deliverable*
HPPCS	*High-pressure pipe cleaning system*
WP	*Work Package*
WS	*Work Stream*

3. Background

The present document constitutes the Deliverable D4.4 "Report on technologies available for a non-interrupted maintenance of tunnels drainage pipes" in the framework of A4R, WS1, WP4, Task 4.3.

4. Objective/Aim

This document has been prepared to provide

- A short introduction why technologies and devices available for non-interrupted maintenance of drainage pipes especially for railway tunnels are necessary,
- an overview of these technologies and
- a conclusion of technologies to be followed up is given in Chapter 7 "Conclusions".

5. Removal of incrustations from long drainage pipes

As already described in Deliverable 4.1, tunnels all over the world are equipped with drainage systems, in which the water accumulated in the tunnel is drained off. If the drainage system becomes clogged or incrusted negative consequences to the system may be the result. These incrustations are caused mainly due to two reasons: the degradation of the construction materials because of the aggressiveness of geological water (high concentration of calcium) or the presence of lime sediments in a rocky environment. [1]

A reduction of the pipe cross section or a clogging of slots and openings of the pipes needs to be avoided by keeping the drainages clean. Otherwise, the capacity to drain the water may drop, allowing leakage of water into the tunnel. This makes up a significant part of the maintenance costs. [1]

Drainage pipes (long-distance) need to be inspected to detect the amount of necessary cleaning maintenance. This can be done for example using camera inspection technology. Here, a camera is introduced into the pipe system to inspect the system visually ([2]; [3]).

Other non-invasive inspection technologies may include remote sensing like satellite and terrestrial light detection and ranging ("LIDAR") or radiometric technologies and ground geophysical techniques like geo-electric, electromagnetic, and potential field methods that provide data from which subsurface conditions may be inferred ([4]; [5]). These technologies were not considered further in this report as they partially cannot be used underground easily because of data transfer issues and partially are too big in size to fit in tunnel pipes together with the cleaning unit.

Several technologies for cleaning tunnel drainages exist on the market, but only some of them are able to clean the pipes without interrupting train operations in the tunnel. Without interrupting means that the tunnel remains in operation during the pipe-cleaning interval, except for a short time that may be necessary for setting up or dismantling the equipment. [1]

All following technologies have advantages and disadvantages depending on their field of application, which is described in more detail in the following.

5.1. High-pressure pipe cleaning system

The high-pressure pipe cleaning system (HPPCS) developed by FCC is a flexible system usable in several drainage pipe systems as cleaning tool [1].

The need for such system was expressed in a tender published by the ÖBB (the Austrian Railway company) in 2016 for the cleaning of tunnel drainage systems to ensure that water, which accumulates on the wall of the tunnels, is drained off the tunnels safely. FCC was awarded as winner of this tender and in November 2017 FCC started with the cleaning of drainage systems in railroad tunnels of the ÖBB (Figure 1). [1]

Figure 1: High-pressure pipe cleaning system [1]

In principle, the developed multi tool consists of three main parts:

- high pressure aggregate which is capable to provide a pressure up to 300 bar,
- high pressure hose pay-off with high pressure hose / cable, as well as a camera cable (Figure 2),
- mechanical drive unit / camera nozzle with a steering unit (steering bus).

All parts can be set up separately, which makes the system very flexible. [1]

Figure 2: Hose and cable pay-off [1]

The HPPCS can be equipped with a "seeing" nozzle as well as a robotic unit. While the "seeing" nozzle is used in standard cleaning situations in drainage pipes, the robotic unit is used in special cases on demand (e.g. if the incrustations inside the pipes are too hard to be removed by high-pressured water only, the milling tool of the robotic unit could be used to remove these incrustations). Thus, the tool can be set up flexibly and cleaning and documentation can be done in one step. The multi-purpose head / nozzle in combination with cameras make the aggregate a multi-functional tool, which can manage the processes listed in Table 1. [1]

Table 1: Processes manageable by the high-pressure pipe cleaning system. [1]

Processes manageable for the high-pressure pipe cleaning system
- high pressure water cleaning in pipes - hydraulic removal of incrustations - re-threading of slots - leading-in of inliners - mechanical pipe cleaning - sewer inspection - TV surveillance and documentation while cleaning.

Due to the complex requirements specification as well as the high safety standards in train tunnels, the whole aggregate is adapted and optimised continuously. The system is usable in various drainage pipes due to its fast set-up time and simple components which can be replaced easily in case of any occurring problems. Furthermore, after setting up the aggregate, it can be steered from outside the tunnel, which means operations are not interrupted during the cleaning interval. Furthermore, the operator of the aggregate is not inside the tunnel which means further advantages in terms of health and safety. [1]

The cleaning is usually done during night-time and the tunnel needs to be closed only to set up and dismantle the parts, which poses a big advantage over interruptive cleaning methods (like the suction truck on train waggon described in Deliverable 4.1). [1]

5.1.1. Basic requirements

To conduct the work properly, some basic requirements must be met; these are listed in Table 2.

Table 2: Basic requirements for the high-pressure pipe cleaning system [1]

Basic requirements for the high-pressure pipe cleaning system

- water connection (can also be delivered by a vacuum truck)
- energy connection (can also be delivered by a generator)
- drainage pipes:
  ▫ lengths up to 600 m
  ▫ inner diameters between 150 and 250 mm
  ▫ sediments must not be too thick (max 1 cm thickness -> preventive maintenance!)
  ▫ pressure resistance up to 150 bars
- space available to place the aggregates – either inside the tunnel or outside (depending on the cleaning length)
- access to the pipes (shafts):
  ▫ 1 m length x 1 m width x 1 m depth to enter the pipes
  ▫ ideally outside the tunnel

5.1.2. Advantages and disadvantages

In Table 3, merits and detriments of the technology presented above are given.

Table 3: Advantages and disadvantages of the high-pressure pipe cleaning system [1]

Advantages	**Disadvantages**
+ Due to its "separate" hose pay-off a longer hose and cable can be installed, which means a flexible utilisation range and therefore higher efficiency and shorter duration of interruptions (shorter set up and dismantling duration).	- An external water supply is necessary, which makes a compatible (tunnel) infrastructure necessary.
+ Cleaning and inspection / documentation can be done in one step.	
+ The cleaning can be done without closing the tunnel completely. In big enough tunnels, the aggregate can be set up inside the tunnel, then steered from outside; in smaller tunnels, the aggregate can be set up at the tunnel entrance and steered from the outside. This also means that no personnel is needed inside the tunnel.	
+ No cleaning agents / toxins necessary.	

5.2. Cleaning jets

Another very effective way to deal with a blocked sewer is to utilise a method known as 'sewer cleaning jetting'. This method is mainly used for cleaning of sewers or pipes in households but also for refineries. The tool in use, a sewer cleaning jet, can generate a high water pressure which can be adjusted in accordance with the particular job to suit more fragile situations and can remove all the blocking debris (hair, grease, oil, roots,…) that has accumulated inside the blocked sewer pipes (Figure 3). [6]

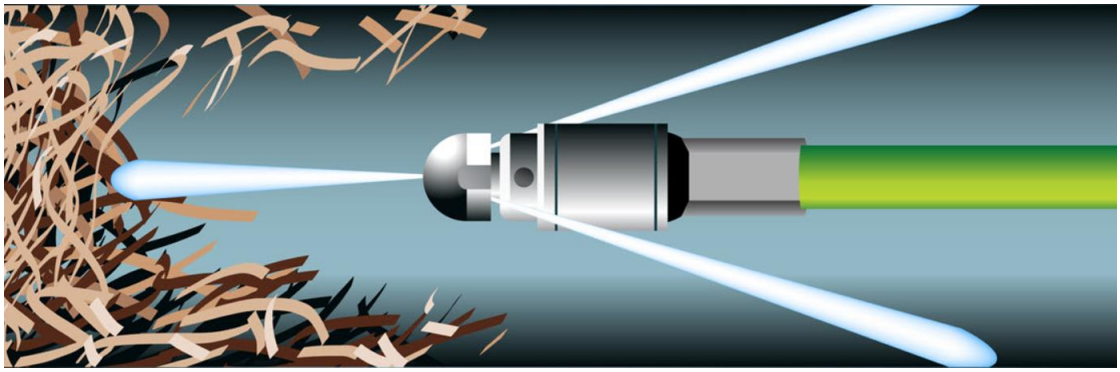

Figure 3: Sewer cleaning jet principle [6]

The hydro-jetting equipment uses high pressure and high-velocity water to blast and break up drainage blockages (Figure 4). [6]

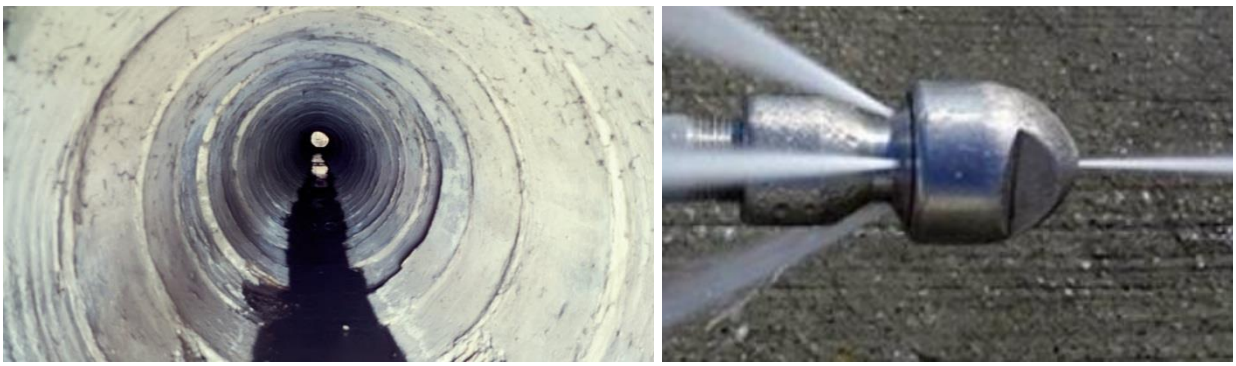

Figure 4: Sewer and sewer cleaning drain jet [6]

A special jetting device is the rotary hose device which gets inside the industrial pipes and blasts away accumulated mineral deposits, scale, biological matter, and other debris that clogs pipes and restricts fluid flow (Figure 5). This technology is used, among others, in the nuclear industry. [7]

Figure 5: Pipeline cleaning with the rotary hose device [7]

Inner lines from 25 mm up to 910 mm can be cleaned with minimal entry points and the technology allows to navigate 90-degree elbows and T-intersections and run long vertical distances (up to 200 m) from one location. Two specialised devices control the process, the first part is a wheeled pay-off to feed the hose in and out and the second one is a wheeled rotor-spinner part that controls the speed and direction of the hose in the pipe. The bullet-shaped rotary hose device uses directional jets to clean the pipe and propel itself through the pipe. [7]

A water collection system allows managing wastewater flow with full contaminant even with full use of 75-150 litres per min. The process is automated and thus the operator is separated from the process which makes it very safe. [7]

A regular pipe cleaning schedule is important to properly maintain capacity and efficiency, while in long term it also reduces the maintenance fees. ([1]; [7])

5.2.1. Basic requirements

To conduct the work properly, some basic requirements must be met; these are listed in Table 4 and Table 5.

Table 4: Basic requirements of sewer cleaning jets [6]

Basic requirements for sewer cleaning jets

- water connection (can also be delivered by a vacuum truck)
- energy connection (can also be delivered by a generator)
- drainage pipes:
  ▫ inner diameters between 40 mm and 250 mm
  ▫ pressure resistance up to 310 bars
- space available to place the aggregates

Table 5: Basic requirements of the rotary hose device [7]

Basic requirements for the rotary hose device
- water connection (can also be delivered by a vacuum truck) - energy connection (can also be delivered by a generator) - drainage pipes: ▫ lengths up to 200 m ▫ inner diameters between 25 mm up to 910 mm ▫ pressure resistance between 340 bars and 1.310 bars - space available to place the aggregates

5.2.2. Advantages and disadvantages

In Table 6, merits and detriments of the technology presented above are given.

Table 6: Advantages and disadvantages of cleaning jets

Advantages	**Disadvantages**
+ The water pressure in cleaning jets can be adjusted in accordance with the particular job to suit more fragile or special situations. [6]	- Mainly used for household-pipe cleaning but also usable at refineries. [6]
+ The rotary hose device can clean lines from 2,5 m to 90 cm diameter with minimal entry points. The Rotary Hose Device allows to navigate through several 90-degree elbows and run long vertical distances from one location. [7]	- Some variants of this technology do not achieve long distance lengths (more than 200 m) and are thus not suitable for cleaning of long-distance tunnel drainages. ([6]; [7])
+ The specially designed water collection system allows managing wastewater flow with full containment. [7]	
+ Mainly used for household-pipe cleaning but also usable at refineries which shows a general capability to clean pipes and thus tunnel pipes. [6]	- No inspection during operation possible. [7]
+ No cleaning agents / toxins necessary. [6]	

5.3. Pigging

Pigging equipment was originally used in the oil and gas industry to clean, inspect and perform other maintenance operations on a pipeline typically without stopping the flow of the product in the pipe. The "Pigs" are inserted with a pig launcher into the pipes and travel along the pipe line to remove scale, sludge built up and other contamination adhering to the pipeline walls (Figure 6). [8]

The pig cleaning system utilizes high-pressure spraying in a special pattern to ensure proper coverage over the entire part. The Pig Clean System is suitable for removing residues, impurities and foreign matters from the insides of all kinds of piping arrangements and prevents pipes from becoming contaminated. A spray parts washer is necessary for keeping pigging equipment operating properly. [8]

Figure 6: Pigging equipment [8]

As a second type of pigging technologies that is being used in other fields of operation, the "PneuClean" System is presented. In here, compressed air is used to propel a "pig-train", comprising of a lead and a trail pig, along a large diameter pipe. A small amount of water is held between the two pigs and, as the pig-train travels, manganese and soft deposits are collected from pipe walls (Figure 7). Usually, multiple runs are necessary to ensure cleanliness. The wastewater is then collected for disposal and the used pigs are replaced for subsequent runs, until sampling shows that the wastewater complies with quality standards, indicating that the pipe is clean. [9]

Pipe pigging reduces water usage and wastewater volumes compared with traditional water jetting and flushing techniques. The "PneuClean" system can also be used to chlorinate pipes up to a length of 10 km using a pig-run post-cleaning, reducing chemical and water usage. [9]

Figure 7: "PneuClean" pig cleaning [9]

As a third type of pigging technologies, ice pigging needs to be mentioned. It provides the operational advantages of flushing and the cleaning impact of soft pigging. The process involves pumping an ice-slurry created on-site by using water and table salt which is then inserted into the system (including bends and butterfly valves) until enough slurry is in the system (ca. 20 min) to start cleaning. For the cleaning, the ice is pushed through the system with the system's pressure. The cleaning process is controlled by temperature and conductivity measurements; the parameters from pre-cleaning and during the interval are compared until the system reaches pre-ice pig parameters, which signals the end of the cleaning interval (Figure 8). The chemical-free ice pig scours the pipe by removing sediment and built-up deposits (Figure 9). [10]

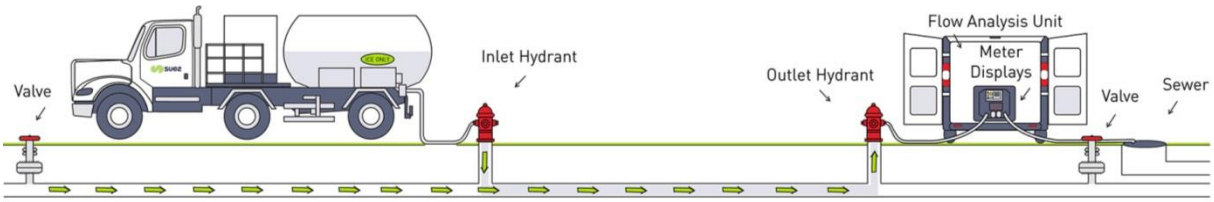

Figure 8: Ice pig cleaning setup [10]

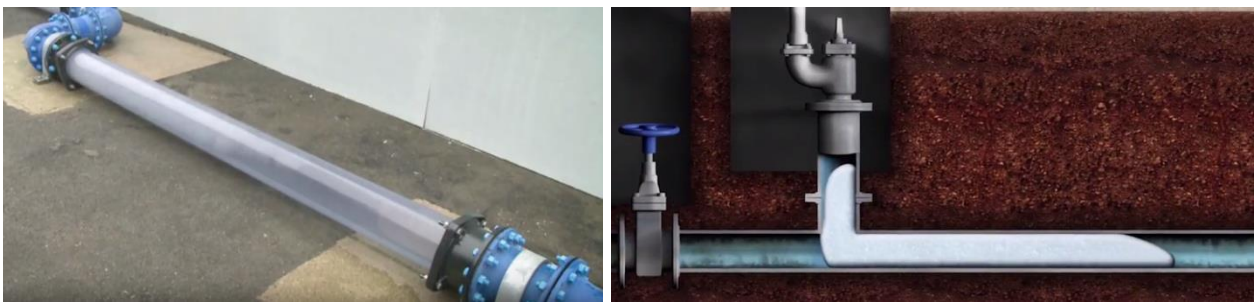

Figure 9: Ice pig cleaning [10]

Unlike hard pigs, there is no risk of the ice getting stuck because the ice-slurry flows like water through the pipe system. Blockages can be resolved by simply allowing the ice to melt. [10]

5.3.1. Basic requirements

To conduct the work properly, some basic requirements need to be given; these are listed in Table 7 and Table 8.

Table 7: Basic requirements of PneuClean pig cleaning [9]

Basic requirements for PneuClean pig cleaning
- water connection (can also be delivered by a vacuum truck) - energy connection (can also be delivered by a generator) - access to high pressure air - drainage pipes: ▫ inner diameters up to 150 mm to over a metre ▫ low pressure resistance ▫ length up to 10 km - space available to place the aggregates (e.g. crane) - deposits need to be soft and not too thick

Table 8: Basic requirements of ice pig cleaning [10]

Basic requirements for ice pig cleaning
- energy connection (can also be delivered by a generator) - ice delivery equipment necessary - drainage pipes: ▫ inner diameters up to 3.7 m ▫ length up to 4.8 km ▫ pressure settings as installed for the system - space available to place the aggregates

5.3.2. Advantages and disadvantages

In Table 9, merits and detriments of the technology presented above are given.

Table 9: Advantages and disadvantages of pigging ([8]; [9]; [10])

Advantages	**Disadvantages**
+ Generally, pipe pigging reduces water usage and wastewater volumes compared with traditional water jetting and flushing techniques ([8]; [9]; [10]).	- Pigging technologies can bear a certain risk, because hard pigs can get stuck needing them to be excavated by digging out the pipe [10].
+ The pipeline pigging system is built do deal with harsh environments, such as chemical and paint environments or wastewater sewers. Furthermore, each pig cleaning system size is customized to the customer application and pig size variation. [8]	- Pipeline pigging was until now mainly used in chemical or paint mixing and in sewer applications which is not focus of this Report. Furthermore, a spray parts washer may be necessary depending on the usage. [8]
+ The ice pigging technique requires no chemicals, because the abrasive property of ice is enough to clean the pipe [10].	- The PneuClean system requires in addition the access to high pressure air, to dry the pipe before cleaning [9].
+ Using the PneuClean system, lengths of 10 km can be reached in a single operation in inner diameters reaching from 150 mm to over a metre. Furthermore, the risk of damages to pipe and lining are eliminated [9].	- The ice that is used in the Ice Pigging technique to clean the pipes could harm or weaken the pipe because of its abrasive properties [10].
	- A spray parts washer may be necessary for keeping pigging equipment operating properly. [8]
	- No inspection during operation possible ([8]; [9]; [10].
	- No real steering is possible as the ice pig is following "least resistance" [10].

6. Comparative analysis of non-interrupting drainage pipe cleaning systems

The technologies described in previous chapters of this deliverable have advantages and disadvantages depending on their field of application. In this chapter, the positive and negative sides of those technologies are described in more detail.

The comparative analysis of three different technologies for cleaning of drainage pipes described in the previous chapter tries to point out the technology with the strongest and the weakest grade regarding the following criteria (Table 10).

Table 10: Criteria for rating the technologies

Criteria for rating the non-interrupting drainage pipe cleaning systems
1. Traffic disturbance: 1.1. Closing of (long distance) tunnel (during operation, not during set-up and dismantling) 1.2. Personnel presence 2. Length of intervention / cleaning duration 3. Pipe damaging 4. Flexibility of the technology to be used in various conditions 5. Sustainability of the technology regarding the reuse of water, sludge and dirt-water treatment 6. Cost 7. Inspection (possibility for simultaneous intervention and inspection via camera)

Table 11 shows the assessment of the applicability of the presented technologies for drainage pipe cleaning. The assessment-grade is relative, related on the performance of the respective technologies. The mark "–" indicates a disadvantageous grade, "+" indicates an advantageous grade, including possible nuances.

Table 11: Rating of intervention measures for cleaning of drainage pipes (updated from D4.1)

Criteria	**1.1**	**1.2**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**
Criteria / Technology	**Closing of (long) tunnel**	**Personnel presence**	**Length of intervention**	**Pipe damaging**	**Flexibility**	**Sustain-ability**	**Cost**	**Inspection**
High-Pressure Pipe Cleaning System	++	+	++	+	+	– / +	– / +	+ +
Cleaning jet	+	+ *	+	+	+	– / +	– / +	– –
Pigging	– –	+	+ +	– – –**	+	– / +	– –	– –

* rotary hose device

** when ice is used

Based on the comparison in Table 11, the high pressure pipe cleaning system seems to achieve the best rating compared to the other two technologies. Thus it seems the most reasonable to further develop this system.

7. Conclusions

Technologies for non-interrupting drainage pipe cleaning were described and compared (Table 11) based on the rating stated criteria. Every technology has its merits and detriments and none of them is a perfect solution for cleaning long drainage pipes.

Regarding the criteria of "Traffic disturbance", "Length of intervention / cleaning duration" and "Flexibility", the HPPCS has in total the most advantages compared to cleaning jets and pigging. However, all technologies seem to be mediocre in terms of "Sustainability", which is mainly because water/ice used for cleaning is not recovered during the cleaning interval and is mainly only collected to be disposed.

Regarding the criteria of "Cost" and "Pipe damaging", the HPPCS and cleaning jets seem to have the same advantages, while pigging is the most expensive technology. The high cost of pigging is either due to the necessity to produce ice slurry on site or because the sites must be closed for the longest time, which increases the costs. Also, pigging seems to cause most pipe damages which is mainly because the pigs need to be in contact with the pipe more or less directly and are usually not as flexible as hoses.

Regarding the criteria of "Inspection", this possibility is given during the cleaning interval only with the HPPCS technique.

The main conclusion reached at this stage of the R&I and highlighted in this report is that due to its flexibility, the existent knowledge of the system as well as its best performance compared to the other technologies, the high-pressure pipe cleaning system is the preferred solution to be further developed in Assets4Rail.

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