Ice pigging : méthode de gestion de la qualité de l'eau dans les canalisations

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Résumé

Le document se concentre sur des études relatives à l'application d'une nouvelle technique de nettoyage des canalisations, appelée « ice Pigging ». Celle-ci utilise de grandes quantités de glace pour enlever les sédiments et les films biologiques de l'intérieur des canalisations. Les avantages liés à l'utilisation de glace pour nettoyer les canalisations sont multiples : rapidité, risques faibles et efficacité exceptionnelle. Les études menées en Allemagne ont révélé que l'ice pigging était la méthode la plus efficace pour enlever les films biologiques et les sédiments dus à la contrainte de cisaillement appliquée sur la surface intérieure de la canalisation. Une démonstration probante sur le terrain a été effectuée dans la ville de Saarbrucken avec des résultats très positifs. On envisage d'introduire l'ice pigging parmi une gamme de solutions en vue de contrôler la corrosion. Plusieurs autres idées sont également présentées dans ce cadre.

Ice pigging as a method for managing in-pipe water quality

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Abstract

The paper focuses on research studies into the application of a new pipe cleaning technique called Ice Pigging that uses large quantities of slush ice to remove sediment and biofilm from the inside of pipes. The benefit of using ice to clean pipes are many - fast, low risk, and exceptionally effective. The Research studies completed in Germany found that Ice pigging was the most effective method of removing biofilms and sediment due to the shear stress applied to the inside surface of the pipe. A successful field demonstration was made in the city of Saarbrucken with very positive results. The potential for ice pigging to form part of a range of solutions to control corrosion is also considered with a number of different ideas presented.

Zusammenfassung

Es werden Ergebnisse eines Forschungsvorhabens zur Entwicklung eines neuen Spülverfahrens vorgestellt, das sogenannte Ice-Pigging. Bei diesem Verfahren wird ein hochviskoses pumpfähiges Eis-Wasser-Gemisch – der Eismolch – als Spülmedium eingesetzt, um Sedimente und Biofilme von Rohrinnenoberflächen zu entfernen. Ein Spülverfahren mit Flüssigeis hat viele Vorteile – es ist schnell, hat ein geringes Risiko und ist ausgesprochen effektiv. Ein in Deutschland durchgeführtes Forschungsprojekt zu Spülverfahren führte zu dem Ergebnis, dass das Ice-Pigging die effektivste Methode darstellte, sowohl Biofilme als auch Sedimente von der Innenoberfläche von Rohren zu entfernen. Im Rahmen des Forschungsvorhabens wurden Praxisuntersuchungen in Saarbrücken sehr erfolgreich durchgeführt. Es werden ebenfalls die Potenziale des Verfahrens als Teil eines Korrosionsschutz-Managements präsentiert.

1. INTRODUCTION

Problems in drinking water networks

Although drinking water standards in developed countries are very high, many water distribution systems still suffer from issues of water quality deterioration within the water supply network. Water that may enter the network at an exceptionally high and consistent water quality, can all too often be subjected to conditions within the pipe network that make the water unpalatable or unwholesome to drink at the point of consumption. The cause of these issues are often complex, but can be largely categorized as:

- Chemical reactions with network materials such as with metallic pipes
- Reaction and contamination with accumulated debris within the network
- Reaction and contamination from biological organisms that exist within the water supply network

In many parts of the world water is distributed via pipe networks that are as old as the cities they supply, often meaning via pipes that are greater than 100 years old. This introduces inherent problems as a deteriorating network – that can often be continually releasing sediment as it corrodes - can be a major cause of debris accumulation within the network that can cause ongoing issues for Operators. In the UK, for example, the most common complaint concerning water quality is of water discolouration – brown or red looking water. Discolouration occurs when fine sediments in the distribution system are disturbed and go into suspension, ultimately arriving at the consumer’s tap. While most water utilities claim that these incidents pose no threat to health, the water is not palatable and water quality regulators in many countries are beginning to take punitive action against water providers who allow these incidences to occur.

In addition to pipe deterioration, water chemistry can often be a cause of unwanted debris in the pipe. Water sources that are naturally high in iron or manganese often experience conditions within the network that create precipitates that remain as particulate within the pipe. Often these precipitates can travel through the network, and have the potential to cause major discolouration events with even the smallest of change in hydraulic conditions.

Ageing networks with accumulated sediment, along with networks suffering from naturally occurring precipitates of iron and manganese also create environments for biological growth to flourish. Micro-organisms can live in amongst sedimentary build-up and within crevices created by the corrosion of metallic pipes. Such biological growth in drinking water networks is not always a major issue if levels can be effectively controlled. But in many situations biofilms – the layer of biological growth in a pipe – can multiply beyond steady state and cause a nuisance, which is a phenomena often seen during the warmer months of the year.

Figure 1 Water meter blocked with biological growth - Holland

In networks where water is disinfected using chlorine or chloramines it is common practice to ensure a level of free chlorine in distributed water to neutralize bacteria or biological contaminants. Where this chlorine reacts with biological organisms within the network, a range of reaction byproducts – such as TriHaloMethanes - can be produced which have more recently been linked with negative health effects. Water Operators often face a difficult balance between controlling the growth of biological organisms within the network through the use of disinfectants, ensuring positive free chlorine at the point of supply, and minimizing potentially harmful disinfection byproducts.

<u>A simple principle that ensures minimal issues from network related contamination of drinking water is to keep the network as clean and free from debris as possible.</u>

2. ICE PIGGING AND COMPARISON WITH OTHER TECHNIQUES

Ice Pigging is a breakthrough method of removing unwanted sedimentary build-up and biological growth from drinking water networks. Ice Pigging compares very favorably with traditional network cleaning methods for the following reasons.

Flushing involves very large volumes of water and is limited to pipes below 150mm. Flushing looks to induce the hydraulic conditions within the pipe that cause sediment to go into suspension but does not normally remove all of the sediment. In certain circumstances pipe flushing can last for many hours with large quantities of water running to waste which can give a very negative public perception, particularly in locations where water is scarce. Flushing is not effective at removing biofilms that may have adhered to the inside pipe wall.

Air scour involves isolating a given length of pipe and blowing high velocity air through it to accelerate the suspension process. It is accepted as a more effective method than flushing as it creates greater turbulence in the pipe and lifts a higher volume of sediment into suspension. However, Air scour is a more aggressive method that has become less popular in certain countries in recent years due to concerns over additional stresses that are exerted on the network during the cleaning process. In certain water utilities the practice has been banned due to these concerns and injecting air into the network remains an issue. It is also usually limited to small and medium diameter pipes.

Swabbing consists of forcing a foam swab, or pig, through the pipe so as to push or wipe any loose material. Swabbing, whilst not limited by pipe diameter, has drawbacks when the risk of a swab becoming stuck or lost within the network is considered. Swabbing tends to be expensive due to the enabling works required to insert and remove the swab, and as the pipe must be emptied and filled a number of times uses a relatively high amount of water. Swabbing jobs can take a number of days to perform which results in either long interruption to supply or the need to find expensive alternative supplies.

Ice pigging provides a simple and effective way of cleaning pipes achieving excellent results in a quick, efficient and environmentally friendly manner. Due to its rheological properties the ice slurry forms an 'ice pig' which provides enhanced cleaning shear on the pipe walls, and easily adapts to the local topology of the pipe. This also means that the ice can be inserted into the pipe through small entry points and will expand to the topology of the pipe, thus removing the need for large and expensive enabling works.

Recent research conducted by IWW Water Center, of Mulheim, Germany[1], concluded that ice pigging can be shown to remove 99.99% of biofilm bacteria. In addition, when compared with both flushing and air scouring, the highest biofilm removal rates were obtained by applying the mechanical, abrasive forces caused by ice crystals using the ice pigging method. Shear stress measurements showed lower stress for ice pigging in comparison to air scour methods, despite a more effective cleaning process using ice. Higher velocities with ice pigging did not result in any

1. [1]„Restoration of Drinking Water Distribution Systems by Removing Contaminated Biofilms with different pipe cleaning methods" (G.Schaule, D.Christen, D.Nottart-Heim, C.Sorge, HG Hammann) 1 July 13

higher biofilm removal rates, underlining that ice pigging does not rely on velocity to be effective.

Figure 2 Column of ice passing through bends and changes in diameter

Ice Pig technology is based on understanding and harnessing the benefits of the specific and complex science behind semi solids and in particular ice slurries. The University of Bristol, who are the ultimate inventors of the process, have spent a number of years investigating the varying effects on shear strength, viscosity, heat transfer characteristics, and the ice's ability to pick up sediment when ice fraction and particulate loading are varied.

Figure 3 Slurry ice as used in Ice Pigging

The ice slurry benefits from being pumpable and conforming to varying topographies like a liquid, and yet behaves in pipe as a solid, providing an enhanced shear stress and therefore more efficient cleaning. The potential advantages of this technology are considerable and include the guarantee that the pig never gets stuck (it eventually melts!), reduced water consumption (typically orders of magnitude less than for water flushing) and suitability for any topology, with minimal introduction/removal costs.

A total of over 500km of pipes have been cleaned with Ice Pigging worldwide to date. The largest diameter cleaned is 600mm, and the longest single length of pipe cleaned in one run is 4500m achieved in four hours in Wales, UK. More recently, full scale ice pigging operations have been performed in Saarbrucken, Germany, on a DN500 cement lined metallic trunk main.

2. HOW IS ICE PIGGING PERFORMED?

Ice Pigging is a specialist technique that requires careful planning, both in the ice making process, and also once the ice has been made and is ready to be inserted into pipes to be cleaned.

Ice Making

Because *slurry* ice is used in ice pigging it requires careful planning to ensure that the consistency and quantity of ice is calculated properly. The quantity of slurry ice required must account for the size and length of pipe to be cleaned, and the amount of ice that is likely to melt so that there is a quantity of useable ice at the pipe exit point. The ice must collect and carry sediment and biofilm from within the pipe along the length of the pipe, so there must be sufficient ice at this ice exit point to ensure that sediments have been properly removed.

Figure 4 Example of ‘Food Grade’ stainless steel Ice conditioning equipment used in Ice Making process

The amount of melting is dependent on factors such as water temperature in the pipe, pipe material, and speed at which the ice can be pushed. Ambient temperature has only moderate effect on ice quantities required, although does have a significant effect on the amount of time required to make the ice.

When cleaning drinking water mains, the ice used must also be hygienic and stand up to rigorous water hygiene requirements. The ice used in Ice Pigging can be chlorinated, and is made with machines constructed from Food Grade materials such as 316 grade stainless steel.

Ice Transport and Insertion

The ice is transported in large stainless steel tanks that are custom made for this purpose. Quantities of ice required for each operation range from 1,000 to 25,000 litres and also includes specially chosen pumps to ensure that there is not a separation between the ice and the liquid in the slurry when pumped. The ice must be constantly agitated to ensure it remains in the right consistency. The tanks are insulated and can carry the ice for up to 18 hours before it requires reconditioning.

Figure 5 Ice Pigging Delivery Units, holding 10,000 and 15,000 litres of ice each

Monitoring the process

The following steps are required for a successful ice pigging operation:

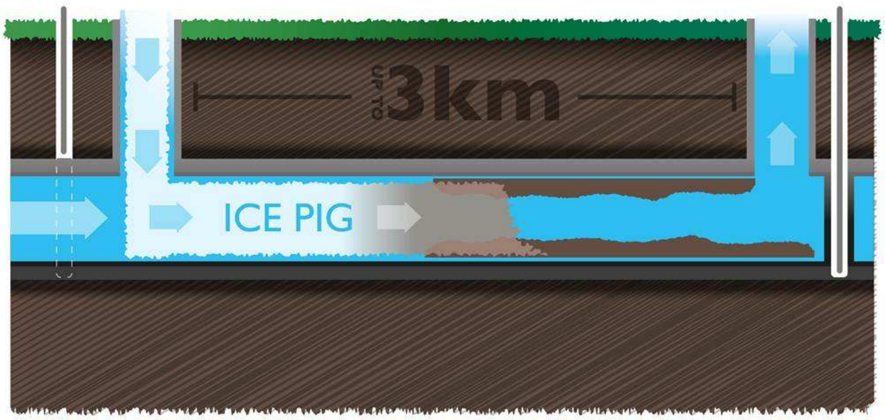

Figure 6 Ice Pigging operation

1. The main to be cleaned must be isolated so that there is no flow passing though the section of pipe to be cleaned. This is usually achieved by closing a valve up and downstream of the section of pipe to be cleaned

2. A fire hydrant at either end of the pipe to be cleaned is opened and ice is injected into the upstream hydrant, with the downstream hydrant opened to allow displaced water to be expelled.

3. After the ice is injected both hydrants are closed.

4. The upstream line valve is fully opened and the section of pipe to be cleaned is fully pressurized.

5. The downstream hydrant is gradually opened to induce a flow, and the ice column begins to move along the pipe as a result of the pressure in the network. As the ice passes along the pipe it collects sediment and biofilm.

6. At the downstream hydrant a specially design Instrumentation Unit is used to monitor key parameters in the operation so that the speed and progress of the ice can be carefully monitored. At the point at which the Instrumentation indicates the presence of the ice, the flow from the hydrant is often diverted to a waste tanker where it is collected for safe disposal.

Measuring success

Key performance parameters during and after the cleaning operation can be measured using the specially designed Instrumentation Unit.

Figure 7 Measuring the operation - the Ice Pigging Instrumentation Unit

Key measurement parameters can be obtained by collecting ice samples as the ice exits the pipe. Sediment loading in the samples can be measured and used to help determine the mass of sediment removed in the operation.

3. RESULTS

A typical ice pigging operation will produce the following results (example taken from mains cleaning project in UK for Northumbrian Water Limited).

Date:	**26 Nov 2012**	Pipe Material:	**Cast Iron (Epoxy Lined)**
Pipe Length:	**1908 m**	Pipe Diameter:	**12”**

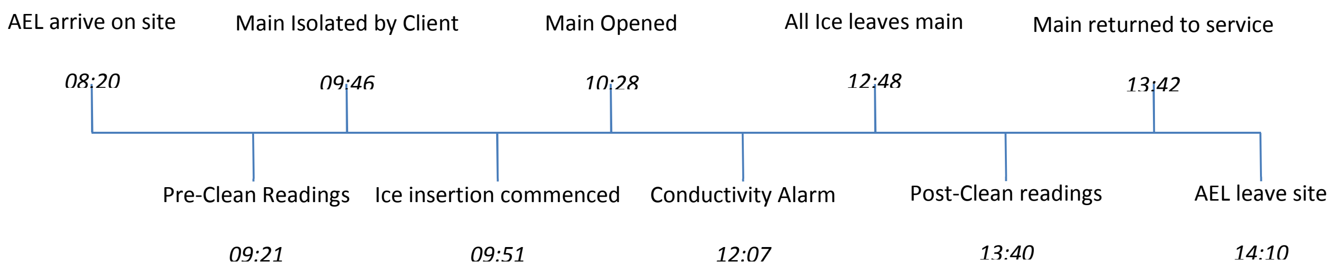

Figure 8 Timeline for operation 26 Nov 2012

The level of disruption with Ice Pigging is considerably lower than all other techniques. The example given is typical of the speed of operation when planned and performed by an experienced team. It is quite normal for the pipe being cleaned to be out of service for less than four hours which is now a standard customer warning duration in many countries.

<u>Quantifiable results</u>

During the operation a range of parameters are measured both by the Instrumentation Unit (see Fig 6) and also taken manually by Operatives during the operation. In order to determine sediment loading samples of ice are taken into standard bottles and sediment loading can be inferred.

Figure 9 Sediment samples taken during the operation

Table 1: Sediment and water quality data collected at outlet; IP03

Sample #	*Time (s)*	*Flow Rate (l/s)*	*Temp (°C)*	*Conductivity (mS/cm)*	*Sample Mass (g)*	*Sediment Mass (g)*	*Sediment Concentration (g/l)*
1	0	20.6375	6.434	50.8569375	529.2	0.01	0.02
2	60	20.64	6.016	49.89925	523.3	0.02	0.04
3	120	20.6425	4.844	54.8866875	533.18	0.15	0.30
4	180	20.63875	4.206	59.5880625	524.29	0.27	0.54
5	240	20.63375	4.15	59.0905625	509.16	0.48	0.99
6	300	20.63875	4.381	55.0235	501.62	0.44	0.93
7	360	20.6375	4.681	49.824625	531.33	0.4	0.79
8	420	20.63875	4.303	48.133125	532.52	0.56	1.11
9	480	20.6375	2.494	49.40175	525.08	0.46	0.92
10	540	20.6375	0.638	65.1351875	522.17	0.42	0.85
11	600	20.6425	-0.64	68.40625	528.01	0.38	0.76
12	660	20.64125	-2.26	46.2799375	535.64	0.32	0.63
13	720	20.6475	-2.74	33.8175625	536.54	0.44	0.86
14	780	20.63875	-2.7	35.247875	467.67	0.53	1.20
15	840	20.6425	-2.61	40.0860625	522.46	0.69	1.39
16	900	20.64125	-2.54	34.17825	477.8	0.67	1.48
17	960	17.73125	-2.33	24.72575	500.94	0.46	0.97
18	1020	20.6375	-2.06	31.044	506.82	0.39	0.81
19	1080	20.64	-1.69	42.03875	514.37	0.39	0.80
20	1140	20.6425	-1.47	24.6635625	499.83	0.33	0.70
21	1200	20.33125	-1.07	21.2308125	508.26	0.19	0.39
22	1260	18.3225	-0.98	15.721	515.32	0.22	0.45
23	1320	20.60625	-0.51	9.029625	464.11	0.1	0.23
24	1380	20.63125	-0.21	5.049625	495.08	0.15	0.32
25	1440	19.945	-0.12	4.7386875	509.06	0.16	0.33
26	1500	20.425	-0.14	4.12925	507.6	0.06	0.12
27	1560	19.66875	0.447	3.184	501.4	0.04	0.08
28	1620	20.28625	0.538	3.159125	514.28	0.05	0.10
29	1680	20.63625	0.453	2.860625	505.67	0	0.00

Sediment Removed: 22.18 Kg	Sediment Removed per Km: 11.20 Kg

When sediment loading, water temperature, and flow rate are compared a picture of the operation can be created to see where the majority of the sediment was held and for how long the ice was passing through the pipe. Total sediment for the operation can be estimated, as can an indication of the volume of sediment removed per kilometer of pipe cleaned. The volume of sediment per kilometer is a useful measure to compare with similar operations. A typical operation will remove between 10 and 20kg of sediment per kilometer and can be a clear indicator of how much sediment build up has accumulated in parts of the network which is very valuable information to water utility operators.

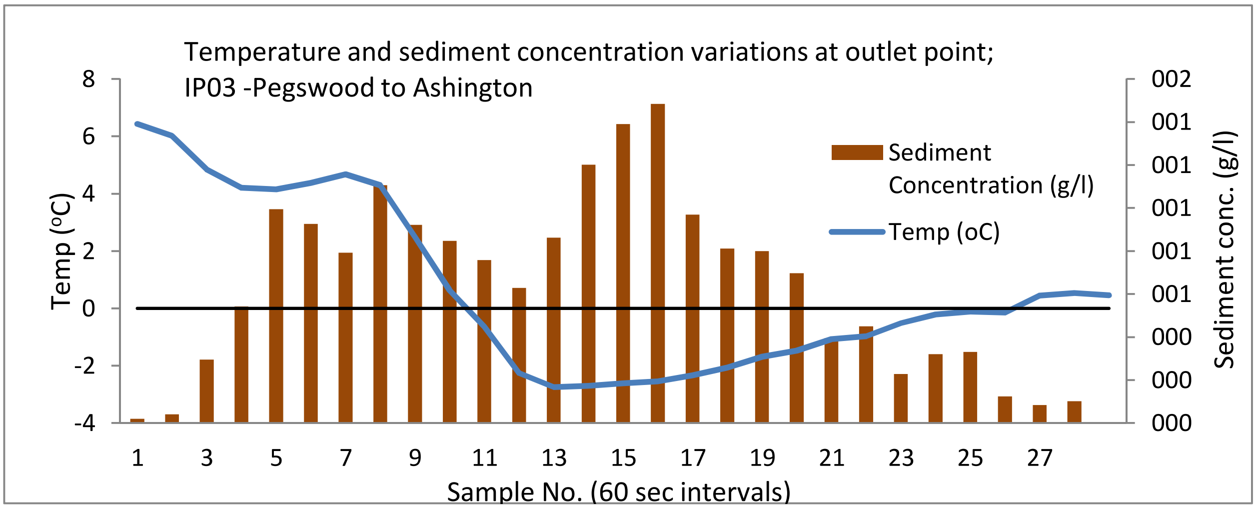

Figure 10 Sediment loading in removed ice

Finally, for the ultimate proof of the efficacy of the process, pipe cut-outs can be taken both before and after the operation. Figure 10 shows the pipe before and after for the operation described above.

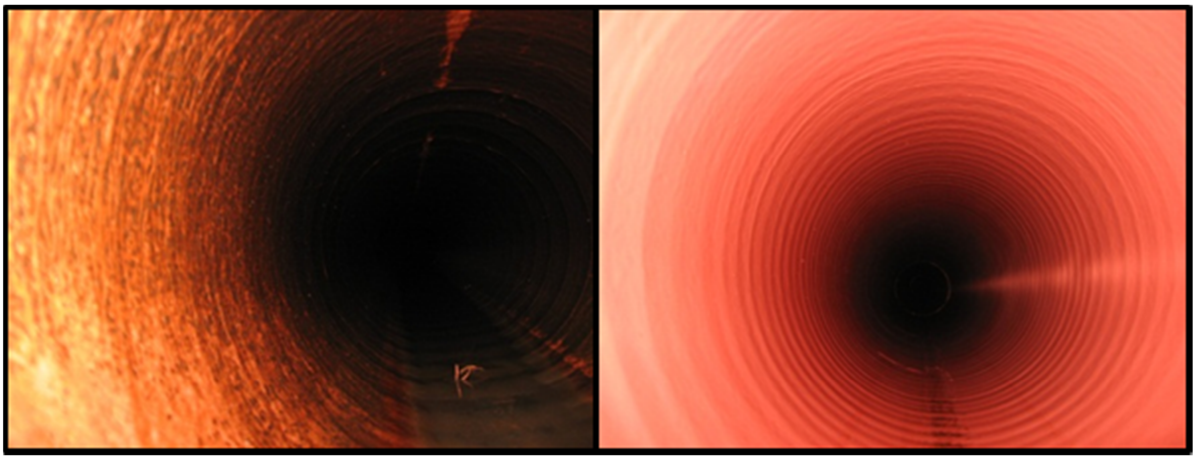

Figure 11 Pipe before cleaning (Left) and after (right)

5. ICE PIGGING AND CORROSION

Ice Pigging offers the potential to aide in the control of corrosion of metallic pipes. There are two potential ways in which Ice Pigging may help:

1. As a preparation to a wide scale change in water chemistry to enable conditions that may slow/reduce the corrosion process
2. The application of rust inhibiting chemicals to specific pipes to halt or slow the rate of corrosion

<u>Wide scale changes in Water chemistry</u>

The chemical characteristics of treated water are not uniformally the same despite internationally recognized and adopted water quality standards. Water from different sources will have differing levels of pH, hardness, and mineral content, and hence they may be more or less aggressive to metal pipes when corrosion is considered. Hard water, that is water that is naturally high in $CaCO_3$ is believed to inhibit corrosion by forming a protective layer of limescale over pipe walls. In general unfavourable water would be that with a high Larson Index, lower pH, and low alkalinity.

Conceptually, it is possible to alter water chemistry by varying the water treatment process, for example by making soft water hard with the addition of $CaCO_3$, or by varying pH.

A number of leading European water authorities are researching the long term effects of altering water chemistry on corrosion rates within the water supply network with the aim of increasing longevity of the largely metallic piped network. The principle aim being to encourage the build-up of a layer of scale on the inside of pipes that protects the pipe from corrosion.

How can Ice Pigging support this concept?

If a water authority is to consider a wide scale variation in the chemistry of the water it supplies then it must first prepare the network in readiness for this change. The removal of sediment that may be preventing the formation of a protective layer should be an initial step. As Ice Pigging is one of the few techniques for removing sediment that does not cause damage to unlined metallic pipes, ice pigging could play an important part in a pre-treatment regime.

Figure 12 Badly corroded cast iron pipe before (left) and after (right) cleaning with ice

<u>The application of rust inhibiting chemicals to specific pipes</u>

Although untested in a live environment the potential to use ice to deliver rust inhibiting chemicals to parts of the network where they are most needed is a realistic possibility. The injection of ice slurry is a simple and low risk process that is ultimately very controllable with the speed and position of the ice easy to determine. Ice containing high concentrations of rust inhibiting (phosphoric based) compounds could be easily applied to pipes that are suffering from high corrosion rates.

Aqualogy and its partners are actively investigating the practicalities and benefits of this potential solution for the control of corrosion.

6. CONCLUSIONS

Ice Pigging is an exciting new pipe cleaning technique that can be applied to drinking water networks. It can help remove the build-up of biofilms and sediment in drinking water pipes which have the potential to reach the consumer's tap and can cause problems with the management of water quality within the network.

Ice Pigging is being effectively used to prevent the potential for water discolouration events in many countries around the world, and more recently in Germany. Ice Pigging is also a highly effective method of controlling or removing biofilm growth that may be causing issues with water quality or issues with consumers if growth is allowed to continue in an unbalanced way.

Ice Pigging may also play a part in methods for the control of corrosion. Two methods are proposed:

1. As a preparation for wide scale water chemistry adjustment – where a water authority may adjust the chemistry of treated water to inhibit the development of corrosion through the natural creation of a limescale layer on metallic pipes. If this is to be successful, pipes that are free of sediment will be vital. Ice Pigging is one of the few methods for removing sediments that will not harm corroded metallic pipes.
2. As a means of delivering rust inhibiting chemicals directly to water pipes – through the addition of high concentration rust inhibiting (phosphoric based) compounds that could be applied to pipes that are suffering from high corrosion rates.