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Formation and prevention of pipe scale in water supply pipelines with anti-corrosion lining

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ABSTRACT

With the continuous requirement for an improvement in tap water quality, the decline of water quality after tap water is transported through water supply pipelines needs to be solved urgently. Pipe scale forms when the anti-corrosive lining of the water supply pipeline is damaged, and it has a significant influence on the chromaticity and turbidity indicators of water quality. Therefore, the reasons for damage to the joint, tee, elbow, and other parts that are prone to damaging the anti-corrosive lining in the pipeline construction were investigated. On this basis, the matters needing attention in the construction and prefabricated parts are proposed, and it is suggested that steel pipes should not be used during construction if the diameter of the pipeline is less than 700 mm. A combination of removal and pipeline rehabilitation should be used to treat pipe scale to ensure water quality and safe water supply.

Key words: anti-corrosion lining, pipe scale, prevention, water supply pipelines

HIGHLIGHTS

- The location of most pipe scale in water supply pipeline.
- Pipe scale caused by construction carelessness.
- Measures to prevent pipe scale.

GRAPHICAL ABSTRACT

1. INTRODUCTION

After continuous development over a number of years, the water quality of many waterworks has now reached a standard that can be drunk directly, but there is still the problem of a decline in water quality when the water reaches the user's tap after long-distance pipeline transportation. In order to ensure the drinking water quality of users, improving the water conveyance environment of water supply pipelines is urgently required. After long-term work practice and the exploration of colleagues, it was found that pipe scale in the water supply pipeline greatly influences the chromaticity and turbidity (Wang 2020) of the water body, and many colleagues have also published corresponding research results. However, there are various opinions on the root causes of pipe scale formation. This paper explores this problem from the perspective of engineering construction to achieve the purpose of removing pipe scale and improving water quality.

1.1. The causes of pipe scale formation

In the water conveyance process and operation of metal water supply pipelines, if there is no anti-corrosive lining or the anti-corrosive lining is damaged in the inner wall, the water directly contacts the metal surface of the pipeline, resulting in the dissolved oxygen in the water acting as an oxidant and causing electrochemical corrosion of metal pipe wall (Yang *et al.* 2012). This corrosion (Liu *et al.* 2012) will produce Fe^{2+}, OH^- (Shang 2013), and other corrosion products. Some of these corrosives are directly released into the pipe network water where they can form pipe scale on the pipe wall through complex reactions such as oxidation, reduction, and precipitation. The lower section of the pipe scale is thicker and the upper section is thinner, and it will become thicker over time with an increase in operation time.

1.2. The harm of pipe scale

Due to the continuous thickening of pipe scale with an increase in operation time, the cross-section of water passing in some areas of the pipeline will be continuously reduced, and the water conveyance delivery of the pipeline will be reduced. When sudden and large-scale fluctuations occur in the flow velocity, flow direction, and water pressure in the pipe network, the pipe scale will release iron element into the pipe network water, resulting in the iron release phenomenon (Gao 2013). Iron release destroys the relatively stable structure of pipe scale (Lytle *et al.* 2005), thus aggravating the corrosion of the pipeline (Li *et al.* 2016a). Excessive iron in the pipe network water will be deposited, leading to an increase in turbidity, chromaticity, and other indicators of pipe network water, resulting in short-term water quality deterioration, and even serious water quality accidents such as yellow water and red water (Du *et al.* 2004; Li *et al.* 2016b). According to the survey of 36 cities, which accounted for 42.44% of the total water supply in China, the average turbidity of the factory level was 1.3 degrees, while the pipe network water increased to 1.6 degrees. The chromaticity increased from 5.2 degrees to 6.7 degrees (Wang 2007). These indicators show the impact of pipe scale on tap water quality to some extent.

2. DISTRIBUTION OF PIPE SCALE IN WATER SUPPLY PIPELINE WITH ANTI-CORROSION LINING

In recent decades, water supply enterprises have adopted pipes with anti-corrosion lining when laying water supply pipelines. It is difficult for pipe scale to form in the water supply pipeline in the sections that have the anti-corrosion lining (see Figure 1) Pipe scale in water supply pipeline is mainly distributed in the damaged parts of anti-corrosive lining such as joint, tee, and elbow of metal pipes (see Figures 1 and 2). This paper uses the cast iron pipe and steel pipe, the two most commonly used piping materials in water supply network, as the main analysis objects.

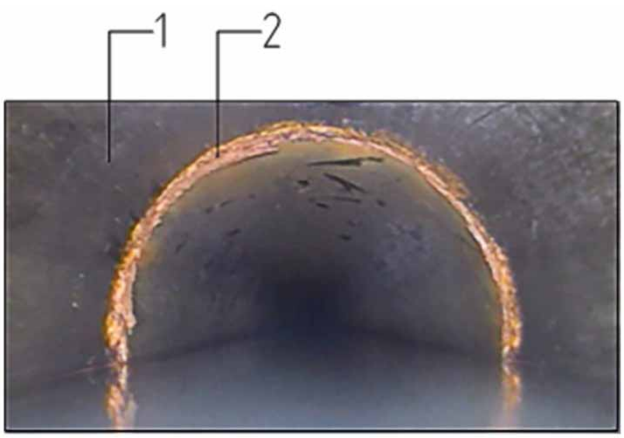

Figure 1 | Facade photo of pipe scale at the joint of cast iron pipes for water supply pipeline. (1) Inner wall of socket and spigot connected cast iron pipes with anti-corrosion lining; (2) facade photo of pipe scale at socket and spigot connected cast iron pipes connection.

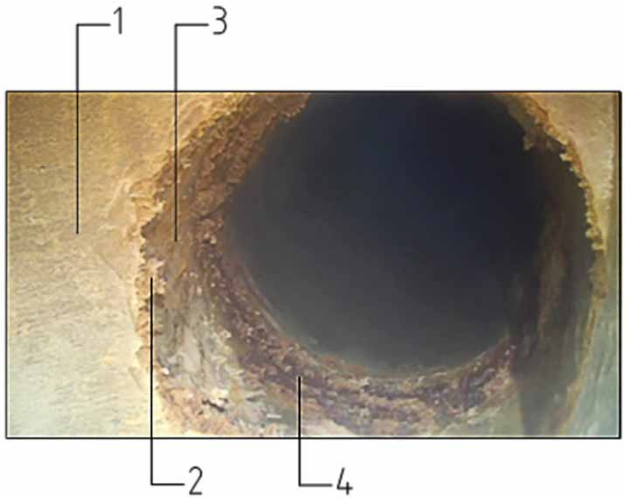

Figure 2 | Pipe scale at the branch pipe of tee for water supply pipeline. (1) The inner wall of the tee main pipe; (2) pipe scale at weld position of tee branch pipe and main pipe; (3) pipe scale at tee branch pipe; (4) pipe scale at weld position of tee branch pipe and flange.

Pipe scale was detected using CCTV of three sections of running water cast iron pipes with anti-corrosion lining (see Table 1).

The data in Table 1 are calculated according to the following principles: (a) when calculating the pipe scale amount inside the pipeline, the pipe scale height can only be measured according to its distribution area; (b) the height of the groove at the connection of the socket and the mouthing is between 10 and 15 mm, and the average value is 12.5 mm; (c) because the pipe scale in the groove at the connection of the socket and the mouthing does not cover the groove, its area is 90% of the groove area at the junction of the socket and the mouthing; and (d) because the pipe scale at the tee branch pipe does not cover the branch pipe, its area is 85% of the area at the tee branch pipe.

According to the statistics in Table 1, in the three sections of the cast iron pipelines, the average proportion of pipe scale area to the inner wall area of the pipeline is 0.34%. Taking a 700 mm diameter water supply cast iron pipes without anti-corrosion lining for an area as an example, the proportion of pipe scale area to the inner wall area of the pipeline is 8.33%, which is 24.51 times of that of the cast iron pipeline with anti-corrosion lining, it can be seen that the anti-corrosion lining inside the water supply pipeline can inhibit the growth of pipe scale.

3. CAUSE ANALYSIS OF PIPE SCALE FORMATION IN WATER SUPPLY PIPELINES WITH ANTI-CORROSION LINING

3.1. Cause analysis of the formation of pipe scale at the joint

3.1.1. Joint of socket and spigot connected cast iron pipes

In the water supply network using socket and spigot connected cast iron pipes, damage to the connection surface between the socket and the mouthing at the pipe joint is due to pipe scale. Although the amount of pipe scale caused by the damage of the connection surface of each socket and mouthing low, for ease of construction and transportation, cast iron pipes are 5–6 m in

Table 1 | Detection statistics of running pipelines' CCTV pipe scale with anti-corrosion lining

	Pipe diameter (mm)	Length (m)	Number of joint/pcs	Number of tee/pcs	Pipe scale area at joint/m^2	Pipe scale area at tee/m^2	Inner wall area of pipeline/m^2	Proportion of pipe scale area to inner wall area of pipeline/%
A section	300	125	26	DN200*1 DN150*1 DN100*1	0.28	0.14	117.75	0.36
B section	500	200	41	DN150*1 DN100*1	0.72	0.08	314.00	0.25
C section	700	91	20	DN500*2	0.49	0.32	200.02	0.40

length, and so this type of pipe scale occupies a large proportion of the whole pipe network. (see Figures 1, 3 and 4). There are two reasons for this damage at the connection surface between the socket and the mouthing.

(1) Connection surface damage of mouthing and socket caused by construction carelessness

Due to the heavy weight of the cast iron pipe body, an excavator is often used to lift the pipe during the pipeline laying construction, which involves (1) excavating the pipe trench; (b) lifting the single pipe into the trench; (c) targeting the latter pipe socket against the former pipe mouthing; and (d) using an excavator bucket to top the latter pipe socket into the former pipe mouthing (see Figure 5).

This construction method means that the anti-corrosion layer of the connection surface between the socket and the mouthing is easily squeezed and damaged by the strong push of the excavator. Pipe scale forms at the damaged surface due to contact between the metal surface and the tap water over a period of time. It forms in the grooves (rectangular cross-section torus body, 10–15 mm height and 10 mm thick) at the connection of the socket and the mouthing (see Figure 6).

(2) Anti-corrosion layer on connection surface of socket and mouthing is missing before construction

There are two reasons for the lack of anti-corrosion layer on the connection surface of socket and mouthing before construction: (a) the anti-corrosion layer is missing during pipeline production, particularly the anti-corrosion layer on the

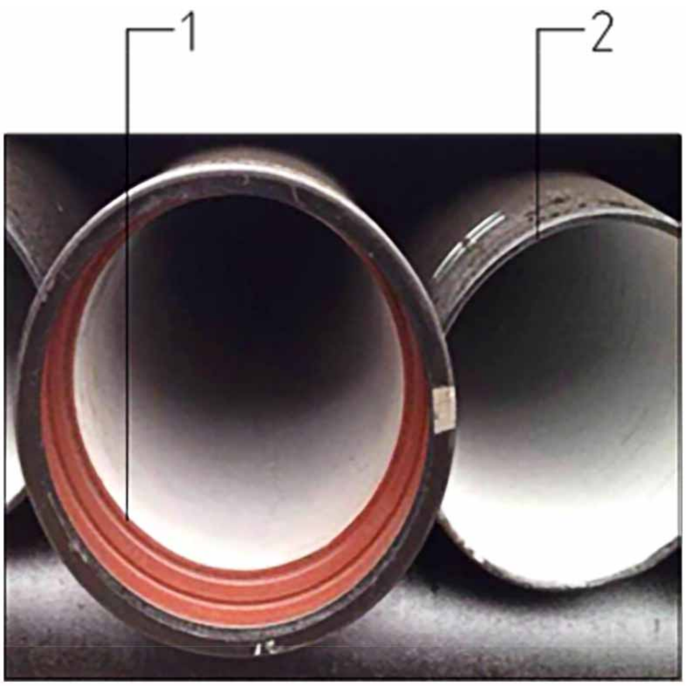

Figure 3 | Socket and mouthing of cast iron pipes for water supply pipeline. (1) Connection surface of the mouthing of socket and spigot connected cast iron pipes; (2) connection surface of the socket of socket and spigot connected cast iron pipes.

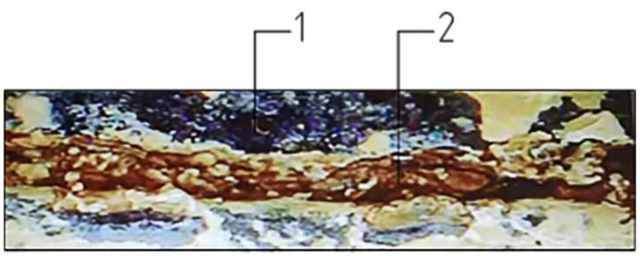

Figure 4 | Pipe scale caused by damage of anti-corrosion layer on connection surface of mouthing and socket for water supply pipelines. (1) Inner wall of socket and spigot connected cast iron pipes; (2) planar photo of pipe scale at socket and spigot connected cast iron pipes connection.

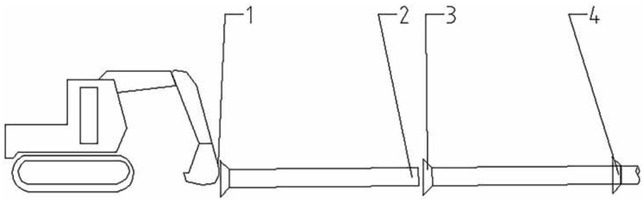

Figure 5 | Schematic diagram of excavator lays socket and spigot connected cast iron pipes. (1) Excavator bucket; (2) the socket of socket and spigot connected cast iron pipes; (3) the mouthing of socket and spigot connected cast iron pipes; and (4) the completed mouthing and socket of pipe.

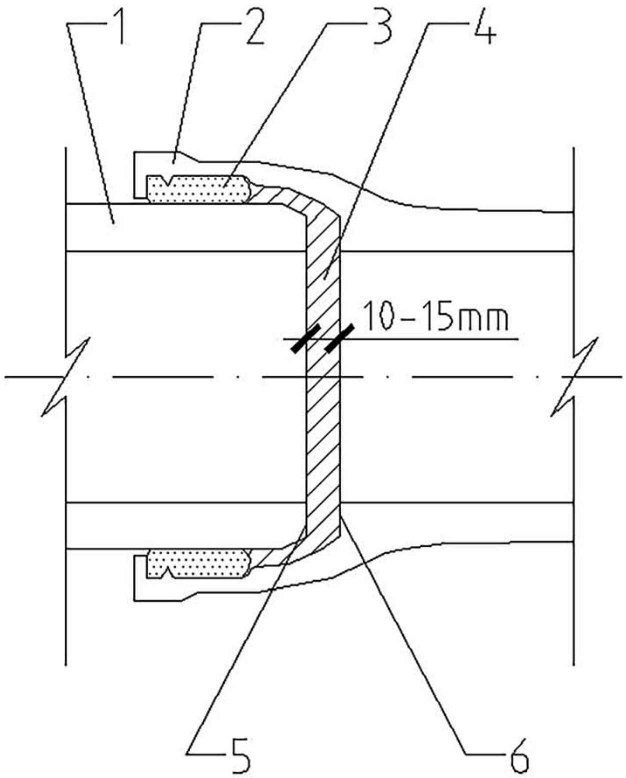

Figure 6 | The formation location of pipe scale at the joint of socket and spigot connected cast iron pipes for water supply pipelines. (1) the socket of socket and spigot connected cast iron pipes; (2) the mouthing of socket and spigot connected cast iron pipes; (3) the sealing member of socket and spigot connected cast iron pipes; (4) grooves at socket and mouthing connections; (5) socket connection surface; and (6) mouthing connection surface.

socket connection surface, which is easily missed during pipeline production; and (b) the anti-corrosion layer is damaged during pipeline handling and transportation.

3.1.2. Joint of steel pipeline

For the convenience of construction and transportation, during on-site construction, the steel pipeline is made into 5–6 m lengths, with 10 cm at both ends without anti-corrosion lining.

After on-site laying and welding are completed, the anti-corrosion layer is constructed on the inner walls of the two 10 cm-long sections of pipeline at the joint where the diameter of the pipeline is greater than or equal to 700 mm. Construction personnel enter the pipeline to coat the cement mortar anti-corrosion lining.

However, due to poor working conditions of the cement mortar ratio and also the mixing on the construction site, the preparation quality of cement mortar does not fully meet the standard requirements. At the same time, because of the nonstandard operation, manually painting the cement mortar lining at the joint during pipeline operation may cause exfoliation due to positive and negative pressure inside the pipeline (Zhang *et al.* 2017). The exposed metal surface at the exfoliated area may result in pipe scale forming due to the long contact with water (Huang *et al.* 2011). If the pipe diameter is less than 700 mm, the joint adopts mechanical coating cement mortar lining, but the construction operation is extremely cumbersome and time-consuming.

3.2. Cause analysis of the formation of pipe scale at the tee

The tee sections of water supply pipelines, whether prefabricated in factories or produced at the construction site, has a lining that is often manually coated with cement mortar. In the production process, due to the operation deviation of the construction personnel, the adhesive force between the cement mortar and the metal inner wall of the tee is not enough, resulting in gradual exfoilation of the cement mortar lining at the tee after a period of operation. Pipe scale then forms on the metal inner wall and affects the water quality.

According to the location of the cement mortar exfoliation, there are two reasons for pipe scale formation:

(a) If it forms in the tee main pipe, the pipe scale forms because of cement mortar exfoliating (see Figure 7)
(b) If it forms at the welding points of tee branch and the main pipe, the welding points of the tee branch and the flange, and the tee branch, then the pipe scale growth is caused by cement mortar coating defects (see Figure 2).

3.3. Cause analysis of the formation of pipe scale at the elbow position

Similar to the tee sections, there are two ways to produce the elbow: prefabricated production and on-site production. On-site production of the elbow is limited by the maximum allowable angle standard, and also because there are many welds on one elbow and the gradually changing angle is narrow. It is difficult to coat the cement mortar lining at this position and so the adhesive force between the cement mortar lining and the steel pipe after coating does not meet the standard requirements, causing exfoliation of the cement mortar lining due to the positive and negative pressure in the operation of the pipeline network. The pipe scale grows at the exfoliated position.

Although the prefabricated elbow can be coated with cement mortar lining in the factory to meet the quality standard, in relation to handling, cement mortar lining is easy to exfoliate using external forces. When schedules are tight and the elbow cannot be replaced on the construction site, manual painting repair method, if used, can leave hidden dangers for the exfoliation of cement mortar lining.

3.4. Broken linings of some units of the water supply pipeline are also the cause of pipe scale growth

There can also be pipe scale growth caused by the exfoliation of the prefabricated cement mortar lining at some sections, e.g. flange mouthing short pipe, flange socket short pipe etc.

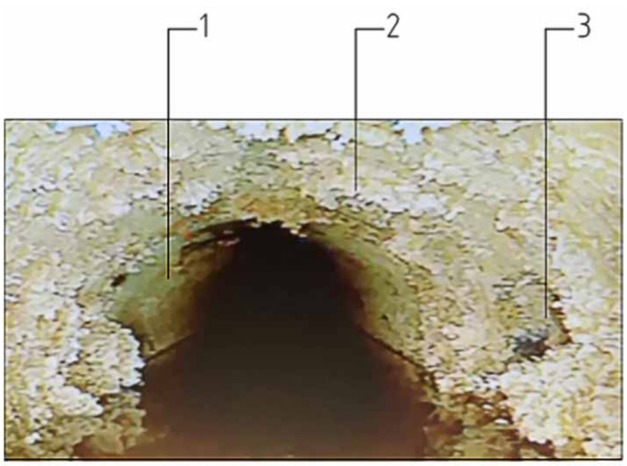

Figure 7 | Pipe scale photo of tee main pipe of water supply pipelines. (1) Inner wall of socket and spigot connected cast iron pipes; (2) pipe scale at tee main pipe; and (3) branch pipe of tee.

4. MEASURES FOR PIPE SCALE OF WATER SUPPLY PIPELINES

There are two measures for pipe scale of water supply pipelines: prevention and treatment.

4.1. Prevention

4.1.1. Attentions in pipeline laying construction

Every year, a large number of new pipelines are laid in the water supply network. At the start of laying, strict quality control and attention to the protection of pipeline lining will prevent any accidents.

(1) For socket and spigot connected cast iron pipes

(a) Strict inspection of the anti-corrosion layer on the connection surface of the socket and the mouthing before pipeline laying is necessary. If a defect is found in the anti-corrosion layer, it should be timely repaired. (b) The length of the top mouthing into the socket during pipeline laying should be strictly controlled so that the connection surface of the socket and the connection surface of the mouthing does not collide. When the pipeline is newly laid, the length of the socket inserted into the mouthing should reach the first marking line of the socket; if it reaches the second marking line, it is a warning (see Figure 8). When the marking line is not seen, it has been inserted too far. The socket should be removed from the socket and the connection surface between the socket and the mouthing checked for any damage. If it is damaged, it should be rehabilitated in time according to the specification.

(2) For newly laid steel pipes and steel parts made on site

(1) Pipes with diameter greater than or equal to 700 mm

(a) On the construction site, the cement mortar should be prepared and coated following standard requirements; (b) the internal anti-corrosion material of the pipeline is designed as polymer coating. After welding on-site, the straight pipe section's joint and the inner wall of steel parts are manually sprayed with polymer material to increase the adhesive force between coating and steel.

(2) Pipes with diameter less than 700 mm

It is recommended not to use steel materials, but rather iron, polyethylene, polyvinyl chloride and, other pipe materials that meet the standard requirements.

Figure 8 | Marking Line for the Socket of Socket and Spigot Connected Cast Iron Pipes. 1-The first marking line of the socket 2-The second marking line of the socket 3-Pipe socket.

4.1.2. Prefabricated pipe parts

Prefabricated pipeline parts should protect the internal anti-corrosion layer during lifting and transportation. The integrity of the lining should be checked before laying and rehabilitating the defect.

4.2. Treatment

At present, there are two effective ways to remove pipe scale: grab-rake scraping (Luo 1998; Fu 2004) and ultra-high pressure water flow impact (Sun 2003; Zhao *et al.* 2019). The metal surface of the inner wall of the pipeline will be exposed after the pipe scale is removed. None of the current methods can ensure that the pipeline lining, sealing, or structures remain intact. Therefore, treatment of pipe scale in the water supply pipeline should be combined with pipe scale removal and pipeline rehabilitation.

The structural performance of the lining chosen for pipeline rehabilitation depends on the structural integrity of the original pipe and can be selected from three aspects: non-structural-only corrosion protection, semi-structural, and structural.

When the original structure of the pipeline is good, if the non-structural-only corrosion protection or semi-structural rehabilitation method is adopted, the protection of the socket sealing of the original pipeline should be considered in the pipe scale removal stage. If the pipe scale is removed using the grab-rake scraping with an elastic steel plate blade, the wire rope of the grab-rake cannot pass through the pipe when the pipe scale is dense, and the high-pressure cleaning vehicle is needed to dredge the pipe. It is necessary to strictly control the output water pressure of the high-pressure cleaning vehicle to ensure the water pressure gradually increases and dredges the internal pipe scale to protect the joint. When using the grab-rake, the elastic steel plate blades should be chosen according to their elasticity from high to low, so that any internal pipe scale is identified and removed in one go in order to protect the joint.

The spraying rehabilitation process of the polyurethane pipeline inner wall (Li 2015) is a new technology suitable for the rehabilitation requirements of water supply pipelines. This process can achieve all the rehabilitation purposes from non-structural-only corrosion protection, semi-structural, and structural by changing the coating thickness (Yang *et al.* 2019). Moreover, due to the variability of coating thickness, this process is the most reasonable in terms of economic cost.

5. CONCLUSION

When the water supply pipeline is coated with anti-corrosion lining, most of the pipe scale is caused by a defect in the anti-corrosion layer on the inner wall of the pipeline, and direct contact between the metal surface and water causes corrosion. There are two reasons for this: (a) the construction specification is not clear, e.g. if there is damage to the connection surface of socket and mouthing, construction specifications and standards must be corrected and adhered to; (b) the normal operation and protection of the inner wall coating during construction are not adequate, e.g. the internal anti-corrosion treatment at the joint of a straight section of large diameter steel pipeline at the construction site; and the loading, unloading, and transportation of pipeline components. These are easily affected by rate of progress, cost, and other non-standard operations. Therefore, strengthening the normative supervision of this part of the construction operation cannot be ignored in future work.

The most appropriate and economic cleaning and rehabilitation methods should be selected to extend the life span of those water supply pipeline that have severe pipe scale are unable to be updated due to, for example, traffic, obstacles on the ground, and underground buildings.

With the continuous requirement to improve tap water quality indicators, such as turbidity and chromaticity, the prevention and treatment of pipe scale in water supply pipelines is vital and requires a lot of time and money. To stop the decline in the quality of tap water due to pipe scale formation, water supply pipelines must be maintained.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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