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

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ABSTRACT

With the continuous improvement of users’ requirements for tap water quality, the problem of water quality decline after tap water is transported through water supply pipelines needs to be solved urgently. In this problem, pipe scale has a significant influence on the chromaticity and turbidity indicators of water quality, and the pipe scale grows when the anti-corrosive lining of the water supply pipeline is damaged. Therefore, the reasons for the damage of the joint, tee, elbow and, other parts that are prone to damage the anti-corrosive lining in the pipeline construction were found out. On this basis, the matters needing attention in the construction and prefabricated parts are proposed, and it is suggested that the steel pipe should be abandoned if the diameter of the pipeline is less than 700 mm on-site construction. At the same time, the combination of removing and pipeline rehabilitation should be used for the treatment of pipe scale so as to achieve the working goal of ensuring 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 the continuous development of these years, the water quality of many waterworks has reached the standard that can be directly drunk, but there is a problem of water quality decline when the water reaches the user water tap after long-distance transport. This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (http://creativecommons.org/licenses/by/4.0/).
pipeline transportation. In order to ensure the drinking water quality of users, it is an urgent problem to improve the water conveyance environment of water supply pipelines. After long-term work practice and the exploration of colleagues, it is found that the pipe scale in the water supply pipeline has a great influence on 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 process of water conveyance and operation of metal water supply pipelines, when there is no anti-corrosive lining or the anti-corrosive lining is damaged in the inner wall, after the water directly contacts the metal surface of the pipeline, dissolved oxygen in the water as an oxidant will cause electrochemical corrosion of metal pipe wall (Yang et al. 2012), corrosion process (Liu et al. 2012) will produce Fe$^{2+}$, OH$^-$ (Shang 2013) and other corrosion products. Some of them are directly released into the pipe network water, some of them form pipe scale on the pipe wall through complex reactions such as oxidation, reduction and, precipitation. The structural feature of pipe scale is that the lower part is thicker and the upper part is thinner, and it will become thicker with the increase of operation time.

1.2. The harm of pipe scale

Due to the continuous thickening of pipe scale with the increase of 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. And when the flow velocity, flow direction and, water pressure in the pipe network occur sudden and large-scale fluctuations, pipe scale will release iron element into the pipe network water, resulting in iron release phenomenon. (Gao 2013) Iron release destroys the relatively stable structure of pipe scale, (Lytle et al. 2005) thus aggravating the corrosion of pipeline. (Li et al. 2016a) Excessive iron in pipe network water will deposit, leading to the increase of 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. THE 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 in the laying of water supply pipelines. It is difficult for pipe scale to grow in the parts with anti-corrosion lining in the water supply pipeline (See Figure 1),

**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.
which is mainly distributed in the damaged parts of anti-corrosive lining such as the joint, tee and, elbow of metal pipes. (See Figures 1 and 2), therefore, this paper takes the cast iron pipe and steel pipe, the two most commonly used piping materials in water supply network, as the main analysis objects.

Now statistics are made on CCTV pipe scale detection of three sections of running water supply cast iron pipes with anti-corrosion lining for an area. (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, because the pipe scale height cannot be measured, it 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 take its average value is 12.5 mm; (c) Since the pipe scale in the groove at the connection of the socket and the mouthing is not cover the groove, its area is calculated according to 90% of the groove area at the junction of the socket and the mouthing; (d) Since the pipe scale at the tee branch pipe is not cover the branch pipe, its area is calculated according to 85% of the area at the tee branch pipe.

According to the statistical results in Table 1, in the three sections of running water supply 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 water supply cast iron pipeline with anti-corrosion lining, it can also be seen from this data that the anti-corrosion lining inside the water supply pipeline can inhibit the growth of pipe scale.

### 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/m² | Pipe scale area at tee/m² | Inner wall area of pipeline/m² | Proportion of pipe scale area to inner wall area of pipeline/% |
|---|---|---|---|---|---|---|---|---|
| Asection | 300 | 125 | 26 | DN200*1, DN150*1, DN100*1 | 0.28 | 0.14 | 117.75 | 0.36 |
| Bsection | 500 | 200 | 41 | DN150*1, DN100*1 | 0.72 | 0.08 | 314.00 | 0.25 |
| Csection | 700 | 91 | 20 | DN500*2 | 0.49 | 0.32 | 200.02 | 0.40 |
3. CAUSE ANALYSIS OF PIPE SCALE FORMATION OF WATER SUPPLY PIPELINE WITH ANTI-CORROSION LINING

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

3.1.1. Cause analysis of the formation of pipe scale at the joint of socket and spigot connected cast iron pipes

In the water supply network of the Socket and Spigot Connected Cast Iron Pipes, the damage of the connection surface between the socket and the mouthing at the pipe joint is the cause of pipe scale. Although the amount of pipe scale caused by the damage of the connection surface of each socket and mouthing is not much, the cast iron pipe is made into a length of 5 m to 6 m because of the convenience of construction and transportation. Therefore, this type of pipe scale occupies a large proportion of the whole pipe network. (See Figures 1, 5 and 4), there are two reasons for the damage of the connection surface between the socket and the mouthing.

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

Due to the large weight of cast iron pipe body, the excavator is often used to lift the pipe during the pipeline laying construction, and the construction steps are as follows: (a) Excavating the pipe trench; (b) Lifting the single pipe into the

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**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.
trench ; (c) Target the latter pipe socket against the former pipe mouthing; (d) Excavator bucket is used to top the latter pipe socket into the former pipe mouthing. (See Figure 5).

This construction method leads to the anti-corrosion layer of the connection surface between the socket and the mouthing is easy to be squeezed and damaged by the strong push of the excavator. The growth of pipe scale at the damaged surface because of the long-term contact between the metal surface and the tap water. The pipe scale grows in the grooves at the connection of the socket and the mouthing. (The groove is a rectangular cross-section torus body with 10–15 mm height and 10 mm thickness.). (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) Missing of the anti-corrosion layer during pipeline production, especially the anti-corrosion layer on the

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

3.1.2. Cause analysis of the formation of pipe scale at the joint of steel pipeline

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

After laying and welding are completed on-site, for the construction of the anti-corrosion layer on the inner wall of the 20 cm length pipeline at the joint, when the diameter of the pipeline is greater than or equal to 700 mm, adopting the way of the construction personnel enter the pipeline to coat the cement mortar anti-corrosion lining.

However, due to the poor working conditions of the cement mortar ratio and mixing on the construction site, the preparation quality of cement mortar cannot fully meet the standard requirements. At the same time, because the construction personnel in the pipeline coating will also have nonstandard operation, so in the process of pipeline operation, the cement mortar lining at the joint may exfoliate under the action of positive and negative pressure inside the pipeline, (Zhang et al. 2017) the metal surface of the steel pipeline exposed at the cement mortar exfoliating place may cause pipe scale due to long-term 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 parts of water supply pipelines, whether prefabricated in factories or produced on the construction site, its lining is often coated with cement mortar by manual. 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 the gradual exfoliating of the cement mortar lining of the tee after a period of operation in the pipe network, so that the pipe scale grows on the metal inner wall and affects the water quality.

According to the position of cement mortar exfoliating, there are two cases of pipe scale growth position

(a) In tee main pipe, pipe scale grows because of cement mortar exfoliating; (See Figure 7)
(b) Pipe scale growth caused by cement mortar coating defects at the welding points of tee branch and main pipe, the welding points of tee branch and flange, and tee branch. (See Figure 2).

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

The same as the tee parts, there are two ways to produce the elbow: prefabricated production and site production. The elbow of site production is limited by the ‘maximum allowable angle’ standard, there are many welds on one elbow, and the area of gradually changing angle is narrow. In this case, the difficulty of coating cement mortar lining at this position is increased, so that the adhesive force between the cement mortar lining and the steel pipe after coating can not meet the standard

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 3-Branch pipe of tee.
requirements, and the cement mortar lining exfoliates due to the positive and negative pressure in the operation of the pipe-line 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 the way of handling, cement mortar lining is easy to exfoliate by external force. In the case of tight schedule and the elbow cannot be replaced on the construction site, if the manually painting repair method is adopted, it will also 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

Some parts on the construction site (flange mouthing short pipe, flange socket short pipe, etc.), there will also be pipe scale growth caused by the exfoliation of the prefabricated cement mortar lining.

4. BE AIMED AT MEASURES FOR PIPE SCALE OF WATER SUPPLY PIPELINES

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

4.1. On prevention

4.1.1. Attentions in pipeline laying construction

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

(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, if 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 reaches the first marking line of the socket is fine, and the arrival of the second marking line is a warning (See Figure 8). When the marking line is not seen, it is too much to insert. The socket should be removed from the socket, and check the

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.
connection surface between the socket and the mouthing if there has any damage. If so, 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 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 suggested not to use steel materials, but instead of cast iron, PE, PVC and, other pipe materials that meet the standard requirements.

4.1.2. Prefabricated pipe parts

Prefabricated pipeline parts should protect the internal anti-corrosion layer during lifting and transportation, and carefully check the integrity of the lining before laying and repairing the defect place in time.

4.2. In the treatment of pipe scale

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. From the current technical means, no matter what kind of removal method can not ensure that the pipeline lining, the sealing member and, structures are intact. Therefore, the treatment of the pipe scale of the water supply pipeline should be combined with pipe scale removing and pipeline rehabilitation to achieve the requirements of removing pipe scale and ensuring pipeline lining, sealing and, structure to be good.

The structural performance of the lining chosen for pipeline rehabilitation is depended on the structural integrity of the original pipe and can be selected from 3 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 removal method of elastic steel plate blade grabbing rake is adopted, when the pipe scale is dense, the wire rope of grabbing rake cannot pass through the pipe, 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, take the way of gradually increase the water pressure, dredging internal pipe scale once and observing once to achieve the purpose of dredging the pipeline and protecting the joint. In the stage of removing pipe scale by grabbing rake, using different elastic steel plate blade grabbing rake according to its elastic from high to low, taking the way of removing pipe scale once and observing once, in order to achieve the purpose of removing the pipe scale and protecting the joint.

The spraying rehabilitation process of 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 to structural by changing the coating thickness. (Yang et al. 2019) Moreover, due to the variability of coating thickness in this process, 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 the defect of the anti-corrosion layer on the inner wall of the pipeline, and the direct contact between the metal surface and water is corroded. There are two reasons for this: (a) In the construction specification is not clear enough, such as the damage of the connection surface of socket and mouthing, it is needed to clear the corresponding construction specifications and standards in the current situation; (b) The normative operation and protection supervision of the inner wall coating in the construction operation are not enough, for example, the internal anti-corrosion treatment at the joint of large diameter steel pipe straight pipe section at the construction site and the loading, unloading and, transportation of pipeline components, these treatment methods in the construction is easy to be affected by rate of progress, cost and, other factors, which are not standardized operations. Therefore, strengthening the normative supervision of this part of the construction operation is the content that cannot be ignored in future work.
At the same time, the most appropriate cleaning and rehabilitation methods should be selected for the water supply pipeline with serious pipe scale and unable to be updated due to traffic, obstacles of ground and underground buildings and, other reasons to achieve the best service life cycle of the pipeline and the economic cost.

With the continuous improvement of users’ requirements for quality indicators such as turbidity and chromaticity of tap water, the prevention and treatment of pipe scale in water supply pipelines is an inevitable work content, which requires a lot of time and money. However, as long as it is maintained, the problem of quality decline of tap water due to pipe scale in water supply pipelines will be solved.

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**INTRODUCTION OF THE AUTHOR**

Weixing Chen (1967 – ), male, engineer, mainly engaged in water affairs technology and management.

**DATA AVAILABILITY STATEMENT**

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

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