Effect of flow on corrosion of water pipelines in petrochemical industry

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Abstract. Effect of flow on corrosion of inner wall of metal pipelines is complex, relationship between them has not been fully revealed yet in existing researches. In petrochemical industry, leakage of water pipelines often occurs. Once sewage pipelines leaking, serious pollution may happen. Therefore, valid researches on effect of flow on corrosion could provide a theoretical basis for process designing and inspection planning of water pipelines in petrochemical industry. In this paper, the static and flow induced corrosion were discussed according to the experimental results, the acceleration and influence of the velocity on flow induced corrosion were discussed.

1. Introduction

Effect of medium flowing on corrosion of the inner wall of pipelines is complex. First, electrochemical exchange process can be accelerated by medium flowing. Further, corrosion products will fall off under the shear force on the inner wall caused by scouring of medium flowing, and raw materials exposing again [1-2]. Due to the particularity of water pipelines, leakage of them are often ignored because of the less economic losses. However, water pipelines in petrochemical industry are generally important for the safety of stations for their certain functions. Additionally, leakage of sewage pipelines will cause serious pollution.

Pipe loop, rotary and jet flow setup are three kinds of normal experimental devices for erosion-corrosion investigations [3-6], the pipe loop is more close to the actual pipelines in industry. Wang et al [7-9] set up a pipe flow erosion-corrosion test ring, however, this kind of device is rarely used in actual experimental researches because of the large space, high cost and complex process. Some researches on erosion mechanism were investigated based on impingement experimental devices [10-12] but not pipe loops. In numerical simulation, Liu et al [13] verified that the flow induced corrosion process is mainly affected by electrochemical factors and the hydrodynamic factors have a serious effect on the flow induced corrosion process also. But, effect of flow on corrosion rate are still not well understood. Therefore, relation between the flow and corrosion obtained based on the experimental results will be a better basis for analyzing corrosion of water pipelines in petrochemical industry. In this paper, research on flow induced corrosion were carried out based on experimental results.
2. Corrosion mechanism for alloy pipelines
According to a case about leakage of a water pipeline in a petrochemical enterprise, the main corrosion formation mechanism of the inner wall was determined based on the medium components analysis. In the test, the analyzed water was obtained from the petrochemical station in Tianjin and the components are shown in Table 1. The main corrosion sensitive ions in the medium are Cl\(^{-}\) and SO\(_4^{2-}\) [14-16].

| Components of the water (mg/L) |
|-------------------------------|
| Ca\(^{2+}\) | Cl\(^{-}\) | Total iron | SO\(_4^{2-}\) | PH | Hardness | Basicity | CODcr | K\(^+\) |
| 45.9 | 54.8 | 0.02 | 102.2 | 8.01 | 249.5 | 105 | 7.715 | 4.64 |

During the test, two kinds of carbon steel materials obtained from petrochemical enterprises were selected. GB-X65 and GB-Q235 were used for specimen preparation. The chemical compositions are shown in Table 2 and Table 3 separately.

| Table 2. Chemical composition of X65 (mass percentage). |
|--------------------------------------------------------|
| C | Si | Mn | P | S | Ni | Cu | Mo | N | Nb | Al | Ti |
| 0.030 | 0.170 | 1.510 | 0.011 | 0.003 | 0.170 | 0.040 | 0.160 | 0.006 | 0.060 | 0.020 | 0.010 |

| Table 3. Chemical composition of Q235 (mass percentage). |
|--------------------------------------------------------|
| C | Si | Mn | P | S | Cu |
| 0.230 | 0.046 | 0.470 | 0.012 | 0.024 |

The main types of internal corrosion of water pipelines in petrochemical industry are chemical corrosion, electrochemical corrosion and erosion-corrosion. Corrosion occurs on the inner wall of pipelines because of the reaction between the metal of inner wall and corrosion sensitive ions (Cl\(^{-}\) and SO\(_4^{2-}\)), O\(_2\) and water in the transported medium. The reaction process are shown as follows:

\[
H_2O + O_2 + 4e^- \rightarrow 4OH^- \quad (1)
\]

\[
2Fe^{2+} + 4e^- \rightarrow 2Fe^{2+} \quad (2)
\]

Fe\(^{2+}\) are further oxidized and becomes into a stable form Fe\(^{3+}\), Fe(OH)_3, or Fe_2O_3 is formed through the hydrolysis process. In water pipelines, this kind of electrochemical corrosion is common and metal corrosion is more serious.

Additionally, scouring is a mechanical process on the inner wall of pipelines when the medium flowing at a certain velocity. The magnitude of scouring is related to the velocity of the flow, the change of the pipe geometry and the content of impurities such as solid particles in the medium.

3. Static corrosion test

3.1. Experiment design

Figure 1. Picture of the specimen for static corrosion test (Unit: mm).
In order to study the effect of the flow on corrosion, static corrosion test results of corresponding solutions and materials were analyzed. Specimens were prepared refers to the national standard for static corrosion test [17]. The size of the specimens are 50 mm × 25 mm × 3 mm, as shown in Figure 1.

The static corrosion test device is shown in Figure 2. During the test, specimens were suspended and immersed in the solution, which is configured according to the components analysis of the sampling water. For each group of tests, three pieces of specimens were set. The mass loss of specimens were weighed by a high-precision balance, and the corrosion rate was calculated according to equation (3) [17].

\[ R = \frac{8.76 \times 10^7 \times (m - m_t - m_k)}{S \times t \times \rho} \]  

Where, \( R \) is corrosion rate (mm/a), \( m \) is the original mass of the metal specimen (g), \( m_t \) is the mass of the corroded metal specimen (g), \( m_k \) is the compensation mass for pickling (g), \( S \) is the total surface area (cm²), \( t \) is the time for testing (h), \( \rho \) is the density of the material (kg/m³).

3.2. Results analysis

Pictures of corrosion surface of specimens immersed in the solution are shown in Figure 3. When the immersion time was short, local spot corrosion rusts occurred on the exposed specimen surface. After immersing for 5 days, a large flake rusts occurred on the surface of specimens, the loose brown corrosion products were more likely falling off the surface under the effect of gravity. After 7 days, obvious corrosion gullies occurred on the surface of specimens, and a large number of corrosion products attached on the surface.

The macro morphologies of Q235 specimen before and after derusting are shown in Figure 4, morphologies of X65 specimen are similar. The upper reddish brown rust layer on specimens is loose. A gray and white corrosion passivation layer is on the surface after removing the reddish brown rust layer. Under the passivation layer, there is a black rust layer on the surface which is tightly attached on the substrate.
The static corrosion rates of Q235 and X65 specimens are shown in Figure 5. The corrosion rates tend to be stable as the immersion time increases. When the immersion time is more than 7 days, the corrosion rates of the two kinds of specimens change a little, the average corrosion rate is about 0.09 mm/a.

![Figure 4. Macro morphologies of Q235 specimens in static corrosion tests.](image)

**Figure 4.** Macro morphologies of Q235 specimens in static corrosion tests.

![Figure 5. Static corrosion rates of Q235 and X65 specimens.](image)

**Figure 5.** Static corrosion rates of Q235 and X65 specimens.

![Figure 6. Schematic diagram of the simulating pipe loop.](image)

**Figure 6.** Schematic diagram of the simulating pipe loop.

### 4. Flow induced corrosion test

#### 4.1. Experiment design

A simulating pipe loop was designed for flow induced corrosion experiments, the schematic diagram is shown in Figure 6. During the test, specimens installed in the laboratory module were the same as used in static corrosion tests. In order to set the flow velocities range from 0 to 2.5 m/s during the test, the diameter of the laboratory module was designed to be 67 mm.

In order to simulate the flow induced corrosion on the inner wall of the pipelines, the laboratory module was designed to install specimens as shown in Figure 7. The size of the laboratory module was designed according to the specimens and the simulating pipe loop. During the test, the specimens were embedded in the inner surface of the laboratory module at 120° direction separately. For each type of tests, three specimens were set for flow induced corrosion tests.

![Figure 7. Picture of the laboratory module.](image)
4.2. Results analysis

4.2.1. Corrosion morphology

The macro morphologies of the specimen surfaces are compared in Figure 8 and Figure 9. Obvious corrosion occurs on the surfaces of the two kinds of materials, the specimen surfaces are covered by a larger corrosion layer in static corrosion tests. The scouring traces along the flow direction on the specimens in flow induced corrosion tests are clear, the medium flowing causes the corrosion layer falling off the surfaces.

![Figure 8. Macro morphologies of X65.](image)

![Figure 9. Macro morphologies of Q235.](image)

The corrosion products are mainly separated into two layers. The bottom corrosion products are black which are closely combined with the base metal, the upper corrosion products are reddish brown and loose which are more likely falling off under the effect of scouring and gravity. In the static corrosion test, the loose corrosion products on the surface of specimens are easy to be removed. In the flow induced corrosion test, the corrosion layer is black and closely attached, because the loose corrosion productions has fallen off due to the scouring effect of the flow.

The micro morphology of Q235 and X65 specimens in static corrosion tests and flow induced corrosion tests were observed by SEM (scanning electron microscope). According to Figure 10 and Figure 11, corrosion pits occurs on the surface of specimens in static corrosion tests, the surface is relatively smooth in the flow induced corrosion test. Similar to the macro morphology, there are scouring traces along the flow direction on the surface of specimens in flow induced test. The medium flowing enhanced corrosion by removing corrosion productions from the surface of specimens continuously.

![Figure 10. Micro morphology of Q235 specimens.](image)

![Figure 11. Micro morphology of X65 specimens.](image)
4.2.2. Flow induced corrosion rate

Corrosion rates for static corrosion tests and flow induced corrosion tests are compared in Figure 12, where the flow velocity is 2 m/s in flow induced corrosion tests. The flow induced corrosion rates of Q235 and X65 are significantly higher than those of static corrosion, they are about 14 to 15 times of those in static corrosion tests. It is obviously that media flowing has a great effect on corrosion rates.

![Figure 12. Corrosion rates comparison of Q235 and X65 in static and flow induced corrosion tests.](image1)

![Figure 13. Corrosion rates of Q235 and X65 in flow induced corrosion tests.](image2)

4.2.3. Effect of velocity on flow induced corrosion

The velocities of the flow induced corrosion tests were set as 0.5 m/s, 1 m/s, 1.5 m/s, 2 m/s and 2.5 m/s to study the effect of flow velocity on corrosion rate. The corrosion rates of different tests are shown in Figure 13. Corrosion rates of the specimens increase as velocity of the flow increases. When the velocity reaches 1.0 m/s, the corrosion rate tends to be stable. When the velocity is higher than 1.5 m/s, the corrosion rates change more obvious than those under low velocities. When the velocity is low, the flow enhances the mass transfer process for corrosion, higher speed would cause more corrosion. The acceleration comes slow when the mass transfer process reaches a balance at the velocity of 1.0~1.5 m/s. When the velocity becomes higher, corrosion rates increase more serious for the scouring effects more on the flow induced corrosion. Corrosion products are easy falling off the surface of the specimens under high velocity of the flow to expose the new base metal in the media, which accelerates the mass loss of the specimen. Therefore, a balance point of velocity for corrosion accelerating could be obtained. Combining with the pipeline transportation efficiency and flow induced corrosion, a better flow velocity could be determined to minimize the inner corrosion of pipelines.

5. Conclusions

According to the static and flow induced corrosion test results, effect of flow on corrosion rate was analyzed. The main conclusions are shown as follows:

1. The corrosion layers on the surface of Q235 and X65 are mainly separated into two layers. The bottom layer is composed with black corrosion products which are closely attached to the base metal and are not easy falling off. The upper layer is composed with reddish brown loose corrosion products which are more likely falling off under the effect of flow and gravity.

2. Obvious scouring traces along the flow direction on the surface of specimens could be observed in micro and macro morphologies of flow induced corrosion tests. Loose corrosion products on the surface are easy falling off the surface as the media flowing. Thus, black corrosion products are observed on the surface of specimens in flow induced corrosion tests.

3. The fluid media would accelerate the corrosion of the steel pipelines. When the velocity was 2 m/s in tests of this paper, the corrosion rates are about 14 to 15 times of those of static corrosion tests.

4. According to the flow induced corrosion test results, corrosion rates of the two kinds of specimens increase as the velocity of flow increase. When the velocities reached 1 m/s, the change of
corrosion rates tends to be stable due to the effect of medium transfer. Effect of velocity on corrosion should be taken into consideration while velocity design of water pipelines in petrochemical industry to reduce the possible corrosion on the wall.

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