Study on aerobic corrosion characteristics of gas injection pipe wall in oil field under dry / wet interaction condition

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Abstract: By studying the corrosion behavior of oilfield pipelines in different oxygen content and corrosive medium under simulated ambient air/air foam flooding environment, the dry/wet interaction between the surface and the interface of the service casing is caused by the air displacement/air foam flooding, which greatly aggravates the aerobic corrosion process. The corrosion process changed from localized corrosion to uniform corrosion with the increase in dry and wet cycles. Pitting corrosion occurs in the early stages of dry and wet cycles, and the increase in chloride concentration and oxygen content will accelerate the initiation and development of pitting.

1. Introduction
As a new technology of low permeability unconventional oil and gas reservoir development, oxygen-reduced air flooding has obvious advantages of easy injection, sufficient gas source, low cost and environmental protection, and has been widely used in China and abroad. However, in the field of industrial operation of oxygen reduction and air flooding, different technologies such as gas liquid injection and gas / liquid / foam alternately injection are usually adopted to improve the injection efficiency and improve the recovery efficiency of target reservoirs. The surface interface of gas injection pipeline will be affected by dry / wet interaction during the implementation of oxygen injection and oxygen reduction air drive with different processes. Under the dry / wet interaction environment, the aerobic corrosion process, the mechanism of aerobic corrosion and the influence on the aerobic corrosion rate of the gas injection pipeline after contact between oxygen and water are the major problems to be solved urgently. For this purpose, the characteristics of the dry / wet interaction oxygen corrosion of the injected gas pipeline were studied under different gas injection processes (gas liquid simultaneous injection and gas / liquid / foam alternate injection).

2. Experiment

2.1. Experimental materials
In the experiment, the produced water of target reservoirs is injected with deoxidized air, and the deoxidized air with different oxygen content (oxygen content is 3%, 5%, 10%, 15%) as gas medium. The corrosion test material is P110 pipeline steel. The concentration of chloride ion in corrosion medium is 100 mg / L, 500 mg / L and 1000 mg / L.

2.2. Dry / wet interaction experiment steps
(1) P110 steel samples were processed into corrosion coupon samples. The samples were grinded into mirror surfaces with different types of abrasive cloth, such as 50 mm, 100 mm, 200 mm and 500 mm, respectively. The surface was cleaned and degreased with acetone;
(2) 40 μL/cm² of liquid phase corrosion medium was added and spread evenly on the surface of the treated P110 steel sample;

(3) Place P110 steel sample in step 2 in a vacuum drying oven, set the temperature at 30°C, and vacuum for 1 hour to make it dry;

(4) The treated P110 steel sample is placed in a constant temperature and humidity chamber for 12 h. The temperature in the test chamber is 30 °C, and the relative humidity is 85%. The oxygen content in the constant temperature and humidity chamber is controlled by the flow rate of N2 and O2. This is the wet state test;

(5) After the wet state test, adjust the relative humidity of constant temperature and humidity box to 60%, and keep it for 12 h, which is the dry state test;

(6) The treated P110 steel sample was used as the working electrode, and the electrochemical test was carried out with three electrode system. The above test cycle is one cycle;

(7) Repeat steps 2 and 4 until the set number of dry/wet alternations (7 times in this test).

2.3. Electrochemical testing

The conventional three electrode system was used for electrochemical tests. The working electrode was a P110 steel sample which was after a dry and wet cycle, the auxiliary electrode was a large area of the Pt sheet, the reference electrode was saturated with calomel electrode. In the electrochemical noise (EN) test, the scanning frequency is set at 4 Hz \[^3\], and the test time of a single dry wet cycle is 20 min. The diagram of the electrochemical test device is as follows:

![Diagram of in situ tracking electrochemical evaluation device for dry wet interactive aerobic corrosion. (1-auxiliary electrode wire; 2-reference electrode salt bridge; 3-platinum sheet auxiliary electrode; 4-sce reference electrode; 5-rubber gasket; 6-P110 working electrode of oil casing steel sample)](image)

3. Results and Discussion

3.1. Effect of oxygen content on Corrosion Behavior of gas injection pipeline surface interface under dry/wet interaction environment
According to the analysis of electrochemical noise data on Fig. 2, under the conditions of 3%, 5%, 10% and 15% oxygen content, the electrode potential tends to move forward as a whole with the increase in cycle times, which is related to the formation of corrosion products on the surface of P110 steel samples.

According to the analysis of electrochemical noise data, with the increase of cycle times, the electrode potential tends to move forward with the increase of 3% oxygen content, which is related to the formation of corrosion products on the surface of P110 samples. In order to further analyze the corrosion type and evolution process of the P110 sample, the electrochemical noise data were analyzed by wavelet transform.

In order to quantitatively evaluate the relationship between characteristics and corrosion rate and corrosion severity of carbon steel in different concentrations of Cl - solution, the energy distribution map of initial 2048 point was analyzed by using fourth-order (DB4) fast wavelet transform (FWT). The total energy (E) of the noise with 2048 data points in the experiment is calculated by the following equation [4]:
\[ x(t) \approx \sum_k S_{j,k} \varphi_{j,k}(t) + \sum_k D_{j,k} \varphi_{j,k}(t) + \sum_k D_{j-1,k} \varphi_{j-1,k}(t) + \cdots + \sum_k D_{1,k} \varphi_{1,k}(t) \] 

\[ S_{j,k} = \int x(t) \varphi^*_j(t) dt \] 

\[ D_{j,k} = \int x(t) \varphi_j(t) dt \] 

\[ \varphi_{j,k}(t) = 2^{-j/2} \varphi(2^{-j}t - k) = 2^{-j/2} \varphi\left(\frac{t-2^j k}{2^j}\right) \] 

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\[ E = \sum_{n=1}^{N} S_n^2 (n = 1, 2, \ldots, N, N = 2048) \] 

Then, the energy fraction associated with each crystal (D and S) can be calculated:

\[ E^D_l = \frac{1}{E} \sum_{k=1}^{N/2} D_{j,k}^2 (l = 1, 2, \ldots, J, J = 8) \] 

\[ E^S_J = \frac{1}{E} \sum_{k=1}^{N/2} S_{j,k}^2 (l = 1, 2, \ldots, J) \] 

Since the selected wavelet is orthogonal, the following equation is satisfied:

\[ E = E^S_J + \sum_{l=1}^{J} E^D_l \] 

According to the calculated relative energy distribution spectrum, D1 and D3 correspond to high-frequency reaction events, that is, rapid metastable state pitting corrosion and nucleation process; D4 and D6 correspond to the corrosion point and grain growth process; D7 and D8 are slowly reaction diffusion processes.

Fig. 4 wavelet analysis results of electrochemical noise of 3% oxygen content

As shown on Fig. 4, when the number of cycles is small, the energy of P110 sample corrosion process is concentrated in the low-order high-frequency region, that is, the pitting corrosion process characterized by fast reaction. With the increase in the number of cycles, the relative energy gradually moves to the high-order low-frequency direction, which indicates the diffusion of slow reaction and other steps \(^{15}\). The results show that the corrosion behavior in the initial stage is the initiation and development of pitting corrosion, in the later stage it evolved into uniform corrosion and the corrosion process is affected by the diffusion of chloride ions through the corrosion product film to the metal surface.
As shown on Figure 5, under the condition of 5% oxygen content, the relative energy in the relative energy spectrum obtained by wavelet analysis is mainly concentrated in the high-order and low-frequency parts, that is, the diffusion of slow reaction and other steps.

As shown on Figure 6, under the condition of 10% oxygen content, the relative energy in the relative energy spectrum obtained by wavelet analysis is mainly concentrated in the high-order and low-frequency parts, that is, the diffusion of slow reaction and other steps.

As shown on Figure 7, under the condition of 15% oxygen content, the relative energy in the relative energy spectrum obtained by wavelet analysis is mainly concentrated in the high-order and low-frequency parts, that is, the diffusion of slow reaction and other steps.

In order to further characterize the corrosion behavior of carbon steel by electrochemical noise technology, we established the following formula based on the results of wavelet analysis [6]:

\[ C_{AE} = E_{d1} + E_{d2} + E_{d3} + E_{d4} + E_{d5} + E_{d6} \]

\( E_{d1} + E_{d2} + E_{d3} \) is the total energy between D1 and D3, \( E_{d4} + E_{d5} + E_{d6} \) is the total energy between D4 and D6, and \( C_{AE} \) is the total energy of nucleation and growth process, which is used to characterize the electrochemical reaction rate.
It can be seen from Fig. 8 that the change rule of $\text{CAE}$ with immersion time is different in different corrosive media with different oxygen content. In general, $\text{CAE}$ increased slowly with immersion at first, and then decreased slowly in the later stages. When the oxygen concentration was low (3%), $\text{CAE}$ value reached the maximum value on the fifth day, and then decreased slowly. With the increase in oxygen content (15%), $\text{CAE}$ value reached the maximum value on the second day of the test, and then slowly decreased to a stable state. Generally speaking, with the increase in oxygen content, the anodic reaction rate increases, and the $\text{CAE}$ value which characterizes the electrochemical reaction rate also increased. However, with the formation of the corrosion products of iron hydroxide, the corrosion reaction is inhibited by the film on the surface. As a result, the corrosion rate of local points decrease, which lead to a slow decrease in $\text{CAE}$ value.

3.2. Effect of chloride concentration on Corrosion behavior of gas injection pipeline surface interface under dry / wet interaction environment

As shown on Figure 9, when the chloride ion concentration is 500 mg / L, with the increase in cycle times, the electrode potential moves forward from -0.66 V on the first day to -0.52 V, which is related to the formation of corrosion film on carbon steel surface.
Fig. 10 wavelet analysis results of electrochemical noise with chloride concentration of 500 mg/L

As shown on Figure 11, when the chloride ion concentration is 1000 mg/L, the electrode potential has no obvious change with the increase of cycle times.

Fig. 11 electrochemical noise test with chloride concentration of 1000 mg/L

As shown on Figure 12, under the condition of chloride ion concentration of 1000 mg/L, at different test times, the relative energy in the relative energy spectrum obtained by wavelet analysis sometimes concentrated in the low-order high-frequency part, sometimes concentrated in the high-order low-frequency part, and there was no obvious change.

Fig. 12 wavelet analysis results of electrochemical noise with chloride concentration of 1000 mg/L
It can be seen from figure 6.26 that $C_{AE}$ shows a different change trend with immersion time under different corrosive medium concentration. When the concentration of corrosion medium is low, $C_{AE}$ increases slowly with the immersion time, and becomes stable at the later stage. When the concentration is high, $C_{AE}$ first increases with soaking time, then decreases slowly, and finally reaches a stable level. It is known that chloride ion is easy to cause local corrosion of metal materials due to its small particle size and characteristic absorption, thus increasing the corrosion rate of anode point. With the increase in Cl$^-$ concentration, we can find that when the maximum value of $C_{AE}$ appears gradually approaching to a short time, which indicates that the initial point corrosion behavior is severer, and with the extension of immersion time, due to the formation of corrosion products covering the carbon steel, it shows that the corrosion behavior of carbon steel gradually changes to uniform corrosion, leading to the slow decrease of $C_{AE}$ value.

4. Conclusion

(1) The dry / wet interaction between the surface of the casing and the service surface caused by the oxygen reduction air flooding / air foam flooding greatly aggravates the aerobic corrosion process. With the increase in dry and wet cycles, the relative energy of electrochemical noise data obtained by wavelet analysis changes from the initial concentration in the low-order high-frequency region to the high-order low-frequency region, indicating that the corrosion process changes from local corrosion to uniform corrosion.

(2) With the increase in chloride concentration in the corrosive medium, the number of cycles required to reach the maximum value of the electrochemical noise activity energy parameter $C_{AE}$ decreases gradually. Moreover, with the increase in oxygen content during the dry/wet cycle, the electrochemical noise activity energy parameter $C_{AE}$ shows the same rule. This indicates that pitting corrosive occurs at the beginning of the wet/dry cycle, and the increase in chloride ion concentration and oxygen content will accelerate the initiation and development of pitting corrosion.

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