Study on Corrosion Prevention and Treatment in Long-Distance Oil and Gas Pipeline

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Abstract. The use of oil pipelines has become increasingly prominent. The corrosion of buried pipelines seriously affects their service life and quality of oil transported, and even causes leakage and pollution of the environment. Through the analysis of the corrosion mechanism of metal pipeline, this paper understands the causes of corrosion and puts forward effective protection measures.

1. Introduction
Gathering pipeline is an indispensable part in the process of oil and gas transportation, which has an important impact on the effect of oil and gas transportation. Therefore, when the problem of corrosion on the inner wall of the gathering pipeline appears, it is necessary to take timely measures to control the corrosion on the inner wall of the pipeline, to reduce the adverse impact of corrosion on the inner wall of the pipeline.

During the exploitation and gathering of natural gas wells and oil wells containing large amounts of CO₂, condensate oil, H₂S and brine in gas fields, serious corrosion exists in oil and casing wellhead devices of oil and gas wells. The accidents caused by the failure of wellhead device, the breakage of gate screw rod, the perforation of oil casing and the explosion of gathering pipeline, etc. Because the medium of oil and gas gathering and transportation pipeline is gas, water, hydrocarbon and solid coexisting multi-phase flow medium, especially in the later stage of oil and gas field development, water content of transportation medium increases due to water injection, which aggravates the corrosion in pipeline [1]. Therefore, the internal corrosion mechanism and technology of oil and gas gathering and transportation pipelines have attracted extensive attention of field and relevant anti-corrosion research institutions, and have increasingly become a hot spot and focus of research.

The corrosion media in oil and gas gathering pipeline are CO₂, H₂S, O₂, Cl⁻ and water. Among them, Cl⁻ is the catalyst, CO₂, H₂S, O₂ is the corrosive agent, and water is the carrier and solvent. Therefore, the internal corrosion study of oil and gas gathering pipelines should focus on the influence of CO₂, H₂S corrosion, O₂ and Cl⁻ on H₂S corrosion and CO₂ corrosion under high temperature and high pressure.

2. Factors affecting corrosion of oil and gas pipelines

2.1. Environmental factors
The corrosion of high-strength long-distance oil and gas pipelines can be divided into seawater corrosion, soil corrosion and atmospheric corrosion. Because most of the land pipelines are laid underground, soil corrosion has become the most important factor affecting the safety of pipeline
operation. PH value, temperature, microorganism and carbon dioxide concentration are the factors that influence the pipeline corrosion. Among them, there are many studies on the pH factors, but the temperature factors have no qualitative impact on the amount of pipeline corrosion, so the environmental factors discussed in this paper are microorganisms and carbon dioxide concentration. Because oil and gas pipelines are buried underground for a long time, microorganisms, including bacteria and fungi, inevitably exist under the anti-corrosion coating, and microbial corrosion will accelerate the corrosion rate of pipelines. This is mainly because microorganisms contain anaerobic sulfate reducing bacteria, SRB. Under SRB environment, cracks will appear in the dense products due to its activity, and sulfide will be produced by its metabolism, thus causing pipeline corrosion. Moreover, the activity of SRB will also result in the decrease of soil pH, the change of corrosive product structure on the surface of pipeline, and the change of corrosive product resistance under SRB environment, so the corrosion rate of pipeline is difficult to slow down.

2.2. Pipeline Operation Parameters
The flow rate of oil and gas resources in pipelines is proportional to the corrosion rate of pipelines. When the flow rate of oil and gas resources is accelerated, the exchange rate of corrosive reactants on pipeline surface itself will be accelerated, and the formation of corrosion protective film will be prevented. The results show that the corrosion rate of pipeline will increase at least twice when the flow rate becomes 0.742 m/s, and 10 times when the flow rate becomes 1.484 m/s. When the flow rate of oil and gas resources increases, the corrosion of pipeline will change from uniform corrosion to local corrosion. When the flow rate of oil and gas further accelerates, the corrosion of pipeline will change from local corrosion to uniform corrosion.

The higher the grade of steel and steel used in oil and gas pipelines, the better the economy of oil and gas transportation. The larger the transportation volume of oil and gas pipelines, the higher the pressure of pipelines, the better the economy. However, when the pressure passes through the pipeline, the corrosion rate will change. Under the great pressure, especially under the pressure, the pipeline cracks will continue to expand, and eventually there will inevitably be very serious accidents. Therefore, the study of pipeline transportation pressure is also very important [2].

Welding technology is used for long distance pipeline connection. Because steel must undergo relatively complex treatment during welding, the mechanical properties of weld zone will change unevenly. In the weld area, there are minor defects, which lead to the weld area is more likely to be corroded, so the weld area is also the cause of pipeline oil and gas leakage.

3. Reasons for Serious Corrosion on the Inner Wall of Oil and Gas Pipeline

3.1. Corrosion of H2S on Oil and Gas Gathering and Transportation Pipeline
H2S corrosion is a common cause of corrosion in the process of inner wall corrosion of gathering and transportation pipelines. When H2S and other gases are dissolved in water, a weak acidic solution will be produced. In the process of dissolution, more products, such as HS−, S2−, will be produced. These products will adhere to the inner metal of the pipeline, and then produce a combination reaction to form Fe (HS)−. In this chemical reaction process, the metal surface will show negative potential, which accelerates the cathodic reaction speed and increases the corrosion ability of the metal. After being corroded by H2S, the metal will become more hydrogen brittle, and hydrogen ions will swim around the metal atoms, thus forming hydrogen molecules, which will cause more intense corrosion of the metal, resulting in serious corrosion of the inner wall of the gathering pipeline. The relevant chemical formulas are as follows:

\[ \text{H}_2\text{S} \rightarrow \text{H}^+ + \text{HS}^- \quad \text{(Hydrolysis reaction)} \]  
\[ \text{HS}^- \rightarrow \text{H}^+ + \text{S}_2^- \quad \text{(Hydrolysis reaction)} \]
\[2H^++Fe\rightarrow Fe^2+H_2↑\] (displacement reaction) \hspace{1cm} (3)

At the same time, \(H_2S\) reacts with metal (containing iron) in the presence of oxygen. At this time, the metal material will lose its original metal properties. The relevant ionization equation is as follows:

\[2Fe+2H_2S+O_2\rightarrow 2FeS+2H_2O\] \hspace{1cm} (4)

\[4Fe+6H_2S+3O_2\rightarrow 2Fe_2S_2+6H_2O\] \hspace{1cm} (5)

\[S+2O_2\rightarrow H_2SO_4, Fe+H_2SO_4\rightarrow FeSO_4+H_2↑\] \hspace{1cm} (6)

3.2. Corrosion of \(CO_2\) on Oil and Gas Gathering and Transportation Pipeline

\(CO_2\) is an important part of the air. In the gathering pipeline, the air cannot be removed clean. \(CO_2\) in the air will be in contact with the inner wall of the pipe made of metal. In this process, carbon dioxide will dissolve in water, ionize \(HCO_3^-\), \(CO_3^{2-}\) two negative ions, and then release \(H_2\). When the concentration of \(CO_2\) in the air decreases and hydrogen increases, the corrosion of the inner wall of the gathering pipeline composed of metals becomes more serious.

\[CO_2+H_2O\rightarrow H_2CO_3\] (hydrolysis reaction) \hspace{1cm} (7)

\[H_2CO_3\rightarrow H^++HCO_3^-\] (hydrolysis reaction) \hspace{1cm} (8)

\[HCO_3^-\rightarrow H^++CO_3^{2-}\] (hydrolysis reaction) \hspace{1cm} (9)

\(H_2CO_3\) is a weak acidic substance. Its main question is to produce hydrolysis reaction, which results in the decrease of pH in the pipeline and the ionization reaction of Fe in the pipeline.

\(Fe + H_2CO_3\rightarrow FeCO_3+H_2↑\) (displacement reaction)

\(CO_2\) causes pit corrosion or flake corrosion, which often occurs slowly over time.

3.3. Erosion of Fluid Medium

The erosion action of the fluid medium in the pipeline consists of three parts: the first part is only erosion wear. The second part is the abrasion of liquid to pipeline. In the third part, the solid particles in the gas correspond to the abrasion of the material. These three parts constitute the multi-phase flow of pipeline erosion [3]. The existence of multi-phase flow includes fluid, gas, debris, solid particles and so on. This multi-phase erosion occurs in the corrosive environment of pipeline. The combination of corrosion and erosion is called erosion corrosion. This effect is very complex. Droplets, bubbles and impure objects (solid particles) in oil and gas in pipelines will have cumulative impact on the inner wall of pipelines, and directly affect the inner surface of pipelines, resulting in new wear and tear.

4. Corrosion Prevention Measures for Internal Wall Corrosion of Long-distance Oil and Gas Pipeline

4.1. Corrosion Control by Internal Coating

Corrosion of gathering pipeline is a very serious problem, which must be solved in order to ensure the safety of oil and gas transportation. In the process of solving the corrosion problem of pipeline inner wall, the way of inner coating can be adopted. The so-called inner coating means that a layer of medium is applied to the inner wall of the pipeline to isolate the corrosion source and the inner wall of the pipeline, to ensure that the probability of corrosion of the inner wall of the pipeline is reduced. The epoxy powder can be coated during the application of the inner coating method. Epoxy powder can prevent oxygen from corroding the inner wall of pipeline. In the process of coating, in order to ensure the effect of coating, the coating solidification method and plastic pipe insertion method should be
applied reasonably to ensure the effectiveness of coating, so as to reduce the damage of corrosion on the inner wall of pipeline, ensure the normal application of the inner wall of gathering pipeline and stable and safe transportation of oil and gas.

Common anti-corrosion technologies for oil and gas pipelines include the following: first, pipeline materials with strong corrosion resistance must be selected, which is the way to reduce the corrosion rate of pipelines from the root [4]. Commonly used corrosion-resistant materials are stainless steel and alloy materials. The common corrosion-resistant non-pipeline metal materials are plastics, ceramics and plastics, among which plastics are the best, with strong corrosion resistance and low production cost. Secondly, adding appropriate corrosion inhibitors in advance in oil and gas resources can help to form a protective film on the inner surface of pipelines, which can reduce the corrosion rate of pipelines. The advantage of using this method is that it is economical, environmentally friendly and easy to operate without additional equipment.

4.2. Corrosion Control by High Density Polyethylene Pipeline Repair Method

It is also a good method to lay coating on the inner surface of pipeline. After adding coating on the inner wall of pipeline, it can not only protect pipeline, but also reduce the roughness of pipeline, so that the flow friction coefficient of oil and gas will be reduced, thus effectively reducing the cost of oil and gas transportation. In addition, lining technology can be adopted, such as rubber lining technology, FRP lining technology and plastic lining technology [5].

High density polyethylene (HDPE) pipeline repair method can be used in the process of controlling the inner wall corrosion of gathering pipeline. When the inner wall of the gathering pipeline is corroded, in order to ensure the safety of oil and gas transportation, it is necessary to replace the pipeline, but the replacement of the pipeline is a cost-consuming and complex work, so after eliminating this method, it is necessary to carry out corrosion control through pipeline repair [6]. In the process of pipeline repairing, high density polyethylene (HDPE) pipeline interpolation technology can be used to insert the pipe with larger outer diameter than inner diameter into the main pipe, and then the HDPE pipe with 24 h memory function can be restored to its original diameter, thus realizing the pipeline repairing. The pipeline repair method can control the corrosion of the inner wall of the pipeline, and the high-density polyethylene pipeline is not rusty and corrosion-resistant, so the pipeline is better for oil and gas transportation.

4.3. Control of corrosion by cathodic protection

Cathodic protection is currently recognized as an economical and effective Anti-corrosion Measure at home and abroad. There are two kinds of cathodic protection systems: applied current and sacrificial anode.

The basis for using applied current or sacrificial anode: The size and geometry of the project. External current is generally used in larger projects, and sacrificial anode is suitable for complex protected metal structures. The conductivity of dielectrics. In the medium with low conductivity, the applied current is usually used. In stray current area, sacrificial anode should not be used when there is a significant fluctuation of tube-to-ground potential. The possibility of replacement of sacrificial anode. If the replacement of sacrificial anode is convenient, sacrificial anode should be chosen, otherwise, the applied current should be chosen. When both methods are applicable, a comprehensive techno-economic analysis should be conducted to determine which system to choose. Main objectives of cathodic protection system design: Provide enough protective current for the protected metal and make the distribution of protective current achieve ideal protective effect. To minimize the interference to adjacent underground metal structures. The life of the cathodic protection system designed should be consistent with that of the protected metal. Anode devices should be located where they are not susceptible to interference and damage.

The cathodic protection method can be used to control the inner wall corrosion of gathering pipeline. The application of cathodic protection can be divided into sacrificial cathode method and forced current method. Gathering pipeline exists in the form of sealing, so in the application of
cathodic protection method, the influence of closed environment should be considered [7]. In the process of cathodic protection, oxygen and hydrogen will be generated. Oxygen and hydrogen dissolved in water will cause corrosion on the inner wall of pipeline. Therefore, in the process of cathodic protection, the consumption rate of magnesium anode should be considered. On this basis, the electrical insulation of the inner wall of pipeline should be considered. In a word, the application of cathodic protection method is conditionally limited, so in the process of practical application of this method, we need to consider many aspects before applying it.

5. Conclusion
Because there are many factors leading to corrosion in pipelines, there are many types of corrosion, including uniform corrosion, pitting corrosion, pitting corrosion and stress corrosion. When choosing internal anti-corrosion technology, we can synthetically compare the anti-corrosion effect, cost and construction difficulty with specific conditions. For example, the common metal corrosion-resistant material is alloy steel, but its production process is relatively complex and high cost, so non-metallic pipeline materials with strong corrosion resistance can be selected, such as plastic materials with strong corrosion resistance and relatively low cost. When adding corrosion inhibitors, attention must be paid to the quantity control, because the increase of concentration will reduce the flow of oil and gas, resulting in poor corrosion resistance. When laying inner coating, economic and technically feasible inner coating materials should be selected according to the characteristics of pipeline corrosion. In summary, internal corrosion protection technology is a major direction of future pipeline corrosion protection research. In application, new pipeline corrosion protection technology with high efficiency, low cost, low construction difficulty and pollution-free should be selected according to specific conditions.

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References
[1] Jiang Z P, Song X Y, He Y H, et al. Study application environment and corrosion resistance of PHC pipe pile. Constr. Technol., 2011, 40(7): 38
[2] Choi Y S, Shim J J, Kim J G. Effects of Cr, Cu, Ni and Ca on the corrosion behavior of low carbon steel in synthetic tap water. J. Alloys Compd., 2005, 391(1/2): 162
[3] Goh J H, Shaw A, Cullen J D, et al. Water pipe leak detection using electromagnetic wave sensor for the water industry. Computers & Informatics (ISCI). UK: 2011: 290
[4] Safuzzadeh M S, Azizzadeh T. Corrosion detection of internal pipeline using NDT optical inspection system. NDT & E Int., 2012, (52): 144
[5] Ma S J, Jia H W, Li F W, et al. Treatment of steel rolling oily wastewater: Performance of a CTAB modified resin fixed column. Appl. Mech. Mater., 2010, (44-47): 2121
[6] Bahadori A, Zeidani K. Predicting scale formation in wastewater disposal wells of crude-oil desalting plants [J]. Petro. Coal, 2012, 54(2): 143
[7] Robin E J, Francesco S, Michael J S, et al. Use of microwaves for the detection of water as a cause of corrosion under insulation. J. Nondestr. Eval., 2012, 31(1): 65