Countermeasure Research on Corrosion and Perforation in Changning Shale Gas Collecting Pipeline

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Abstract

During the development of the Changning shale gas field in Sichuan, the gathering and transportation system faced problems such as erosion corrosion and electrochemical corrosion. With the increase of gas field development time, different levels of corrosion and perforation have occurred in the gathering pipelines of Changning shale gas field. Corrosion control has gradually become the key to the safe development of shale gas. Through the analysis of the failed pipeline section of the Changning shale gas field, for the corrosion and perforation of the gathering pipeline in the Changning shale gas field, methods such as pipe selection, corrosion inhibitor injection, chemical sterilization program, pigging program, corrosion monitoring and other methods can be used as Changning Page Provide reference for the protection of rock gas gathering pipelines.

Keywords

Shale Gas, Perforation Corrosion, Corrosion Factors, Countermeasures.

1. Introduction

With the increasing demand of the global natural gas market, countries around the world are paying more and more attention to the development and utilization of unconventional natural gas, especially shale gas. At present, my country is conducting a resource evaluation of shale gas nationwide. It is expected that by the end of 2020, 30 billion cubic meters of shale gas production capacity will be formed nationwide. The temperature in the shale gas pipeline will decrease, and water and heavy hydrocarbons in the transmission medium will precipitate out, which will accumulate in the low-lying areas of the pipeline or uphill sections. Shale gas contains highly corrosive media such as CO2 and SRB, which uses condensed water as a carrier, which aggravates the electrochemical corrosion in the pipe, causing corrosion and perforation of the pipeline and affecting the normal production of the gas field. Therefore, this work has conducted a detailed study on the transport medium, pipeline material and corrosion products of the Changning gas gathering pipeline. Finally, according to the characteristics of corrosion perforation in the Changning shale gas field, corresponding corrosion control countermeasures are proposed [1].

2. Current status and development trend at home and abroad

The surface gathering and transportation system of the Changning shale gas field adopts the "wet gas transportation and centralized dehydration" gathering and transportation process. The medium, flow and working conditions in the gathering and transportation pipeline are complicated. Corrosion and perforation have become the main reason for threatening the safe operation of the pipeline. The gas-liquid medium containing carbon dioxide and produced water (produced liquid) is transported in the ground gathering and transportation system, and the corrosion damage to carbon steel and low alloy steel is mainly manifested in the following types:

(1) Electrochemical corrosion (uniform corrosion / pitting corrosion) caused by CO_2, Cl- and other corrosive media;

(2) Microbial corrosion caused by anaerobic sulfate reducing bacteria (SRB) and aerobic iron oxidizing bacteria (IOB);

(3) Corrosion under the scale caused by the deposition of sand or corrosion products at the low points or dead points of the pipeline or equipment.

2.1 Research Status of Main Control Factors of Internal Corrosion

2.1.1 CO_2

After CO_2 is dissolved in water, the total acidity is higher than hydrochloric acid at the same pH value, so the corrosion of steel is very serious. There are various forms of CO_2 corrosion damage, either full-scale corrosion of steel that is damaged uniformly over all or a large area, or partial damage to the local area of the steel while the rest is not corroded or only slightly corroded . The destruction of CO_2 local corrosion mainly manifests as perforation and damage. The most common types are pitting, platform erosion, and flow-induced local corrosion. Uniform corrosion and localized corrosion are common in the development of oil and gas fields, but localized corrosion is often the most fatal form of failure of oil and gas field equipment and tubing. CO_2 corrosion always has both uniform corrosion and local corrosion under the typical corrosion product film. Since metal equipment is mostly terminated due to local corrosion perforation and fracture, and the wall thickness has not been seriously reduced at this time, in recent years, the characteristics of local corrosion have generally been used to evaluate and predict CO_2 corrosion in oil and gas wells and gathering and transportation pipelines.

2.1.2 Cl^-

It is generally believed that the effects of chloride ions on corrosion are mainly divided into two aspects: on the one hand, the presence of chloride ions makes it difficult to form a passivation film, even if the formed passivation film may be damaged, thereby forming a large cathode and a small anode Situation, causing local corrosion. On the other hand, the chloride ion will slow down the corrosion when the concentration is relatively high. It is due to the adsorption competition between the chloride ion and oxygen, which causes the position of the metal surface oxygen to be replaced by the chloride ion, and when the chloride ion concentration is large, the solution The dissolved oxygen will be reduced, thereby slowing the corrosion. Zhang Yu and others studied the corrosion behavior of 304L stainless steel under the action of Cl^- and found that due to the presence of Cl^-, the destruction of the stainless steel metal's passivation film will inevitably lead to the acceleration of the ion diffusion rate during the corrosion process, and Cl^- has a significant passivation effect on it .

2.1.3 Microorganism

Microbial corrosion is mainly caused by anaerobic sulfate reducing bacteria (SRB) and aerobic iron oxidizing bacteria (IOB). Under actual working conditions, most of these two microorganisms accelerate the corrosion of engineering materials through a synergistic effect. IOB consumes oxygen in the medium to create a suitable growth environment for anaerobic SRB and promote SRB corrosion to the substrate. Microbial corrosion is closely related to the biofilm formed by microorganisms on the surface of carbon steel. SRB is widely found in oil field gathering pipelines and other anaerobic environments. Therefore, the research on the corrosion and control of carbon steel under SRB biofilm has been paid much attention. The corrosion of carbon steel by SRB is closely related to the formation of biofilm. Some studies have shown that with the growth cycle of SRB, the roughness and heterogeneity of SRB biofilm on the surface of carbon steel are increasing [2].

SRB can reproduce in large quantities under anaerobic conditions, producing a large amount of mucous extracellular polymer (EPS), forming a thick layer of biofilm scale on the inner wall of the pipeline, causing blockage of the water injection pipeline, and causing severe local corrosion in the pipeline facility . Studies have shown that low-concentration EPS can form a film on the surface of carbon steel to inhibit the cathodic reaction process, thereby inhibiting the corrosion of carbon steel; high-concentration EPS has a strong complexation of Fe^{2+} and can promote the anode dissolution of the matrix material. In turn, promote the corrosion of carbon steel. Under the actual working conditions of the oil field, the non-uniformity of corrosion potential and corrosion current will be caused during the formation of the biofilm, which shows a trend of increasing first and then decreasing. Under the complete biofilm, the corrosion is weakened. When the biofilm is partially shed, the corrosion tendency of the matrix material is increased.

2.1.4 Effects of CO_2, Cl^{1-}, microorganisms and flow rate on the synergistic effect of steel corrosion

In 1993, Zheng Yugui et al. Studied the influence of flow rate on the erosion and corrosion interaction of four typical materials X60, AISI321, 316L and wear-resistant corrosion-resistant alloy F5 in 10% H_2SO_4 + 15% corundum sand medium. The results show that with the increase of flow rate, the weight loss rate of the four materials interaction increases significantly, and the proportion of interaction in the total weight loss rate decreases first with the increase of flow rate, and then further increases with the flow rate (> 7.5 m/s).

In 2013, Cui Yue and others took Xushen 6 gas-gathering station-gathering gas pipeline in Daqing Oilfield as the analysis object, predicted the influence of CO_2 partial pressure on its internal corrosion rate based on the Norsok corrosion model, and combined the on-site internal corrosion thickness measurement data to obtain The influence of CO_2 partial pressure on the corrosion of natural gas pipelines under erosion. The results show that the turbulent kinetic energy rises to a maximum of $75m^2 / s^2$ in the area of sharp changes in the inner flow channel (elbows and T-shaped pipes), which has a significant promotion effect on local corrosion of CO_2; the flow pattern and velocity of the fluid medium will The CO_2 on the inner wall of the pipeline is evenly corroded to produce a strong promotion effect. In 2013, the Joana ST study found that the flow rate of the pipeline was different, and the formed (E. coli) biofilm thickness was similar, the biofilm formed by the low Reynolds number pipeline had a high amount of active bacteria; the high Reynolds number pipeline formed the cells in the biofilm The outer polymer content is high; even in the pipeline with low Reynolds number and low floating cell concentration, a biofilm with a thickness of 1.2 mm or more can be formed.

In 2014, Xin Zheng and others showed that SRB and Cl^- have a synergistic effect to promote metal corrosion when Cl^-concentration is low; SRB grows well when Cl-concentration is less than 30g / L, and Cl^- concentration is higher than 100g/L At that time, the cells were dehydrated and died. Fe_2^+ in the medium is needed for SRB growth. The proper concentration of Fe_2^+ can reduce the electron donor concentration required for the sulfate reduction process, increase the activity of SRB, make SRB quickly reach the maximum value and extend the stable period of SRB growth. The presence of Cl^- ions can not only promote the occurrence of corrosion but also affect the growth of SRB. The concentration of inorganic ions in the medium affects the change of osmotic pressure in water, which results in changes in the transport of bacterial substances. When the concentration of inorganic ions is too high, it will cause cell dehydration and death. Excessive Cl^- concentration can inhibit the metabolism of SRB, but SRB has a strong viability and can still grow at a higher Cl^- concentration [3].

In 2015, Fan Jiaxi proposed the method of anti-corrosion of inner coating combined with the addition of oil soluble corrosion inhibitor to the problem of high CO_2 and Cl^- in the gathering pipeline of Xushen Gas Field, which effectively reduced the corrosion in the pipeline.

In 2017, G.A. Zhang et al. Studied the pitting corrosion of pipeline steel in a solution containing CO_2, and pointed out that the galvanic corrosion formed between the metal surface covering $FeCO_3$ and the metal surface in the exposed state promotes the occurrence of pitting corrosion. When the organic carbon source in the environment is poor, the presence of CO_2 can provide a carbon source for SRB, which is beneficial to the growth of bacteria. Under the condition of CO_2 and SRB coexistence, SRB continuously produces hydrogen sulfide and the combination of CO_2 and Fe_2^+ in the solution, thereby producing $FeCO_3$ and FeS films, continuously changing the structure of the corrosion product film, and synergistically promoting metal corrosion.

In 2019, Zhang Xiqing [used the corrosion test instruments such as high-temperature and high-pressure reactors and ultrasonic scanners to study the serious corrosion and perforation problems caused by the existence of CO_2 and Cl^- in crude oil gathering and transportation pipelines. The influence of CO_2 partial pressure and flow rate change in the corrosive medium of crude oil on the corrosion behavior of steel for L245M crude oil gathering and transportation pipeline. The results show that increasing the environmental conditions such as flow rate and CO_2 partial pressure will increase the corrosion rate of L245M pipeline steel.

2.2 Research Status of Corrosion Protection Countermeasures

2.2.1 Corrosion Inhibitor Filling

In 2014, Galio [4] et al. Summarized the environment-friendly corrosion inhibitors used in different corrosion environments of shale gas gathering and transportation pipelines, and highly toxic corrosion inhibitors are gradually being banned.

In 2018, Liu Zhongyun [5] investigated the corrosion inhibitors of gas pipelines under the coexistence of shale gas CO_2 and H_2S, and found that imidazolines, thiourea compound system types, acetylene alcohol system systems, oxyethylene groups and The two-phase corrosion inhibitors of the enterprise have certain effects. The imidazoline biological corrosion inhibitors containing oxygen compounds have a good effect, and the prospect of gas-liquid two-phase corrosion inhibitors is broad.

In 2019, Palumbo [6] et al. Confirmed that gum arabic, as an environmentally friendly corrosion inhibitor in the shale gas industry, inhibits the pipeline carbon steel (N80) in CO_2 saturated chloride (0.5M KCl) solution. The results show that the gum arabic's corrosion inhibitory efficiency increases with the increase of the inhibitor concentration and decreases with the increase of temperature.

2.2.2 Cathodic Protection

In 2019, Yang Changhua and others studied the risk analysis and preventive measures for the leakage of gathering pipelines in the Fuling Shale Gas Field. The external corrosion and perforation leakage of the gathering and transportation pipelines in the Fuling Shale Gas Field are mainly due to the following two factors:

(1) The Fuling shale gas field is located in a typical mountainous and hilly area. The pipeline construction is complicated. During the small backfill of the pipeline, it cannot be completely backfilled with fine soil. The backfilled small stones may cause damage to the outer corrosion protection layer of the pipeline;

(2) The cathodic protection system is the key to guarantee the service life of the pipeline. When the cathodic protection system works abnormally and the potential cannot be loaded normally, local corrosion of the external corrosion protection layer of the pipeline will occur.

After the local corrosion of the external anti-corrosion layer of the gathering pipeline occurs, pitting corrosion, pitting corrosion and small hole corrosion will form, and the pipe body will be perforated and leaked. In order to prevent external corrosion of gathering pipelines in Fuling Shale Gas Field, one is to use the underground pipeline anticorrosion layer detection leak detector to regularly detect the damaged points of the outer pipeline anticorrosion layer and repair the damaged points in time; The protection system conducts a potential test to ensure that the cathodic protection system works normally and ensure the stable operation of the gathering pipeline.

2.2.3 Corrosion-resistant alloy sSteel Applications

Compared with common pipeline metals, the corrosion-resistant alloy steel itself has strong resistance to CO_2 corrosion. The alloy contains Cr, Ni and other corrosion-resistant elements, which can play a protective role. Among the corrosion-resistant alloy steel materials, low-Cr alloys and high-Cr stainless steels are metals with good resistance to CO_2 corrosion. These two metals are widely used in oil and gas gathering and transportation pipelines, but they are more widely used in long-distance pipelines. less.

In 2016, Hu Yaoqiang and others summarized and analyzed the corrosion factors, corrosion mechanisms and corrosion control measures of different steel materials during the CO_2 pipeline transportation process, and provided technical support for the CO_2 pipeline transportation process in the CCUS project.

2.2.4 Pipe coating

This kind of pipe mainly depends on the coating or coating to isolate the pipe from contact with the corrosive medium to achieve the anticorrosive effect. Commonly used coatings are epoxy type, modified epoxy type, phenolic epoxy type resin and nylon, etc. The coating layer includes zinc, aluminum and its alloys. The process has little effect on the production of oil and gas fields, the process is simple and the cost is low.

According to the technical status at home and abroad, we have known that there are mature research methods for the influence of single factors on the gathering pipeline, but the corrosion under the conditions of variable factors such as gas, water, sand, microorganisms and other cooperative conditions has not formed a perfect theory System, less research work has been carried out. Corrosion and perforation phenomena often occur on site, and no effective corrosion protection countermeasures have been formed. Therefore, it is urgent to carry out the analysis of the main controlling factors of the corrosion of the gathering pipeline of Changning shale gas field and the optimization of countermeasures.

3. Research Content

3.1 Sample Collection on Site

Investigate the surface production system of the Changning shale gas field, including the production wells, production platforms, gas production pipelines, gas collection pipelines, and various types of stations in all well areas that have been built; collect and put the surface production system from the wellhead to the center for processing from production to 2019 All relevant data of the plant, including design data, production data, pipeline operation records and corrosion status records, etc. Focus on the historical failures, high-risk, and low-efficiency equipment and pipelines of ground production systems. Formulate detailed survey data forms, comprehensively collect effective data on site survey content, and determine the data sources and operational management status required for the development of Changning shale gas field scientific research projects.

Samples were collected on Ning 209H8, Changning H25, Ning 209H20, Ning 209H1, Ning 209H29 platforms and four platforms with normal production period, see Table 1.

(1) Gas samples: 9 × 1 group (one group of gas samples from 9 production platforms);

(2) Water samples: 9 × 3 groups (three groups of water samples from 9 production platforms, including fracturing fluid and flow-back fluid);

(3) Pipes: 7 groups (5 failed pipelines + L245 new pipes + L360 new pipes).

Table 1: On-site sampling table

Numble	Platform	Water sample	Gas sample	Pipe
1	Ning 209H8	3 groups	1 group	1 group (invalid) +1 group (new)
2	Ning H25	3 groups	1 group	1 group (invalid) +1 group (new)
3	Ning 209H20	3 groups	1 group	1 group
4	Ning 209H1	3 groups	1 group	1 group
5	Ning 209H29	3 groups	1 group	1 group
6	Drainage periodNH14	3 groups	1 group	—
7	Early production platform	3 groups	1 group	—
8	Medium production platform	3 groups	1 group	—
9	End-of-production platform	3 groups	1 group	—

3.2 Indoor Test Analysis

(1) Use gas chromatography-mass spectrometry to analyze the composition of shale gas, determine the CO_2 content in different periods, analyze the corrosion situation, 9 groups.

(2) Use inductively coupled plasma emission spectrometer to analyze water quality components, analyze pH, salinity, grit and scaling of the solution, 9 groups.

(3) Use extinction dilution method to count the content of microorganisms (SRB, TGB, FeB) in the produced water, 9 groups.

3.3 Experimental Study on Corrosion Mechanism of Changning Shale Gas Wet Gas Gathering and Transportation Pipeline

Based on sample testing, multi-phase flow simulation calculations and on-site working conditions, the on-site water samples were selected for high-temperature and high-pressure dynamic reaction kettle simulation experiments (a total of 8 groups). The experimental scheme is shown in Table 2, and the experimental period is 7d, 14d, 28d and 56d.

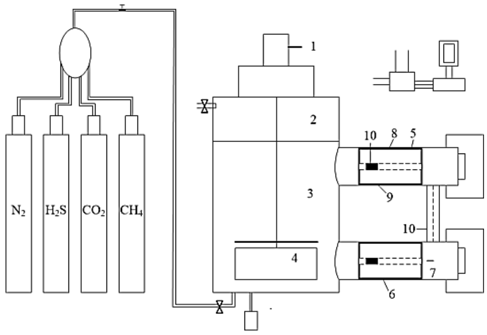


Figure 1: Schematic diagram of high temperature and high pressure dynamic reactor and test piece structure

Table 2: High temperature and high pressure dynamic reactor experiment

Material	Temperature (℃)	Pressure (MPa)	CO_2 partial pressure (mol%)	Liquid velocity (m/s)	Microbial biomass (Pc /mL)	Salinity (mg/L)	Experiment period (d)
L245/ L360	40	6	0.5	0.001	4500	25000	7/14/28 /56

Based on sample testing, multi-phase flow simulation calculations and field conditions, the multi-phase flow experiment undulating unit in the mountainous area of the ring road is shown in Figure 2. Samples (L245 / L360), to study the flow corrosion mechanism of the pipeline uphill section, a total of 6 groups.

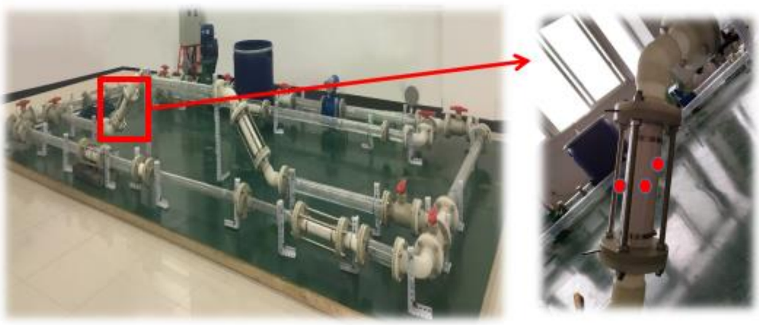


Figure 2: Multi-phase flow experimental loop

Table 3: Experimental parameters of multi-phase flow experiment loop

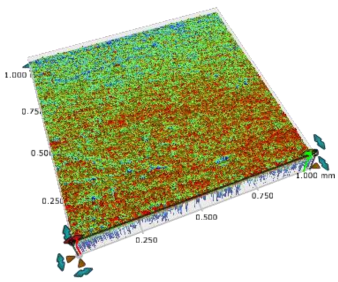
Temperature：40℃		Pressure：0.1MPa	
Salinity：25000mg/L		Experiment period：14h	
Material		Flow rate（m/s）	
L245	0.001	L245	0.001
L360	0.001	L360	0.001

Use a 3D microscope to scan as shown in Figure 3 to obtain the local corrosion pit depth of the corrosion sample, and calculate the local corrosion rate of the sample according to the formula;

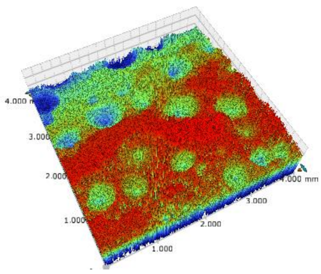
$$R_L = \frac{0.365h}{t} \tag{1}$$

Among them: RL means Local corrosion rate(mm/a); h means Pitting depth(μm); t means Corrosion time

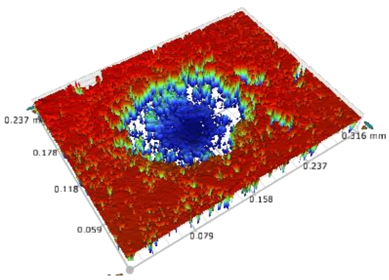
Figure 3: 3D microscope



(a) 7d



(b) 28d

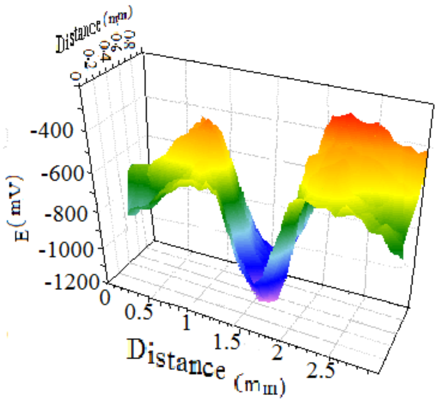


(c) 56d

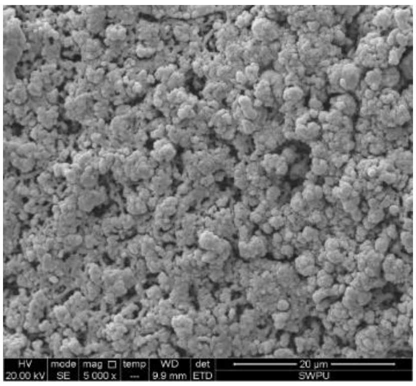
Figure 4: 3D microscope characterization of dynamic changes of corrosion pit depth in different experimental periods

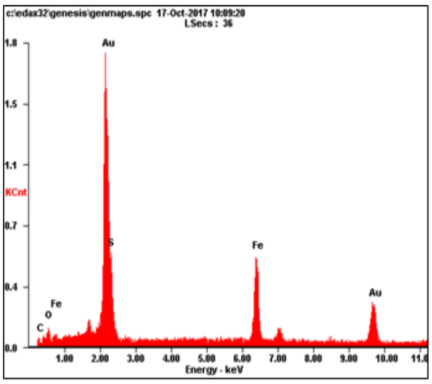
The calculated local corrosion rate is compared with the on-site corrosion perforation degree, and the direct cause of pipeline perforation failure is analyzed.

Micro-area electrochemistry, scanning electron microscopy, X-ray photoelectron spectroscopy, SEM and other instruments were used to characterize the corrosion products and corrosion morphology. Corrosion mechanism, and analysis of the dynamic expansion process of corrosion morphology and corrosion dynamics at different times [12].



(a) SKP three-dimensional potential distribution map





(b) SEM picture of corrosion morphology (c) Corrosion morphology EDS diagram

Figure 5: Schematic diagram of corrosion product characterization

4. Research on the Optimization of Protective Countermeasures

In view of the corrosion problems of the gathering and transportation pipelines in the Changning shale gas field, through optimization studies, anti-corrosion measures including but not limited to pipe selection, corrosion inhibitor injection, chemical sterilization, pigging and corrosion monitoring, etc. were formulated to effectively reduce the frequency of corrosion perforation .

4.1 Pipe Optimization Research

Aiming at the problem of corrosion, corrosion and perforation of the gathering and transportation pipelines in the Changning shale gas field, four types of anti-corrosion materials were selected for the high-temperature and high-pressure reaction kettle corrosion test. The test period is 7 days. The test parameters are shown in Table 4.

(1) Material selection: L360NB L360NC, 304 stainless steel, duplex stainless steel;

(2) Corrosion resistance research: high temperature and high pressure dynamic reactor simulation experiment;

(3) Material recommendation: corrosion resistance + economy.

Table 4: Experimental parameters of pipe optimization

Material	Temperature℃	Pressure MPa	CO_2 partial pressure mol%	Liquid velocity m/s	Microbial biomass（Pc /mL）	Salinity mg/L	Experiment period（d）
L360NB、L360NC、304 stainless steel、Duplex stainless steel	40	6	0.5	0.4	9500	25000	7

4.2 Corrosion Inhibitor Filling

A special evaluation of the corrosion inhibition effect was carried out for the four corrosion inhibitors. With reference to the internationally accepted corrosion inhibitor evaluation methods and industry standards, the corrosion inhibitors suitable for on-site conditions were selected and the optimal additive concentration was determined [7].

Using SEM, XRD, XPS and other equipment to observe the corrosion products, the selected corrosion inhibitors should have a corrosion inhibition efficiency greater than 70% and good compatibility with water samples. The average corrosion rate should be less than 0.076 mm/a.

Figure 6: The corrosion inhibitor to be evaluated

4.3 Research on chemical sterilization scheme

(1) Select cationic, non-ionic, oxidizing and other fungicides, mix the fungicide with the corrosion inhibitors and other agents used on site and let it stand for 24 hours to analyze the compatibility of the fungicide [8];

(2) Choose 4 kinds of reactor experiments and evaluation, each fungicide is analyzed in three concentrations, a total of 12 groups of experiments;

Figure 7: Fungicide screening

(3) Use SEM, XRD, XPS and other equipment to test the corrosion products and analyze the sterilization effect;

(4) Evaluate the effect of sterilization performance, screen out the bactericide suitable for on-site conditions, determine the filling concentration (corrosion rate is less than 0.076mm/a), and formulate a bactericide filling plan (device, Location, method, cycle).

4.4 Research on Pigging Scheme

(1) According to the pipeline transportation efficiency and the growth rule of microorganisms, comprehensively determine the pigging cycle;

(2) Add fungicides and corrosion inhibitors during the pigging operation to achieve corrosion inhibitor pre-filming [9];

(3) Formulate pigging process plans including but not limited to pig selection, pig speed and period;

(4) Piping process carries inspection equipment to detect the wall thickness of the pipeline and identify the corrosion of the pipeline.

4.5 Research on Corrosion Monitoring Scheme

(1) According to ICDA, internal inspection, multi-phase flow simulation and experimental results, analyze the corrosion detection probe and hanging piece data, determine the high-risk area of Changning shale gas wet gas gathering and transportation pipeline, and guide the installation location of corrosion monitoring equipment

(2) Compare and select monitoring technologies such as corrosion coupons, resistance probes, ultrasonic online thickness measurement, and hydrogen flux monitoring, as shown in Figure 8;

(3) Formulate corrosion monitoring programs including but not limited to equipment selection, installation location, and data analysis requirements.

Figure 8: Resistance probe

In view of the corrosion problems of the gathering and transportation pipelines in the Changning shale gas field, through optimization studies, anti-corrosion measures including but not limited to pipe optimization, corrosion inhibitors, chemical sterilization, pigging process and corrosion monitoring, etc were formulated to effectively reduce the frequency of corrosion perforation.

5. Conclusion

Corrosion and perforation of pipelines will affect the normal operation of gas fields, resulting in waste of resources and environmental pollution. Clarify the main risk factors of pipeline perforation, and then formulate scientific and effective prevention and control measures to achieve prevention in advance and the combination of prevention and control will greatly improve the safe operation level of pipelines and ensure safe and efficient operation of gas fields[10].

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