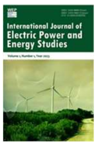
International Journal of Electric Power and Energy Studies
ISSN: 3006-2004 (Print), ISSN: 3006-0826 (Online) | Volume 3, Number 2, Year 2024
DOI: https://doi.org/10.62051/ijepes.v3n2.04
Journal homepage: https://wepub.org/index.php/IJEPES/index



Study on Corrosion Regularity and Mechanism of a Gathering and Transportation Pipeline in Jiyuan Oilfield

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ABSTRACT

Aiming at the serious problem of corrosion of surface pipelines in Jiyuan Oilfield, this paper analyzes the corrosion law and corrosion mechanism of a gathering pipeline in Jiyuan Oilfield based on a variety of experiments. Research shows: through the spectrometer on the sampling pipe L245N composition analysis shows that the main elements of the pipeline tubing to meet the national standard requirements; the analysis of corrosion products and bacterial species shows that the corrosion type of this gathering pipeline is mainly CO_2 corrosion and bacterial corrosion; based on the corrosion hanging experiment, it can be seen that the temperature in the temperature range of 10℃~50℃, with the increase in temperature corrosion rate becomes larger, the pressure on the pipeline corrosion rate has less impact; based on the results of water quality analysis and pipe corrosion microscopic morphology observation, the pipeline extracted water Cl- ion content is high, there is pitting corrosion, especially weld corrosion is more serious.

KEYWORDS

Gathering Pipeline; Corrosion Rate; Corrosion Pattern; Corrosion Mechanism.

1. PREFACE

At present, with the development of Changqing low-permeability oilfield gradually increasing, to achieve the goal of high-efficiency, stable production development of low-permeability oilfields, the oilfield water injection development method is being more and more adopted[1,2]. The injected water is usually the effluent from the oil well's extractive fluid, often referred to as produced water, which contains large amounts of dissolved gases, inorganic salts, oxygen sulfide, oxygen, and other substances, leading to increased corrosion rates on the pipeline[3,4]. According to the statistics of Changqing No.3 Oil Extraction Plant, the average maintenance cycle of each site in the plant is only 3 to 5 years, and the frequency of leakage breakage is 2.44 times/year on average. Due to the severe corrosion of the pipeline, the annual maintenance cost remains high, up to $7.5 million per year[5]. If corrosion-induced pipeline leaks are not detected or disposed of in a timely manner, they may cause safety and environmental protection accidents such as flash explosions, fires, oil and gas poisoning of personnel, and the outflow of crude oil into environmentally sensitive areas[6]. Therefore, it is of great significance to study the pipeline corrosion influencing factors and corrosion mechanism in this oilfield and put forward effective anti-corrosion measures.

2. CORROSION STATUS

As Changqing No. 3Oil Recovery Plant enters the middle and late stages of exploitation, the average water content rate increases year by year (currently up to 65%), making the amount of water extracted increase with each passing year, leading to more and more prominent pipeline corrosion, resulting in the pipeline maintenance workload and costs increase every year[7]. In the first half of 2024, the statistics of corrosion in the Dashuikeng Operation Area of Oil Production No.3 Plant are shown in Table 1. Whether it is crude oil gathering and transmission, or sewage reinjection, pipeline corrosion and perforation seriously impede the normal production of oilfields[8,9]. Pictures of pipeline corrosion perforation are shown in Figure 1. In addition, since the utilization rate of L245N steel pipeline in Dashuikeng Operation Area of Changqing Oil Producing Plant No.3 is more than 90%, it is necessary to study the corrosion mechanism that causes corrosion of L245N steel pipeline[10,11].

Figure 1. Corrosion perforation pictures

Table 1. Summary of pipeline breakage records in the Dashuikeng Operation Area in the first half of 2024

Name of damaged pipeline	Pipe breakage Time	Broken pipeline specifications	Type of damaged pipeline	Service life of damaged pipelines	Location of breakage	breakage Cause
Red 16-021 water injection branch	2024/4/2	DN60 high pressure water injection line	water injection line	8	30 meters outside the Red 16-021 well site	External corrosion damage
Salt 28 injection skid to new salt 109-97 injection branch line	2024/5/7	DN60 high pressure water injection line	water injection line	10	Approximately 6 meters from the fence inside the new salt 109-97 well site, above the side of the pipeline body	Corrosion in the pipeline, natural damage
New Red 4 well field water injection branch line	2024/5/8	DN60 high pressure water injection line	water injection line	2	Approximately 100 meters outside the fence of the new Red 4 well field,	Corrosion in the pipeline, natural damage

					directly under the pipeline body	
Wang Yiji No. 2 pump inlet pipeline	2024/6/1	DN150	Injection pump inlet line	4	Approximately 50 centimeters below the ground at the inlet of pump No. 2 of Wang Yikei	Corrosion in the pipeline, natural damage
Yellow 316 Triassic System General Organization Square 532-01 oil pipeline	2024/6/30	Φ60*5	oil sump line	4	Near the location of the 532-01 oil tee in the General Organs Square	Corrosion in the pipeline, natural damage
Yellow 15 Additional Jurassic Outfall Pipeline	2024.7.9	Φ89*5	oil sump line	5	Approximately 40 meters outside of Huang 15 additional station, corrosion breaks on the side of the pipeline inwards	Lateral inward corrosion breaks in pipelines
Salt 1 to Triassic clear water distributor outflow salt 28 trunk line	2024.7.25	Φ76*8	water injection trunk	6	Injection pump room manifold outlet, underground location	Corrosion in the pipeline, natural damage
Salt 1 to Triassic production feed pipeline	2024.7.26	Φ114*5	oil sump line	4	Leakage of exposed lateral pipeline on the ground above the valve of 2# heating furnace oil supply	Corrosion in the pipeline, natural damage

3. EXPERIMENTAL RESEARCH

3.1. Sample Selection

In order to comprehensively analyze the corrosion mechanism, corroded pipeline samples were selected from different well stations of Changqing Oil Producing Plant No.3 respectively, the corroded pipeline samples were all crude oil gathering pipelines, and the water quality samples were the Jurassic water quality separated from the extracted fluid.

3.2. Experimental Methods

(1) For the corrosive pipe samples, according to GB/T 4336-2002 "carbon steel and low alloy steel spark source electron emission spectrometry analysis method" using ARL 4460 direct reading spectrometer to analyze the composition of the pipe.

(2) Water quality samples were analyzed by water quality chemical titration, ICP inductively coupled plasma mass spectrometry, and ion chromatography and mass spectrometry analysis.

(3) The bacterial content of water samples was analyzed using the principle of the extinct dilution method, using sterile syringes, bacterial culture bottles, thermostats and other instruments.

(4) The corrosion hanging test method was used to test the corrosion rate of the extracted water on the pipe at different temperatures and pressures, and to confirm the effect of temperature and pressure on the corrosion of the pipe.

(5) X-ray diffractometer (XRD) was used to carry out the analysis of the composition of corrosion scaling products, and a microscope was used to observe the corrosion micro-morphology.

4. RESULTS AND DISCUSSION

4.1. Corrosion Pipe Composition Analysis Results

ARL 4460 direct reading spectrometer was used to analyze the pipe composition, the pipe was L245N pipeline steel, corrosion pipe composition test results are shown in Table 2.

Table 2. Corrosion Tubing Composition Test Results(mass fraction)

serial number	C	Si	Mn	P	S	Cr	Ni	Cu	Mo	Ti	Fe
1	0.211	0.23	0.364	0.032	0.01	0.046	0.01	0.001	0.042	0.002	99.052
national standard	0.17~0.23	0.17~0.37	0.35~0.65	≤0.035	≤0.035	≤0.25	≤0.30	≤0.25	/	/	/

Analysis results show that the pipeline carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulfur (S), chromium (Cr), nickel (Ni), copper (Cu) and other major elements to meet the national standards GB/T 699-1999 requirements.

4.2. Results of Water Quality Analysis

The results of water quality analysis of extracted water in Dashuikeng Operation Area of Jiyuan Oilfield are shown in Table 3.

Table 3. Table of water quality analysis results

Sample Information		Jurassic water quality
Project analysis		ρ/(mg/L)
Total mineralization/(mg/L)		79839.414
Cl^-		46361.480
Cationic	Ca^{2+}	3789.020
	Mg^{2+}	369.440
	Sr^{2+}	827.980
	Ba^{2+}	390.080
Anionic	SO_4^{2-}	80.360
	HCO_3^-	1438.136
Water-based		$CaCl_2$

It can be seen from Table 3 that: the total mineralization of the water quality test results was 79,839.414 mg/L. The Cl^- content was high at 46361.480mg/L and was prone to pit. Among the scale-forming cations, the content of calcium ions was 3789.020 mg/L, magnesium ions was 369.440 mg/L, barium ions was 390.080 mg/L, and strontium ions was 827.980 mg/L; among the scale-forming anions, the content of bicarbonate ions was 1438.136 mg/L, and sulfate ions was 80.360 mg/L. The water type was $CaCl_2$ type.

4.3. Analysis of the Structure of Bacterial Experiment

By analyzing the water quality separated from the extractive fluid of the Changqing Oil Producing Plant No.3, the results show that its water quality is highly mineralized, so it is necessary to consider the effect of bacteria in the extractive fluid on metal corrosion, especially sulfate-reducing bacteria are more hazardous to the oilfield production and operation, and it is necessary to experimentally determine the type and content of bacteria in the extractive fluid. The results of the water quality analysis also showed that the sulfate content in the extracted fluid was high, and the metabolite H_2S of the sulfate-reducing bacteria would further corrode and block the pipeline, in addition, the content of iron bacteria and saprophytic bacteria exceeding a certain value would form a precipitate, which would in turn block the oil and gas pipeline.

Table 4. Test results of bacterial species and content in water extracted from the Jurassic system

serial number	Bacterial species	Bacterial content(Pieces/mL)
1	Sulfate-reducing bacteria (SRB)	672
2	Saprophytic Bacteria (TGB)	85
3	Iron Bacteria (FB)	345

Table 4 shows that: the sulfate-reducing bacteria (SRB) content and ferric bacteria (FB) content in the Jurassic extracted water of Dashuikeng Operation Area of Jiyuan Oilfield exceeded 1.0×10^2 bacteria/mL(Indicators of bacterial content in water quality indexes and analytical methods of water injection in clastic reservoirs SY/T5329-2012[12]), So the bacterial corrosion of oil well extracted water is an important influence factor of pipeline corrosion in the region, and then in the anti-corrosion work of the pipe in the region bacterial corrosion should be used as an important reference corrosion factors.

4.4. Analysis of Factors Affecting Corrosion Rate

4.4.1. Effect of Temperature on Corrosion Rate

The experimental setup uses a high-temperature and high-pressure reactor as shown in Figure 2. The operating temperature of the oil field pipeline is between 10℃~50℃, the experimental pressure is 1.0Mpa, the fluid rate is controlled at 1.5m/s, and the corrosion rate versus temperature curve is shown in Figure 3.

Figure 2. High-temperature and high-pressure dynamic reactor experimental device

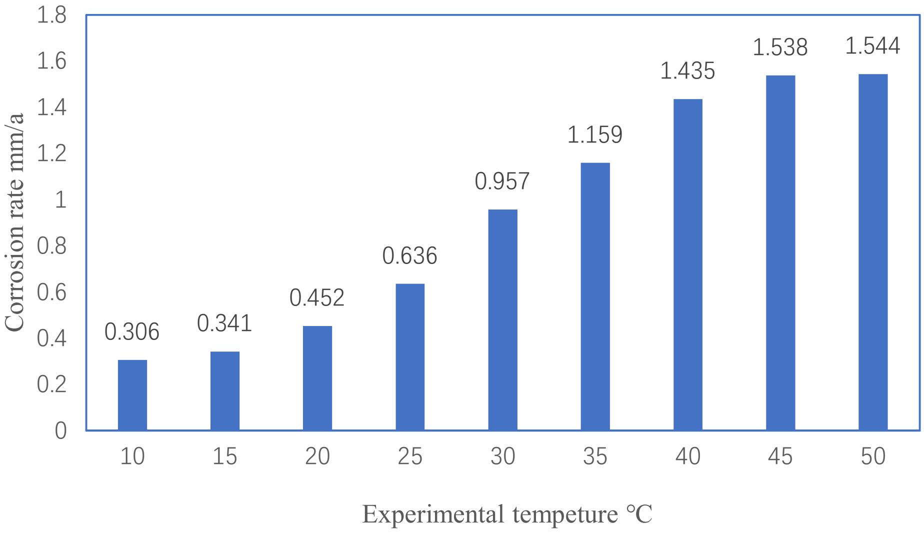

Figure 3. Effect of temperature on the corrosion rate of pipelines in the Dashuikeng Operation Area

The operating temperature of the pipeline at the site is 10℃~50℃. The high-temperature section of the pipeline is mainly concentrated in the front section of the pipeline, which is seriously corroded at the site. This is because when the operating temperature is 25℃, the uniform corrosion rate of the pipe is only 0.636mm·a^{-1}. When the temperature exceeds 25℃, the uniform corrosion rate increases rapidly and can reach 1.544mm·a^{-1} at 50℃. As a result, pipelines operating at higher temperatures in the range of 25 to 50℃ are subject to severe corrosion. The uniform corrosion rate of the pipe decreased from 1.544mm·a^{-1} to 1.538mm·a^{-1} when the operating temperature of the pipe was decreased from 50℃ to 45℃, and to 1.435mm·a^{-1} when the temperature was decreased from 50℃ to 40℃. The increase in corrosion rate slows down when the temperature exceeds 40℃.

4.4.2. Pressure Effect on Corrosion Rate

The operating pressure of the oil and gas pipeline of the Changqing oilfield No. 3 oil recovery plant is 0.1~2.5Mpa, the temperature conditions are fixed, and the temperatures are taken to be 20℃ and 40℃, respectively, and the fluid rate is controlled to be 1.5m/s, through the hanging piece of the experiment to verify the pressure on the pipeline corrosion rate of the pressure was taken as 0.1Mpa, 0.5Mpa, 1.0Mpa, 1.5Mpa, 2.0Mpa, 2.5Mpa for the determination of corrosion rate, the experimental results are shown in Figure 4.

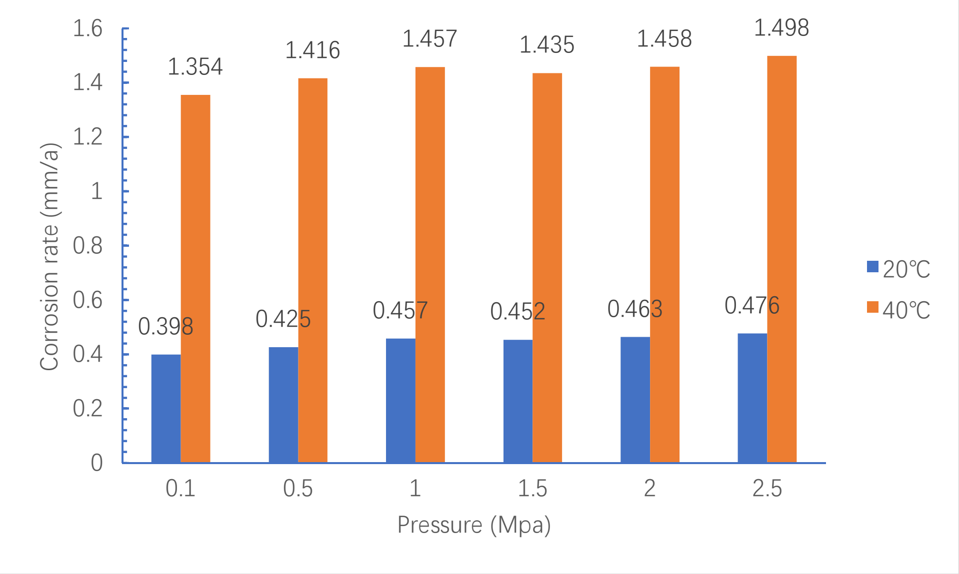

Figure 4. Corrosion rate versus pressure curve

It can be seen from Table 4 that: the corrosion rate does not change much with pressure, the red color in the figure is the corrosion rate versus pressure curve at a temperature of 40 ℃, and the blue color is the corrosion rate versus pressure curve at a temperature of 20 ℃. The trends of the two curves are essentially the same, the corrosion rate is larger when the temperature is high, and the effect of temperature on the corrosion rate is more obvious. The overall effect of pressure on the corrosion rate is that the corrosion rate does not change much with the increase of pressure, but increases slightly. And, as the pressure increases, the fluid velocity increases, which will increase the corrosion rate of scour corrosion, but the pressure has little effect on the corrosion rate in this pipeline steel working pressure range.

4.5. Results of Corrosion Composition Analysis

In order to study the corrosion mechanism of L245N pipeline steel, the corrosion products of the hanging sheet experiment were analyzed by X-ray energy spectrometer for composition, and the corroded hanging sheet was observed by microscope to analyze the corrosion mechanism of this pipeline steel.

The pressure of the experiment was controlled at 1.5Mpa, the temperature was 20°C, and the fluid rate was controlled at 1.5m/s. By the experimental process photos can be observed, corrosion before the specimen surface is very bright(As shown in Figure 5a), while the corrosion of the specimen after the surface of the black, obviously a layer of brown product attached to the surface of the specimen, the corrosion product looks more fluffy and there is a certain phenomenon of fouling(As shown in Figure 5b). After removing the corrosion products, a large number of corrosion pits can be seen on the surface of the test piece(As shown in Figure 5c and Figure 5d), but corrosive liquid corrosion before and after the naked eye to observe no obvious changes, the bottom of the container has a small amount of yellow precipitate.

Scale samples from the corrosion of the experimental specimens were taken and analyzed for their composition. The experiments used in the U.S. KEVEX company 8000 type X-ray energy spectrometer, experimental scale sample line scanning analysis results are shown in Figure 6.

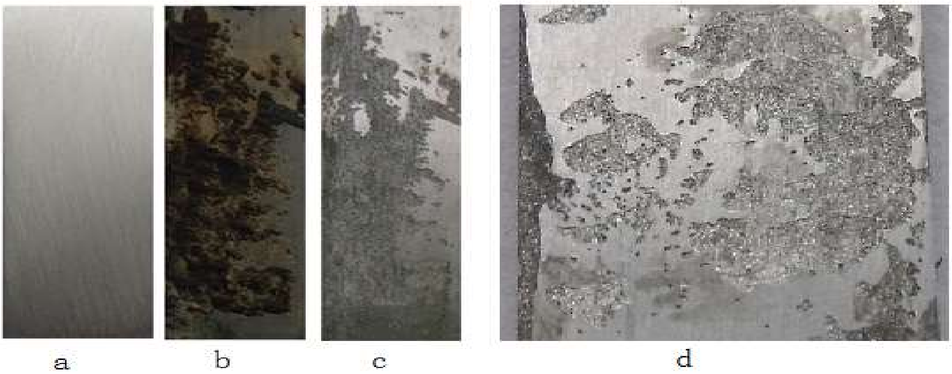

Figure 5. Photo of corrosion test at 20°C. (Figure a shows the photo before etching, b shows the photo without treatment after etching, c shows the photo after treatment, and d shows the enlarged photo)

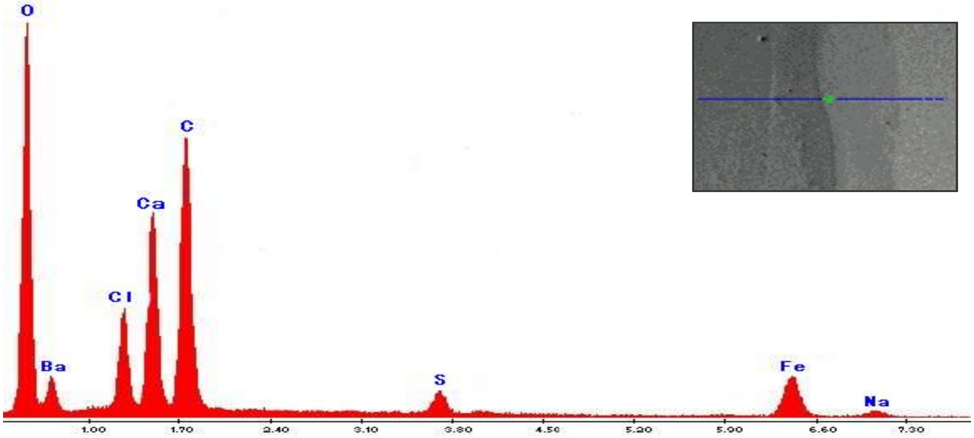

Figure 6. X-ray spectra of corroded pipe section scale samples in oil fields

Through the statistics of the experimental results, the surface elements of the scale samples on the corrosion specimens were analyzed by using the X-ray spectrometer type 8000, and the results were summarized as follows, see Table 5.

Table 5. Energy spectral analysis data of pipeline scale samples

Element	percentage of mass (%)	mole fraction (%)	Element	percentage of mass (%)	mole fraction (%)
C	21.65	5.82	S	1.43	1.48
Ca	18.42	42.51	Cl	15.17	17.48
Na	0.78	1.25	O	31.43	14.3
Fe	7.06	4.67	Ba	4.06	12.48

Table 5 data can be seen: the main chemical elements contained in the scale samples are C, O, Ca, Cl, Fe, indicating that the main component of this scale samples for the calcium carbonate, while containing a small amount of chloride, ferrous carbonate, sulfide and other corrosion products.

5. CORROSION MECHANISM RESEARCH

5.1. Electrochemical Corrosion Process

The analysis of corrosion products shows that the corrosion type in the Dashuikeng Operation Area of Jiyuan Oilfield is mainly dominated by a single CO_2 corrosion.

For a single CO_2 corrosion, CO_2 gas reacts with water to form H_2CO_3 in a series of chemical reactions. The reaction is shown in the following equation:

Anodic reaction: $Fe \rightarrow Fe^{2+} + 2e^-$ (Iron loses electrons to form Fe^{2+} ions)

Cathodic reaction: $CO_2 + H_2O \rightarrow H_2CO_3$ (Carbon dioxide reacts with water to form carbonic acid)

$H_2CO_3 \rightarrow HCO_3^- + H^+$ (Carbonic acid decomposes into bicarbonate and hydrogen ions)

$HCO_3^- \rightarrow CO_3^{2-} + H^+$ (Further decomposition of bicarbonate)

$2H_3O^+ + 2e^- \rightarrow 2H_2O + H_2$ (Hydrated hydrogen ions gain electrons to form water and hydrogen gas)

Total corrosion reaction: $CO_2 + H_2O + Fe \rightarrow FeCO_3 + H_2$ (Carbon dioxide, water and iron react to form iron carbonate and hydrogen gas)

5.2. Microbiological Influences on Corrosion

In an environment containing sulfate-reducing bacteria (SRB), SRB metabolites are interwoven with corrosion products to form a complete and continuous film, which may have some mitigating effect on uniform corrosion. However, the corrosion product film was wrapped with a large number of SRB bacteria and FeS products, and the distribution was not uniform. SRB bacteria are in a strictly anoxic environment, SO_4^{2-} and H^+ can reach the membrane for SRB metabolism, and SRB itself possesses the ability to obtain electrons directly from Fe or indirectly utilize the conduction electrons from FeS, biofilm, nucleic acid, etc. to satisfy the energy required for its own metabolism, which further promotes localized corrosion under the membrane.

Ferrobacteria (FB) gain energy by oxidizing Fe^{2+} to Fe^{3+} and in the process produce iron hydroxide precipitates. In oilfield pipelines, the presence of iron bacteria may lead to pipeline corrosion because their metabolic activity alters the chemical environment within the pipeline and promotes oxidative reactions of metals.

6. SUMMARY

(1) Composition analysis, corrosion product analysis and bacterial analysis of pipelines in Jiyuan Oilfield show that: the elemental composition of pipeline materials at the site meets the requirements of national standards, and the main types of pipeline corrosion in this area are CO_2 corrosion and bacterial corrosion.

(2) Jiyuan Oilfield pipe corrosion hanging experiments show that: There is a positive correlation between temperature and pipe corrosion rate, while pressure has little effect on pipe corrosion rate.

(3) The results of water quality analysis and pipe corrosion show that: the pipeline extracted water has high content of Cl^- ions, pitting corrosion is serious, especially at the weld corrosion is more serious.

ACKNOWLEDGEMENTS

The authors wish to thank the Research Project on Pipeline Corrosion Mechanism and Countermeasures for Prevention and Control in Jiyuan Oilfield (CQYT-CQCY3C-2024-JS-2754) for financial support.

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