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Research on tubing material selection for preventing corrosion in high sour gas well under existence of bacteria corrosion

Lingfeng LI[1]*, Jian Xiong[2]

[1]Key Laboratory of Exploration Technologies for Oil and Gas Resources, Ministry of Education, Petroleum Engineering College of Yangtze University, Hubei, 430100, (CHINA)

[2]State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Sichuan, 610500, (CHINA)

ABSTRACT

The corrosive attack of material that is caused or promoted by the life activity of bacteria is known as bacteria corrosion. For high sour natural gas wells, formation water may possibly contain sulfate-reducing bacteria (SRB), iron bacteria, sulfur bacteria, and so on, which lurk in formation water and rock. The most common microbiological corrosion in high sour natural gas wells is sulfate-reducing bacteria corrosion. Material selection of tubing for preventing corrosion are very important factors of gas production system life. In order to ensure the long-term development of high sour gas well under existence of bacteria corrosion, this paper mainly study the material selection of tubing for preventing corrosion in high sour gas well under existence of bacteria corrosion. For material selection, traditional method is using sulfur-resistant steels. This paper proposes a new option: using corrosion-resistant alloy. By studying, traditional sulfur-resistant steels in high sour gas wells under existence of bacteria corrosion may have severe corrosion. For high sour gas wells under existence of bacteria corrosion with high hydrogen sulfide and carbon dioxide content, the new option(selecting corrosion-resistant alloy) is a good measure. By taking CY-T gas field as an example, this paper optimizes the material selection. By corrosion coupon test and galvanic corrosion test, the experiment results show that there have serious galvanic corrosion and electrochemical corrosion for the traditional sulfur-resistant steel. Despite the high cost, the new option(selecting corrosion-resistant alloy) has long service life, and has no need for adding corrosion inhibitor. For high-productivity and high sour gas wells under existence of bacteria corrosion, the new option(selecting corrosion-resistant alloy) is an effective and economic corrosion prevention measure. For on-the-spot application, the study above has a good practicality, and can provide reference for the similar high sour gas wells under existence of bacteria corrosion.

KEYWORDS

Bacteria corrosion;
Tubing;
Material selection;
Preventing corrosion;
High sour gas well.

INTRODUCTION

Natural gas is widely used and is an important energy source. Corrosion in gas well production systems is a serious factor in failures. In recent years, with the rapid development of gas industry, natural gas production engineering have also been more and more important. Corrosion may cause economic losses and bring with it problems of safety and protection of resources[1]. Some gas wells have adverse working environments, so their service lives and properties will seriously affect the production and the operating benefits of gas fields. For sour gas fields under existence of bacteria corrosion, dangerous safety accidents and environmental problems may be generated.

Figure 1 is the tubing material corrosion in a sour gas reservoir under existence of bacteria corrosion. Understanding the mechanisms and rules of corrosion of gas wells and making rational corrosion prevention design are crucial. TABLE 1 shows application of tubing and the corrosion to the gas field in Chuanyu gas field[2].

Figure 1 : The tubing corrosion in a sour gas reservoir under existence of bacteria corrosion

This paper mainly study the methods and procedure of tubing sizes optimization, and material selection of tubing for preventing corrosion in high sour gas well.

INTERACTION OF CORROSIVE COMPONENTS AND THE EFFECT ON CORROSION

The produced fluid may include the following corrosive components: (1) acidic gas (H_2S, CO_2, and H^+); (2) dissolved oxygen; (3) salt ($HCO3^-$, $SO4^{2-}$, Cl^-, and OH^-); and (4) bacteria (sulfate-reducing bacteria, aerophile bacteria, and so on)[3].

The interaction of some components may aggravate or mitigate corrosion.

TABLE 1 : Application of tubing to the high sour gas well in Chuanyu gas field

Well No.	Tubing Steel Grade	H_2S Concentration (g/m^3)	CO_2 Concentration (g/m^3)	Corrosion Description
Cheng 34	SM90S KO80S	3.566	50.724	Weight loss, pitting, fracture, and dropou
Zhang 6	NT80SS	0.005	101.87	Weight loss, fracture, and dropout
Cheng 18	C75 C95	3.59	51.199	Pitting, weight loss
Chi 18	KO95SS	0.058	15.057	Weight loss, pitting, deformation fracture, and dropout
Tieshan 12	BGC90 NT80SS	15.16	16.501	Weight loss, pitting, fracture, and dropout

Effect of coexisting hydrogen sulfide and carbon dioxide on corrosion

Sulfide-containing well production practice indicates that when sulfide-resistant carbon steel or low-alloy steel is selected, electrochemical corrosion (metal thinning and pitting corrosion, and so on) will be predominant in comparison with corrosion due to coexisting H_2S and CO_2. Electrochemical corrosion is not fully dependent on the contents and partial pressures of H_2S and CO_2 due to the interaction of corrosive components and is related to the specific dynamic corrosion environment of each gas reservoir. There may be differences between laboratory evaluation and the on-site situation and greater differences between software prediction and the on-site situation. Software prediction may overestimate corrosion severity.

The effect of hydrogen sulfide on carbon dioxide corrosion includes two aspects. Hydrogen sulfide may speed up carbon dioxide corrosion due to cathodic reaction and mitigate corrosion due to FeS precipitation. The change is directly related to temperature and hydrogen sulfide content. In general, at low temperature (30°C), a small quantity of hydrogen sulfide (0.2%) may doubly speed up carbon dioxide corrosion, while high hydrogen sulfide content (such as 21.5%) may reduce the corrosion rate. At high temperature, the corrosion rate is lower than that of pure carbon dioxide when hydrogen sulfide content is higher than 2.1%. When temperature is higher than 150°C, the corrosion rate may not be affected by hydrogen sulfide content. At the same time, low hydrogen sulfide concentration may aggravate corrosion because hydrogen sulfide may directly attend the cathodic reaction, while high hydrogen sulfide concentration may mitigate corrosion because hydrogen sulfide may react with iron to form FeS film. In addition, hydrogen sulfide may greatly reduce the corrosion resistance of the corrosion-resistant steel, which contains Cr, to cause serious local corrosion and even stress corrosion cracking.

Effect of coexisting oxygen and carbon dioxide on corrosion

Oxygen Corrosion. In injected water or other injected working fluids, oxygen lurking is unavoidable. In addition, underground water that is connected with surface water may also have oxygen that lurks in it. In an oxygencontaining solution, the oxygen depolarization reaction will be generated on the electrode surface[4]. The reaction mechanism is very complicated. Intermediate particles or oxide may be generally formed. Different solutions have different reaction mechanisms. The corrosion during which the cathodic process is an oxygen reduction reaction is known as oxygen absorption corrosion. In comparison with a hydrogen reduction reaction, an oxygen reduction reaction can be conducted under positive potential. The corrosion of most metals in neutral or basic solution and the corrosion of a small quantity of metal with positive potential in oxygen-containing weak acid are oxygen absorption corrosion or oxygen depolarization corrosion.

The coexistence of oxygen and carbon dioxide may aggravate corrosion. Oxygen may take a catalytic effect during carbon dioxide corrosion. The higher the oxygen content, the higher the corrosion rate when protective film has not been generated on the steel surface[4]. When protective film has been generated on the steel surface, oxygen content may have a low or almost no effect on corrosion. However, in a solution that is saturated with oxygen, the existence of carbon dioxide may greatly increase the corrosion rate. At this time carbon dioxide takes a catalytic effect in corrosive solution.

Effect of coexisting hydrogen sulfide, carbon dioxide, and chloride on corrosion

For different types of steel, the effects of chlorion are different, and serious local corrosion (pitting corrosion and crevice corrosion, and so on) of steel may be generated[5]. In accordance with the film formation theory, due to small diameter and strong penetrating power, chlorion most easily penetrates the very small pore, reaching the metal surface and interacting with metal to form a soluble compound and change the structure of oxide film and generate corrosion of metal. In addition, chloride may also generate stress corrosion cracking of corrosion-resistant steel.

MATERIAL SELECTION UNDER CORROSIVE CONDITIONS OF HIGH SOUR GAS WELL UNDER EXISTENCE OF BACTERIA CORROSION

Material selection based on standards

Proper selection of the material of tubing, casing, downhole accessories, Christmas tree, and surface equipment is a key problem in corrosion prevention of oil and gas wells. Improper selection of material may not only cause waste, but it may also generate unsafe conditions.

Environment-assisted fracture should be predominantly consideredwhen the material is selected in corrosion prevention design that is in light of sour environments of hydrogen sulfide. The ISO 15156-2 standard can be used for selecting the cracking-resistant material in a sour environment. After sulfide-resistant carbon steel and low-alloy steel are selected, electrochemical corrosion should be emphatically considered. A corrosion inhibitor may be used for preventing or mitigating electrochemical corrosion. Its feasibility is dependent on technical feasibility, reliability, and risk assessment; medium- and long-term cumulative investments and rate of return; and the cost of replacing tubing during well servicing and the loss assessment.

For a serious corrosive environment (such as high pressure and carbon dioxide; high pressure, carbon dioxide, and hydrogen sulfide), stainless steel, or alloy steel should be adopted in a corrosion-resisting design. Stainless steel or alloy steel is expensive and has a long delivery time[6]. They also have downhole service environment restrictions. Thus test evaluation and technical economical analysis are required. The strength design should be in accordance with the ISO 10400 standard on the basis of ISO 15156. When carbon steel and low-alloy steel are used under sour environment conditions, corrosion-resistant steel grade with yield strength lower than 95 ksi (655 MPa) should be selected as far as possible. If the strength is insufficient, increasing wall thickness is proper in order to meet the requirement of strength, but not increasing steel grade.

Fitness design method

Selection of the material suitable for some corrosive environments cannot rely on the ISO 15156 standard. Sometimes the material required is restricted by delivery or technical economical condition. NACE Method A and A solution is a serious sulfide stress cracking evaluation method. Practice indicates that material that is unqualified in accordance with the NACE Method A and A solution has not been cracked during long-term functioning. Therefore, when the source of goods is restricted or technical economical evaluation indicates that higher-grade material is unsuitable, the selection of material on an evaluation based on field environment simulation is admissible. Under normal conditions, corrosive components and temperature are objectively present; however, optimizing structure design may reduce working stress and make material selection convenient or enhance reliability.

ISO 15156-1 provides a principle of fitness design for determination of material on the basis of on-site empirical data, but the following requirements should be met: (1) the field experience provided should continue for two years at least, and a full inspection after field use is included and (2) environment severity should be lower than that of the field experience provided.

In sulfur-containing high-pressure deep wells, the standard sulfide-resistant tubing and casing with yield strength of 125 ksi are used, and the fitness design method (fit for service, fit for purpose) is adopted. Tubing and casing with yield strength of 125 ksi cannot meet the requirements of a serious sulfide stress cracking evaluation test in accordance with NACE Method of A and A solution.

However, the steel material can be adopted, provided that the hydrogen sulfide content of sulfide-containing oil and gas wells and the downhole pH value are lower than the sulfide stress cracking tolerances of this steel material.

Figure 2 is a tubing corrosion in sour gas reservoirs under existence of bacteria corrosion. Selecting corrosion-resistant material should be considered first as a corrosion prevention measure[1]. The application of corrosion-resistant material is mainly related to the following:

a. Oil and gas well production environments
b. Material performance, laboratory test, evaluation data, and on-site use experience
c. Whether corrosion inhibitor, cathodic protection, and comprehensive protective measures are adopted
d. Economic evaluation

Figure 2 : The tubing corrosion in sour gas reservoirs under existence of bacteria corrosion

APPLICATION

In this paper, we take CY-T gas field as an example, which is a typical sulfide containing gas field under existence of bacteria corrosion. CY-T gas field is located in the Sichuan Basin, southwest China. Analytical Data of Formation Water of CY-T gas field is in TABLE 2.

Optimization on material selection of tubing for preventing corrosion

Contents of H_2S and CO_2 in CY-T gas field are very high, so taking effective anti-corrosion measures is very necessary. For high-temperature, high-pressure, highproductivity, and high sour gas wells under existence of bacteria corrosion similar to those of CY-T gas field, selecting high-alloy austenitic corrosion-resistant alloy stainless steel or nickel-based corrosion-resistant alloy steel is the main measure of serious hydrogen sulfide and carbon dioxide corrosion prevention to ensure long-term, safe, and stable production and avoid well servicing and workover as far as possible to ensure stable natural gas supply. This type of corrosionresistant alloy has a chrome content of 20% to 30% and nickel content of 20% to 35%. High strength is achieved by cold working. It has the highest resistance to corrosion and the highest mechanical performance in all stainless steels.

TABLE 2 : Analytical Data of Formation Water of CY-T gas field

Well Code	Negative Ion mg/L				H_2S mg/L	Water Type	Total Degree Of Mineralization g/L
	Cl^-	SO_4^{2-}	HCO_3^-	CO_3^{2-}			
No.8	17400	8470	4180	0			47.2
No.10	45538	770	835	0	1548	$CaCl_2$	53.38
No.6	32448	79	483	0	2574	$CaCl_2$	75.05

Advantages of corrosion-resistant alloy steel corrosion control technology

For high-productivity wells in the main position, corrosion-resistant alloy steel tubing should be selected in order to ensure the longterm safety and stable production of the gas well, ensure stable gas supply, avoid well servicing as far as possible, and prolong the workover-free period of gas wells[6]. Using corrosion-resistant alloy steel tubing has the following advantages:

a. No need for corrosion inhibitor adding system
b. Relatively high strength and thin tubing wall, which make corrosion-resistant alloy steel tubing have a relatively large inside diameter and high throughput capacity in comparison with carbon steel tubing under the same outside diameter
c. The tubing life, which is almost same as well life
d. High reliability during service time
e. Higher quality than that of low-alloy steel tubing
f. No need for corrosion monitoring
g. No need for corrosion inhibitor adding and transport

Corrosion-resistant alloy steels mainly include martensitic stainless steel, diphase martensite-ferrite steel, austenitic stainless steel, and nickel-based alloy steel.

RESUITS AND DISCUSSION

Based on such experiences in development of high sulfur content oil & gas field in foreign countries[8], such as Lacq Gas Field of France, Thamama Gas Field in the Middle East and Bearbery Gas Field in Canada, this article will mainly discuss two options: corrosion-proof plan of corrosion-resistant alloy tubing and corrosion-proof plan of sulfur-resistant tubing.

(A) corrosion-proof plan of corrosion-resistant alloy tubing:

Tubing of full well section is with high nickel alloy steel tubing (eg G3), and it has no need for adding corrosion inhibitor. But its cost is high, which is 10 to 15 times the cost of corrosion-resistant steel.

(B) corrosion-proof plan of sulfur-resistant tubing: high nickel alloy steel is used for tubing for following the packer and above the safety valve. The scheme has two main problems: the first is sulfur-resistant steels under the high H_2S, CO_2 environment has severe corrosion; the second is the junction of a high sulfur-resistant steel and high nickel alloy has serious galvanic corrosion. experimental data of galvanic corrosion for high sulfur-resistant steels and high nickel alloy steel are shown in TABLE 3 and TABLE 4.

TABLE 3 : Static corrosion coupon test data

Index Temperature	average corrosion rate (mm/a) 3%NaCl+0.5%CH_3COOH + saturated H_2S and CO_2	3%NaCl+saturated H_2S and CO_2
120℃	2.16	0.21
80℃	5.98	0.501
40℃	1.18	0.66

TABLE 4 : Static galvanic corrosion test data

Index temperature	galvanic corrosion rate (mm/a) C-276	825	G3	SM-2535
120℃	0.09	0.021	0.61	0.029
80℃	0.50	0.51	0.46	0.57
25℃	0.95	0.93	0.66	0.29

Test medium: +3% sodium chloride, saturated hydrogen sulfide and carbon dioxide

Experimental data above show that: corrosion rate of anti-sulfur steel(40°C) is 0.66 ~ 1.18 mm / a, which is 8.9~15.6 times to ministerial standards; corrosion rate of anti-sulfur steel(80°C) is 0.501 ~ 5.98 mm / a, which is6.6 ~ 78.7 times to ministerial standards. So the corrosion is very serious. Galvanic corrosion(25 ~ 80°C) of sulfur resistant steel and four kinds of alloy is very serious, the corrosion rate is 0.29 ~ 0.95 mm / a.

From the experimental data above, it is clear that there have serious galvanic corrosion and electrochemical corrosion for high sulfur-resistant tubing. Despite the high cost, the corrosion-resistant alloy has long service life. The service life of corrosion-resistant alloy tubing is similar to the production lives of several gas wells. The corrosion-resistant alloy tubing can be repeatedly used in multiple wells and has no need for adding corrosion inhibitor and replacing tubing, and so on. Thus the total cost is reasonable for corrosion-resistant alloy tubing. For high-pressure and high-productivity oil and gas wells that have strong corrosiveness, this may be an effective and economic corrosion prevention measure.

CONCLUSION

In order to satisfy the need of long term, safe and reasonable production of sour natural gas well under existence of bacteria corrosion, this paper introduces the material selection of tubing for preventing corrosion in high sour gas well under existence of bacteria corrosion. Aiming at the actual situation of CY-T gas field, which is a typical sulfide containing gas field under existence of bacteria corrosion, this paper optimizes the material selection of tubing for preventing corrosion. Material selection of tubing for preventing corrosion mainly includes two options: corrosion-proof plan of corrosion-resistant alloy tubing and corrosion-proof plan of sulfur-resistant tubing. Despite the high cost, the corrosion-resistant alloy has long service life. For high-productivity wells in the main position, corrosion-resistant alloy steel tubing should be selected in order to ensure the longterm safety and stable production of the gas well, ensure stable gas supply, avoid well servicing as far as possible, prolong the workover-free period of gas wells, and may be an effective and economic corrosion prevention measure. Application shows that these technologies above can better meet the requirements of the scene, and can provide reference for the similar high sour gas wells under existence of bacteria corrosion.

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