

Corrosion of Gathering Pipelines in Oil and Gas Field and Its Mitigation Measures in China

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ABSTRACT

The service environment of oil and gas gathering pipelines becoming more and more complex and harsh, resulting in frequent failure, which not only causes the loss of oil and gas resources, but also the environmental and safety issues. Therefore, this paper focuses on the internal corrosion characteristics and most concerned issues of the oil and gas gathering pipelines and its mitigation measures. Firstly, several typical corrosion-induced failures of oil and gas gathering pipelines are introduced, moreover, the internal corrosion characteristics and advanced understanding of corrosion causes and mechanisms are analyzed. Then, internal corrosion control techniques including inhibitor, coating, clad pipe, non-metallic pipe, and life extension techniques including PE pipe insertion lining repair, air pressure extrusion coating repair, local repair and reinforcement were introduced.

Key words: gathering pipelines, corrosion perforation, inhibitor, coating, clad pipe, non-metallic pipe, PE pipe insertion lining, air pressure extrusion coating repair, local repair and reinforcement

INTRODUCTION

The exploration and development of oil and gas resources towards the direction of ultra-deep, low permeability, and unconventional in China.¹ In addition, some oil and gas fields have developed into the middle or late stage, the application of various EOR technologies, such as acid fracturing, CO₂ flooding, air foam flooding and polymer flooding, resulting in the service environment of oil and gas gathering pipelines becoming more and more complex and harsh, such as high temperature, high pressure, high H₂S/CO₂, Cl⁻ and bacteria, corrosion failures became one of the biggest challenges of oil and gas gathering pipelines.^{2,3}

Oil and gas gathering pipelines are the connecting line between each unit of oil and gas field ground system, which characterizes by widely distributed, long distance, complex structure with different pipe diameters, and the transportation medium is highly corrosive, therefore, the corrosion failure of oil and gas gathering pipelines frequently occurred. Based on the material type, the oil and gas pipelines can be categorized as metallic pipe (carbon steel, stainless steel, etc.), non-metallic pipe (glass fiber reinforced plastics (FRP) and flexible composite pipe), and composite pipe (metal-metal, metal-nonmetal, and nonmetal-nonmetal). Coating and inhibitor are widely used in oil and gas gathering pipelines due to most of them are carbon steel.⁴ According to statistics, 90% and 97% failures of oil and gas gathering pipelines in A and B onshore oilfield are caused by corrosion, and nearly 50% failures of subsea pipelines in C offshore oilfield are caused by corrosion. The “Qingdao Crude Oil Leaking and Explosion Accident” resulted from corrosion failure, which happened on November 22, 2013, has once again sounded the alarm for the safety production and operation of the oil and gas industry.⁵ It is worth noting that the corrosion failure of oil and gas pipelines is not only the economic problems causing oil and gas loss, but also the environmental and safety issues, therefore, the protection of oil and gas pipelines corrosion has attracted unprecedented attention.^{6,7}

This paper focuses on the internal corrosion situation of the oil and gas gathering pipelines and its mitigation measures. Firstly, several typical corrosion-induced failures of oil and gas gathering pipelines are introduced, moreover, the internal corrosion characteristics and advanced understanding of corrosion causes and mechanisms are analyzed. Then, internal corrosion control techniques including inhibitor, coating, clad pipe, non-metallic pipe, and life extension techniques including PE pipe insertion lining repair, air pressure extrusion coating repair, local repair and reinforcement were introduced.

INTERNAL CORROSION CHARACTERISTICS AND MOST CONCERNED ISSUES



Figure 1: Typical morphologies of corrosion induced failure of ground gathering pipelines

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Carbon steel pipe is the most widely used in oil and gas gathering pipelines compared with clad and non-metallic pipe, therefore, corrosion induced failures is one of the great threatens to oil and gas gathering pipelines in China with increasing of service time. Figure1 displays some representative failure cases of carbon steel gathering pipelines: Figure1 (a) shows the corrosion perforation morphology after remove the deposited sand at the bottom of the 20# steel pipe; Figure1 (b) shows the internal coating failure due to improper coating selection; Fig.1 (c) shows another failure due to the misuse of corrosion inhibitors, resulting in corrosion perforations on the 20# steel; the sulfide stress corrosion cracking of L360QS girth weld is displayed in Figure1 (d), which is mainly due to the combined effect of high H₂S and elastic laying. Based on failure analysis and statistics of huge amount of oil and gas gathering pipelines in China, internal corrosion characteristics and most concerned issues are summarized as follows.

What is the dominant contribution to the corrosion perforation of carbon steel pipe?

More than 90% of the corrosion perforation occurred in 4~8 o'clock direction of the pipeline, especially in 6 o'clock. However, simulation corrosion test in laboratory always indicated the mildly uniform corrosion rather than severe localized corrosion which really occurred in oil and gas field. The discrepancy maybe ascribe to sample surface state, sample geometry, medium flow rate, corrosive medium content, and experiment duration. Although corrosive media (such as H₂S, CO₂, Cl⁻, SRB, etc.) are the substantial factor causing corrosion, the decisive factor is the sediment (oil sludge, silt, corrosion products, etc.) at the bottom of the pipe, as a result of under-deposit corrosion. Therefore, in order to better simulation of corrosion perforation in laboratory, besides the corrosive medium as the primarily consideration, it is more important to consider surface sediment covering (oil sludge, silt, corrosion products), such as structure, composition, proportion, and thickness. In addition, if possible, design larger size corrosion coupons, and consider extending the test duration, based on 15 to 30 days, increase to 60 days, 90 days, and even to 180 days.

Is there a difference of corrosion rate between different carbon steel pipes?

As mentioned above, carbon steel (16Mn、20#、20G、L245、L360) is widely used for oil and gas gathering pipelines, much attention has been paid to the difference of corrosion resistance between various carbon steels due to the frequently corrosion induced failures in the oil and gas field. Attempts have been made to find the correlation between corrosion resistance and chemical composition, microstructure, mechanical properties, grain size etc., actually, there is not much substantially difference between various carbon steels according to corrosion data obtained from both laboratory and field. In addition, although there were frequent localized corrosion and perforation of gathering pipelines in oil and gas fields, laboratory failure analysis results usually indicated that the pipe material is qualified, hence, this discrepancy always confused the field corrosion technicians. In fact, the selection criteria of metallic pipeline is based on GB/T⁽¹⁾ 9711 Standard⁸ Petroleum and natural gas industries - Steel pipe for pipeline transportation systems, which mainly stipulated geometric dimensions, chemical composition, microstructure, mechanical properties, surface conditions, etc. However, the specific corrosion rate does not involve in the standard, mainly due to there is a significant difference of the corrosion environment (CO₂, H₂S, Cl⁻, temperature, flow rate, etc.) from one oil/gas field to another, it is consequently difficult to give a unified and specific standard. It is recommended to refer to the NACE TM 0177 Standard⁹ to select a relatively extreme environmental condition as unified standard for pipe corrosion evaluation as a recommended reference. Alternatively, the oil/gas field proposes its own corrosion rate requirement or standard with consideration of the actual corrosion environment.

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How does flow velocity affect carbon steel pipe in crude oil?

The influence of flow velocity on corrosion behavior as well as mechanism of oil and gas gathering pipelines is very complicated, involving medium phase, velocity, flow pattern, phase holdup, pipeline geometry, pipeline surface state, etc.¹⁰ Generally, flow velocity can accelerate corrosion by enhancing the species transport and effecting the formation of corrosion scales.¹⁰ The crude oil flow velocity in most oilfield gathering pipelines is relatively low (<5 m/s), three cases of crude oil gathering pipeline corrosion perforation are as follows: 1) the corrosion perforation times are 1457 when the flow velocity is <1 m/s; the corrosion perforation times greatly decreases to 269 when the flow velocity is between 1–2 m/s; the corrosion perforation times continually decreases to 30 when the flow velocity is >2 m/s, during the operation period 2008–2011; 2) the corrosion perforation times are 2274 when the flow velocity is <0.8 m/s; the corrosion perforation times greatly decreases to 411 when the flow velocity is between 0.8–2 m/s; the corrosion perforation times continually decreases to 83 when the flow rate is >2 m/s, during the operation period 2017–2021; 3) an extreme case is that very severe corrosion and perforation was found when the crude oil intermittent pipelining in some oilfields due to low production, the flow velocity will periodically decrease to 0 m/s during intermittent pipelining. The above three cases from oilfield gathering pipeline corrosion perforation indicated that the lower flow velocity caused higher perforation rate, it is mainly due to the low flow velocity keeps the fluids in laminar flow pattern, the more completely separation of oil and water at lower flow velocity, and the more adequately deposition of the solids in the pipeline.¹¹ However, this explanation is only applicable to crude oil pipelines with low flow velocity, and the effect of flow velocity on corrosion failure to natural gas gathering pipelines with high flow velocity and high sand content is another different story.

How does Cl^- concentration relate to localized corrosion of carbon steel pipe?

It takes for granted that the carbon steel pipe corrosion perforation owing to the high concentration Cl^- in formation water in gathering pipeline, it is generally believed that the higher the Cl^- content, the higher the corrosion rate and the faster the corrosion perforation occurs. The corrosion rate and perforation rate of carbon steel is indeed related to Cl^- concentration, while the relation is neither positively nor linearly. With regard to carbon steel, Sani et al.¹² investigation shows that the carbon steel corrosion rate reached a maximum and then decreased continuously by further increase of Cl^- concentration. With respect to stainless steel, Sunaba et al.¹³ studied the effect of Cl^- on the corrosion rate of conventional 13Cr, modified 13Cr, and 15Cr in high temperature of 150°C , the results indicated that the corrosion rate of conventional 13Cr increase with increasing Cl^- concentration, while the corrosion rates of modified 13Cr and 15Cr were independent of the Cl^- concentration, it is generally recognized that the pitting potential exhibited a linear correlation with the logarithm of the Cl^- concentration. It is inappropriate to use “pitting corrosion” to describe the localized corrosion of carbon steel occurred in high Cl^- containing formation water, this usually happened in oil and gas field, pitting corrosion is normally related to stainless steel with involving the destroy of passive film.

How to select corrosion inhibitor evaluation method and standard?

Corrosion inhibitor as one of the most cost-effective measures to protect carbon steel pipes from corrosion, which has been widely used in most oil and gas fields in China. Corrosion inhibitor evaluation method and inhibition efficiency standard are critical for inhibitor selection and field application. Corrosion inhibitor was evaluated in simulated formation water by weight loss method using a coupon with same material which used in field gathering pipe. The simulated formation water prepared in laboratory (no other agents) is usually different from the formation water in the on-site pipeline (often added with scale inhibitors, emulsifiers, fungicides, etc.), under the premise of the compatibility of corrosion inhibitor with other agents, whether these agents have a positive impact (+), no impact (0), or a negative impact (-) on the inhibition efficiency is currently unclear. It is recommended to carry out the comparative tests of the inhibition efficiency at the same time with consideration of taking the formation water produced on site

(containing one or more chemicals) and the simulated formation water prepared in the laboratory (without other chemicals). And secondly, it is recommended to develop 'multi-functional agents' with two or more functions, such as anti-corrosion and anti-scale simultaneously, which can reduce the frequency of filling and the risk of incompatibility. In addition, 'Inhibition efficiency (>80%)' and 'Biggest corrosion rate (< 0.076mm/a)' are two key parameters for evaluation corrosion inhibitor, which one should be selected is the most concerned issue for technicians in oil and gas field. If the blank corrosion rate is extremely high, the corrosion rate is still much higher than 0.076mm/a even enough inhibitor was added, it is recommended to use 'Inhibition efficiency (>80%)'; If the blank corrosion rate is pretty low, the inhibition efficiency is much lower than 80% even enough inhibitor was added, it is recommended to use 'Biggest corrosion rate (< 0.076mm/a)'. One more important issue is that the current standards for corrosion inhibitor evaluation without consideration of localized corrosion rate and morphology, since sometimes even the corrosion inhibitor evaluation results meet 'Inhibition efficiency (>80%)' or 'Biggest corrosion rate (< 0.076mm/a)', severe localized corrosion occurred, generally this corrosion inhibitor is not acceptable to use in the field.

INTERNAL CORROSION PROTECTION TECHNOLOGIES

Materials selection for internal corrosion protection

The material selection of oil and gas gathering pipelines generally considers factors such as operating conditions, service life and environmental characteristics, and is determined after technical and economic comparison. According to the H₂S partial pressure and CO₂ partial pressure in the transmission medium, the service conditions of oil and gas gathering pipelines of in Western China are generally divided into four categories: Conventional (H₂S partial pressure < 0.0003MPa and CO₂ partial pressure < 0.05MPa), CO₂ dominant (H₂S partial pressure < 0.0003MPa and CO₂ partial pressure ≥ 0.05MPa), H₂S dominant (H₂S partial pressure ≥ 0.0003MPa and CO₂ partial pressure < 0.05MPa), H₂S / CO₂ dominant (H₂S partial pressure ≥ 0.0003MPa and CO₂ partial pressure ≥ 0.05MPa).^{14,15} On this basis, combined with the operating temperature and pressure of the pipeline, the recommended material selection of oil and gas gathering pipelines is shown in Table 1. It can be seen that the main pipes include non-metallic, carbon steel, low alloy steel and stainless steel. Since the key performance of non-metallic pipes is significantly affected by the pipeline operating temperature and pressure, the environmental applicability of different non-metallic materials should be fully considered, which will be described in detail in the following chapters and sections.

Table 1: Material selection recommendation for oil and gas gathering pipelines in China

Service condition	T/ °C	P/MPa	Materials	Brand / Category	Standards ^e
Conventional	<60	See remarks ^b	Non-metallic pipe ^c	High pressure glass fiber pipe, Reinforced thermoplastic composite pipe	SY/T ⁽²⁾ 6267 SY/T 6662 SY/T 6795
		-	Carbon steel or low alloy steel	20	GB/T 8163 ¹⁶ , GB 6479 ¹⁷
				20G	GB 5310 ¹⁸
				L245~L415	GB/T 9711
	≥60	-	Carbon steel or low alloy steel	20	GB/T 8163, GB 6479
				20G	GB 5310
				L245~L415	GB/T 9711
CO ₂ dominant	<60	See remarks ^b	Non-metallic pipe ^c	Same as conventional condition	Same as conventional condition

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