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Downhole corrosion behavior of Ni—W coated carbon steel in spent acid & formation water and its application in full-scale tubing

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ABSTRACT

Downhole corrosion behavior of Ni—W coated carbon steel tubing was investigated in spent acid (dilute HCl) solution and formation water by using autoclave and electrochemical techniques, in which dilute HCl with different pH is used to simulate the spent acid during flowback in acidizing process before well production, and the formation water is used to simulate the fluid during well production. Weight loss test in autoclave and electrochemical measurement indicated that Ni—W coated carbon steel exhibited higher corrosion resistance than carbon steel in spent acid and formation water, especially in spent acid with low pH and formation water at high temperature. According to weight loss test, corrosion rate ratio of carbon steel and Ni—W coated carbon steel in spent acid with pH = 1, pH = 2, and pH = 4 is 13.7, 14.5, and 6.9, respectively, while corrosion rate ratio of carbon steel and Ni—W coated carbon steel in formation water at 30 °C, 60 °C, and 90 °C is 85.5, 73.5, and 125.9, respectively. Moreover, the sealing performance of full-scale Ni—W coated carbon steel tubing was evaluated by using make-and-break test, hydraulic bursting test, and extreme downhole condition corrosion test. No sticky thread was found after 4 times of make up and three times of break out by using maximum recommended makeup torque of 4258 lbf ft, no leakage was detected after hydraulic bursting test at 95.0 MPa for 30 min, and it is observed very slight corrosion on the tubing shoulder experienced make-and-break test under extreme downhole condition.

1. Introduction

With the continuously growing demand in oil and gas energy globally, the search for new sources of oil and gas makes the operation condition became more and more severe. High temperature high pressure (HTHP) gas well was developed in northwest China increasingly with years. The average reservoir temperature is 90 °C and the initial reservoir pressure is nearly 100 MPa, the downhole partial pressure of CO_2 and H_2S is up to 4 MPa and 2 MPa, respectively, and chloride concentration is as high as 150,000 mg/L. Acidizing is employed to enhance the productivity of HTHP gas well, the acid system is HCl-based including 15% HCl, 1.5% HF, 3% HAc, and inhibitor. Super 13Cr martensitic stainless steels tubing was used for well completion and production, field statistics shows several gas well failure after 1–3 years of production due to pitting corrosion of 13 Cr tubing, moreover, over 70% failed gas well was acidized before production. Besides the corrosion attack by acid during acidizing process, in the long-term production process, the presence of CO_2, H_2S, and high chloride concentration in formation water plays a key role in the corrosion

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Table 1
Chemical composition analysis of Ni—W coated carbon steel and carbon steel (wt%)

Element	C	Fe	Si	P	Ni	W	Cr	Mn
Ni—W coated carbon steel	/	2.02	/	3.29	73.37	21.32	/	/
Carbon steel	0.62	97.78	0.21	/	/	/	0.88	0.51

failure of downhole tubing. The corrosivity of downhole environment is further complicated and enhanced by the high temperature and high pressure, it is well acknowledged that temperature accelerated the kinetics of corrosion reactions, as well as pressure contributes to internal corrosion in terms of higher downhole pressure increasing the partial pressure or solubility of naturally occurring corrosive acid gases, such as CO_2 and H_2S [1,2].

Both field data and lab research indicated that 13Cr martensitic stainless steel tubing is no longer the best choice for HTHP well, especially in spent HCl solution during flowback and high chloride concentration at high temperature [3–5]. The correct strategy in the choice of tubing material is becoming increasingly significant, safety and cost have to be preferentially considered for tubing material selection, in the petroleum exploration and production industry, the major corrosion resistant alloys used fall into three categories: martensitic stainless steels, duplex stainless steels, and Ni-based alloys [6]. It is well-known that the Ni-based alloys are the best choice with overall desirable properties, but the biggest disadvantage is that the Ni-based alloys are prohibitively expensive used as downhole tubing. However, development of Ni-based alloy coating on carbon steel is an economical alternative choice, providing excellent corrosion resistance and wear resistance. Extensive studies have been carried out to investigate the mechanical and corrosion performance of Ni-based alloy coating, such as Ni—P [7], Ni—P—W [8], Ni—SiC [9], Ni—TiN [10], under various environmental conditions.

In this work, downhole corrosion behavior of Ni—W coated carbon steel tubing was studied in HCl solution with different pH and formation water by using autoclave, HCl solution with different pH is used to simulate the spent acid during flowback in acidizing process before well production, and the formation water is used to simulate the fluid during well production. Meanwhile, corrosion mechanism in terms of electrochemical corrosion behavior was characterized by potentiodynamic polarization technique, electrochemical impedance spectroscopy (EIS). For all the tests, the carbon steel sample without coating was used for comparison. Moreover, Ni—W coating was applied to full-scale carbon steel tubing, the full-scale tubing sealing performance was evaluated by using make-and-break test, hydraulic bursting test, and extreme downhole condition corrosion test. It is expected that this work would provide technical support for potential application of Ni—W coated carbon steel tubing in HTHP gas well.

2. Experimental

2.1. Electrode and solution

Carbon steel tubing and Ni—W coated carbon steel tubing (Hunan Nanofilm New Material Technology Co., Ltd.) were used in this work, in which Ni—W coated carbon steel is being planned to use for gas well tubing in western China. The chemical composition is given in Table 1, and microstructure is shown in Fig. 1. The specimens for weight loss test in autoclave were machined into pieces with a dimension of 40 mm × 10 mm × 3 mm. The specimens for electrochemical measurement were machined into pieces with a dimension of 10 mm × 10 mm × 2 mm, and then embedded in epoxy resin with an exposed working area of 1 cm^2. For Ni—W coated carbon steel sample, part of the machined coupons, including autoclave test and electrochemical measurement sample, were electrodeposited with Ni—W coating. Prior to experiment, the working surface of carbon steel specimen was sequentially grounded with 320 grit, 600 grit, 800 grit, 1000 grit and 1200 grit SiC papers, polished with 0.1 μm alumina polishing powder. Then the surface-treated carbon steel sample and as-prepared Ni—W coated carbon steel sample degreased with alcohol, cleaned in water, and finally dried in air.

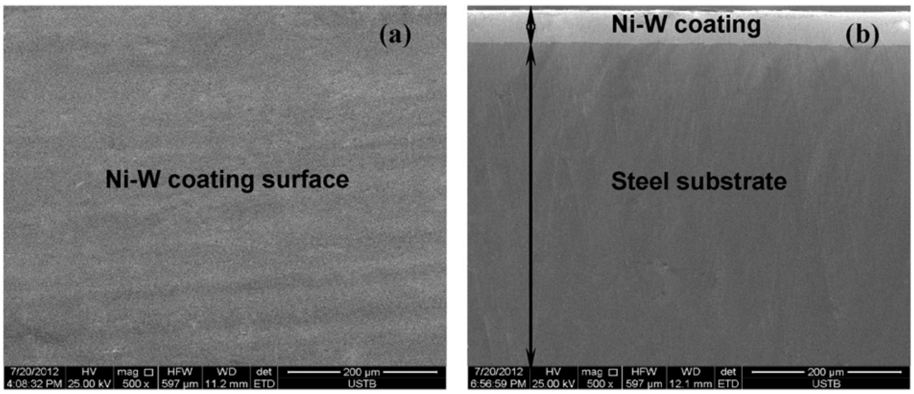

Fig. 1. SEM images of Ni—W coating (a. top view; b. cross-sectional view)