

Research on Well Casings Cathodic Protection Based on Field

Testing and Numerical Simulation

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Abstract

Cathodic protection (CP) is often used to protect steel well casings from external corrosion. However, it is difficult to measure the CP potential distribution along the well casing, which brings about difficulties on CP design and effectiveness evaluation. In this paper, the polarization characteristics of casing steel in different soil layers were obtained by polarization testing at different soil depths in the field. Based on measured polarization characteristics, geometry of well casing and soil resistivities of different soil layers, a numerical simulation model for CP of well casing was established. CP current requirement and CP potential distribution of well casings were estimated by calculating and field testing. Additionally, the effects of soil resistivity and casing polarization characteristics on CP potential distribution of well casing were studied by numerical simulation.

INTRODUCTION

Deep well casing is an important part of oilfield production. In the long service life of well casing, corrosion can result in wall thinning and even perforation of the casing due to contacting with soil, water and other naturally occurring substances within the formation. The most economic and effective method to decrease corrosion of well casing is cathodic protection (CP). However, the vertical depth of casing is several kilometers, and CP current requirements of casing in different layers are quite different [1-2]. At the same time, the conductivity of different formations will affect the distribution of CP current. It is difficult to measure CP potential distribution along well casing, which brings about difficulties on CP design and effectiveness evaluation.

With the development of computer, many studies have shown that numerical simulation can determine the distribution of CP current and potential [3-8]. But things such as soil structural model and appropriate boundary conditions have to be addressed as the technology is applied for well casing. In this paper, E-log I method was used to determine the current requirement of single well casing. The polarization characteristics of well casing steel at different depths were measured by integrated coupon reference assemblies put at different depths. The numerical simulation technology was adopted to analyze the influence of soil resistivity on the CP potential distribution along casing.

MATHEMATICAL MODEL

The mathematical model of CP potential distribution in deep well casing is described by equations (1) - (5):

$$\left\{ \begin{array}{l} V: \frac{\partial}{\partial x} \left(\sigma \frac{\partial \varphi}{\partial x} \right) + \frac{\partial}{\partial y} \left(\sigma \frac{\partial \varphi}{\partial y} \right) + \frac{\partial}{\partial z} \left(\sigma \frac{\partial \varphi}{\partial z} \right) = 0 \quad (1) \\ \Gamma_A: \sigma \frac{\partial \varphi}{\partial n} + j_a = 0 \quad (2) \\ \Gamma_C: \sigma \frac{\partial \varphi}{\partial n} + f(\varphi_c - \varphi) = 0 \quad (3) \\ \Gamma_I: \partial \varphi / \partial n = 0 \quad (4) \\ \varphi_a - \varphi_c = \Delta \varphi_{\text{power}} \quad (5) \end{array} \right.$$

Where, V- soil area; x, y, z- spatial coordinates; φ - the potential within soil area; Γ_A -soil boundary around auxiliary anode; σ - soil conductivity; j_a - polarization current density on auxiliary anode surface; Γ_C - soil boundary around well casing; φ_a -auxiliary anode potential; φ_c -cathodic potential of well casing; Γ_I -insulating boundary of soil area; $\Delta \varphi_{\text{power}}$ -external power supply potential.

In the above mathematical model, the impressed current cathodic protection is used for deep well casing, without considering the potential drop along anode, cathode and cable. Equation (1) describes the potential distribution after the whole system is stable in soil. Equation (2) is the boundary condition of the auxiliary anode, with the constant current density condition. Equation (3) is the cathode boundary condition described by polarization characteristics of well casing at different depths. Equation (4) is the insulation boundary condition. Equation (5) determines the potential relationship between anode and cathode. After the potential reference point is selected and relevant parameters in equations (2) and (3) through field tests could be determined, and the potential distribution in the whole soil domain can be calculated by boundary element method.

ESTABLISHMENT OF CASING GEOMETRIC MODEL AND MESHING

The studied well casing crosses various geological structures such as soil layer, rock layer and water layer. The basic information of the casing is as follows:

Casing size: the depth of well casing is 1880m. 0~210m: $\Phi 244.5\text{mm}$; 210~1880m: $\Phi 139.7\text{mm}$.

Deep well anode groundbed size: the active length of anode groundbed: 20m; the depth of deep anode groundbed: 120m; the diameter of the groundbed: $\Phi 215\text{mm}$.

As shown in Figure 1, the CP system for a single well was established according to the actual size of casing and auxiliary anode ground bed.

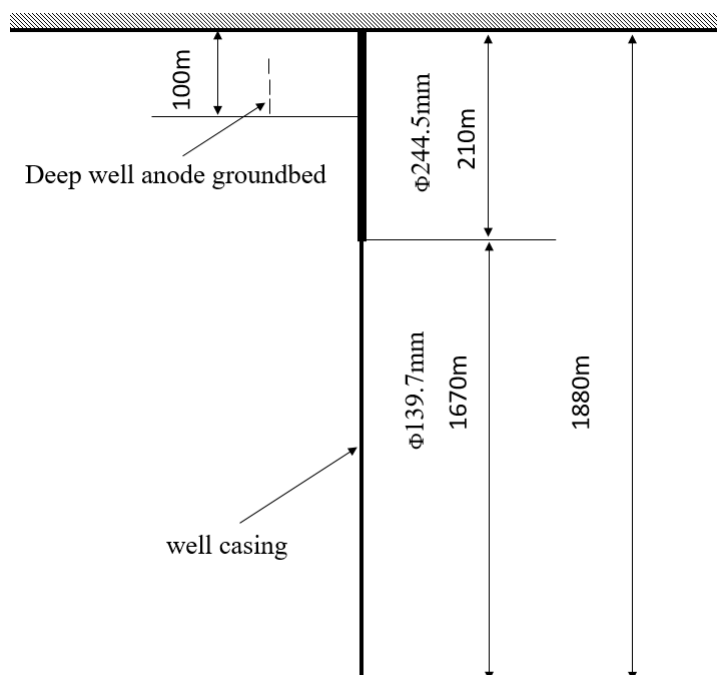


Figure 1 the cathodic protection system for single well

Soil resistivity of different layers were collected by electricity method, as shown in Table 1.

Table 1 Typical topology of field soil layers

Geometric Modeling Data				
Soil layer	Depth/m	Soil Resistivity $\Omega \cdot m$	Soil Interface	Depth/m
1	0-180	45	1	180
2	180-280	25	2	280
3	280-450	14	3	450
4	450-810	13	4	810
5	810-860	2	5	860
6	860-1100	18	6	1100
7	1100-1330	19	7	1330
8	1330-1880	13	8	1880

After geometric model established, the model was meshed, and the resulting graph was shown in Figure 2.

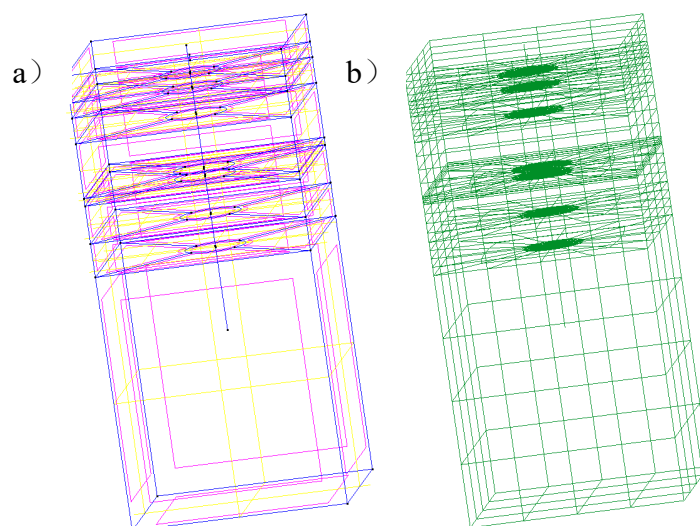


Figure 2 a) Three-dimensional models of well casing b) Mesh generation of well casing

POLARIZATION CHARACTERISTIC TEST

In order to get the polarization characteristics of casing steel in different depths, one coupon reference assembly with three electrodes was designed. The coupon reference assembly contained three casing samples, one MMO auxiliary anode, one long-term CuSO_4 reference electrode and one MnO_2 reference electrode, as shown in Figure 3. Copper-copper sulfate electrode (CSE) is the most commonly used half-cell

in soil applications, whereas MnO_2 reference electrode has longer lifetime, therefore these two kinds of reference electrodes were adopted in the tests to ensure the long life time of the assembly. Because there is difference between these two kinds of reference electrodes, so it is necessary to record the difference between MnO_2 and CuSO_4 potential, as shown in Table 2. They were installed at different depths of 1m, 20m and 40m in a dedicated vertical borehole. The polarization testing was conducted after two days to allow polarization levels to stabilize. The assembly, as it was laid out prior to installation is shown in Figure 4. the test result was shown in Figure 5. The blue line, red line and black line represent the polarization curves of casing sample in the depth of 1m, 20m and 40m respectively. As shown in Figure 5, because the oxygen content in soil decreases gradually with increasing depth and the free corrosion potential of the samples becomes more electronegative as a result. It also can be found that the polarization characteristics of the samples are significantly different with increasing depth. When the buried depth is only 1m, the sample has the region where the cathodic reaction is controlled by the diffusion of oxygen. When the buried depth reaches 20m and 40m, the samples are not controlled by the diffusion of oxygen. The CP criteria of samples are different under different levels of oxygen saturation. According to NACE-SP0169-2013, protection criterion of carbon steel is $-850\text{mV}_{\text{CSE}}$ in aerobic conditions. In contrast, the protection criterion was $-950\text{mV}_{\text{CSE}}$ in anaerobic conditions. Based on the results of the polarization tests in the field, the current density is 58.01 mA/m^2 , as the sample at 1m reaches $-850\text{ mV}_{\text{CSE}}$ ($-665\text{ mV}_{\text{MnO}_2}$). The current density of sample reaching $-950\text{ mV}_{\text{CSE}}$ ($-787\text{ mV}_{\text{MnO}_2}$) was 57.52 mA/m^2 at 20m and $-950\text{ mV}_{\text{CSE}}$ ($-778\text{ mV}_{\text{MnO}_2}$) was 18.30mA/m^2 at 40m. By comparison of polarization curves, for sample installed at 40m the minimum protection current density is 68% less than the sample installed at 1m in order to achieve the $-850\text{ mV}_{\text{CSE}}$ polarization potential.