Research on Anti-Corrosion and Coating Technology of Outer Pipes of Submarine Pipelines Shallow Sea by Physical Testing

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Abstract. In this paper, by discussing the characteristics of the beach and shallow sea marine environment, combining with engineering design and application, studying the anti-corrosion coating and coating technology of the outer pipe of the pipeline, and analyzing the design of the concrete counterweight layer of the submarine pipeline. According to the submarine pipeline of the environment, structural characteristics, construction methods, etc, the reasons for the damage of the external protective coating under certain conditions are explained, so as to select the external protective coating more reasonably, and provide data for the anti-corrosion and coating selection of the marine pipeline.

Keywords: Subsea pipeline, Coating process, Corrosion damage, Beach and shallow waters.

1. Introduction
With the continuous development of offshore oil, the amount of submarine pipelines used to transport petroleum and natural gas has increased dramatically. In order to prevent the invasion and destruction of the marine environment, new and higher requirements for the anti-corrosion of submarine pipelines have been put forward and a comprehensive analysis has been carried out. How to determine the design and coating process of the outer protective coating thickness of the pipeline to make further analysis and demonstration.

2. Corrosion and damage characteristics of submarine pipelines in shallow waters
Due to the high salt content of seawater, it is one of the most corrosive media among natural corrosives. Studies have shown that the same pipeline material for transporting fluid media is 300-400 times more corrosive in the sea than in other dry areas. Salt spray, humidity, dissolved oxygen, salt concentration, waves, currents and impacts, marine organisms, bacteria, etc. in the ocean atmosphere can cause damage to the steel structure of submarine pipelines. Corrosion damage is a very prominent problem when submarine pipelines are laid in a complex and changeable submarine environment. Corrosion of
submarine pipelines on beaches and shallow seas has the characteristics of shallow water, high levels of oxygen, silt, suspended solids, and microorganisms in the seawater, and strong corrosion resistance in the seawater [1].

3. Corrosion factors of submarine pipelines in shallow waters

3.1. The influence of temperature
The increase in sea water temperature will promote the corrosion reaction rate. The changes in temperature will cause changes in other marine environments. As the temperature of sea water rises, the diffusion rate of dissolved oxygen will increase with the increase in temperature, which further accelerates the corrosion rate of metals.

| Temperature  | Distance     | Corrosion rate (mm/a) |
|--------------|--------------|-----------------------|
| -8~9         | natural      | 0.031                 |
| 15           | North        | 0.0528                |
| 25           | South        | 0.0128                |
| 50           | Interface temperature | 0.0129               |

3.2. The influence of dissolved oxygen
Dissolved oxygen is an important factor affecting pipeline corrosion. Increasing oxygen. Increasing oxygen concentration will accelerate the corrosion process, but for metals such as aluminum and stainless steel that rely on passivation film to improve corrosion resistance, the increase in oxygen concentration in the ocean will help the formation and repair of passivation film, which can improve the passivation film. Stability, reduce pitting and crevice corrosion of metal pipes.

3.3. The influence of salinity
The salt content affects the conductivity and oxygen content of seawater, and therefore impacts on corrosion. As the salt content increases, the conductivity of water increases while the oxygen content decreases, so the salt content will have a parabolic effect on corrosion.

4. The structure and cathodic protection design of submarine pipelines

4.1. The structural form of submarine pipeline
The structure of submarine pipelines is generally determined by the characteristics of the conveying fluid and the marine environment in which the pipeline is located. The anti-corrosion coating of the outer pipe of the pipeline is required to separate the outer layer of the steel pipe from the harsh marine environment. Most of the double-layer steel insulation pipes are used, which are composed of an inner pipe, an outer pipe, an insulation layer, an anti-corrosion layer or a protective layer and a counterweight layer.

![Figure 1. Structure of submarine pipeline.](image)
4.2. Requirements for outer anticorrosive coating materials of submarine pipeline

Anti-corrosion materials for submarine petroleum pipelines have a variety of performance requirements: impermeability, good surface adhesion; resistance to erosion and collision; strong resistance to cathodic disbondment; good durability and low cost; health, environmental protection, and safety. At present, the commonly used outer coatings are: fusion bonded epoxy coating, polyethylene coating, coal tar enamel coating, composite coating, coal tar epoxy coating.

When choosing the coating in the actual project, the specific environment of the coating must be considered, such as the diameter of the pipeline, the temperature of the pipeline system, the nature of the carried items, the pipeline laying method, and the cathodic protection system used in conjunction.

4.3. Submarine pipeline sacrificial anode material

The material of the sacrificial anode method should meet the following basic requirements: (a) There is a sufficiently negative stable potential; (b) The self-corrosion rate is small and uniform, with high and stable current efficiency; (c) High electrochemical equivalent; (d) The anode polarization should be small, dissolve uniformly, and the product is easy to fall; (e) Wide source, easy to obtain, low price, no pollution. The materials of sacrificial anode method for marine pipelines are mainly zinc, magnesium, aluminum and their alloys. Zinc alloy materials produce intergranular corrosion at a temperature higher than a certain temperature to accelerate the loss of zinc, while the driving potential of metal aluminum can remain unchanged, so the anode protection material is mainly aluminum alloy.

5. Design principle of pipeline concrete counterweight layer

5.1. Design density of concrete counterweight layer

The material of the submarine pipeline concrete counterweight layer is made by mixing sand, cement, lead ore aggregate and water in proportion. The purpose of the submarine pipeline counterweight is to increase the weight and stability of the pipeline. The requirements for higher density concrete are relatively strict. The iron content of these iron ore sands must be high, mainly to increase the weight of the cement. The concrete density of the counterweight layer determines a reasonable range according to the relative sensitivity of the submarine pipeline structure to the fluid dynamics acting on it.

5.2. Extrusion strength of concrete counterweight

The compressive strength refers to the ultimate strength when an external force is applied. The concrete weight layer should have sufficient compressive strength to ensure that the weight layer will not be crushed and fall off under complicated conditions. The higher the weight layer’s compressive strength, the greater the stiffness, and vice versa. The lower the compressive strength, the lower the stiffness. The submarine pipeline is divided into three sections in the laying process: pipe-laying vessel operation area, trusteeship area, and catenary area. Generally speaking, the thickness of the concrete counterweight layer is positively related to the stiffness of the soil ring. Even if the concrete compressive strength is large enough, the concrete ring may be crushed by the clamping jaws. Therefore, the design of concrete counterweight layer should consider the compressive strength and minimum stiffness of concrete at the same time [2].
Figure 2. Laying diagram of conventional S-type submarine pipeline.

The squeezing load of the tensioner clamping claw on the coated steel pipe can be calculated according to formula (1):

$$F_s = \frac{F_T}{\mu}$$  \hspace{1cm} (1)

Formula: $F_s$ - The total squeezing force of the tensioner clamping claw on the coating tube, N; $F_T$ - Axial tension of the pipe, N; $\mu$ - The coefficient of friction between the surface of the clamping jaw of the tensioner and the outer coating of the steel pipe.

The squeezing stress of the tensioner clamping claw on the coated steel pipe can be calculated according to formula (2):

$$R_{tc} = \frac{F_s}{N_t A_t}$$  \hspace{1cm} (2)

Formula: $N_t$ - The total number of clamping jaws of the tensioner clamping the coating tube; $A_t$ - The contact area between the clamping jaws of the tensioner and the pipe.

$$\varepsilon_{mean} = -\frac{D}{2R} + \varepsilon_{axial}$$  \hspace{1cm} (3)

$$\gamma_{cc} \cdot \varepsilon_{mean} \geq \varepsilon_{cc}$$  \hspace{1cm} (4)

Formula: $R$ - Steer radius (Bend radius of pipe upper bend) m; $D$ - Steel pipe diameter, m; $\varepsilon_{mean}$ - The calculated average strain of the upward bending section; $\varepsilon_{axial}$ - Axial strain effect; $\gamma_{cc}$ - Concrete extrusion safety factor; $\varepsilon_{cc}$ - The ultimate average strain of concrete extrusion.

6. Coating process of outer anticorrosive coating for submarine pipeline

6.1. Coating process of outer anticorrosive coating for submarine pipeline
Before laying the submarine pipeline, an evaluation test must be carried out. First, spray brushing to remove rust; second, paint brushing, heat shrinkable tape and intermediate frequency heating; third, fill with high-density polyurethane. Shot blasting, rust removal, heating and removal of oil and oxide treatment [3].
6.2. Coating process of concrete counterweight layer

The coating process of the concrete weight layer is generally divided into two types: spray coating and extrusion coating. The former is used for concrete reinforcement, and the latter is used for concrete reinforcement and steel mesh.

7. Conclusion and Suggestion

(1) Through the above analysis, we have a clearer understanding of the environment and corrosion characteristics of the submarine pipeline in the shallow sea and the structure of the pipeline.

(2) Introduce the external anti-corrosion coating materials and coating technology of the beach and shallow sea pipelines, the parameters and material selection of the sacrificial anode method protection design, and provide a basis for scientific selection.

(3) By comparing the fluid dynamics and stability of the concrete counterweight layer pipeline, we understand how to choose the most economical concrete density.

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