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# Research on Erosion Mechanism and Protection Technology of Sand Bearing Fluid Pipeline

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**Abstract:** The purpose of this study is to explore the influencing factors of sand bearing fluid on pipeline erosion and evaluate the effects of different protection technologies. Through the construction of erosion testing equipment, the influence of sand particle size, concentration and flow rate on the erosion rate was systematically studied. The results show that the increase of sand particle size and concentration and the increase of flow rate will significantly increase the erosion rate. In addition, coating protection technology and alloying technology have been proved to be effective in reducing the erosion rate, and coating protection technology shows better protection effect. It provides theoretical basis and data support for pipeline design and protection in sand bearing fluid environment.

**Keywords:** Sand Bearing Fluid; Pipeline Erosion; Velocity of Flow; Coating Protection.

## 1. Introduction

Pipelines often face erosion problems in sand-bearing fluid environments, which pose a serious threat to the safe operation and service life of pipelines. Understanding the factors that affect the erosion rate and evaluating the effectiveness of different protection technologies are critical to improving the corrosion resistance of pipelines. In this study, the effects of sand particle size, concentration and flow rate on corrosion resistance were systematically studied, and the protective effects of coating protection technology and alloying technology were evaluated to provide theoretical and data support for pipeline design and protection in sand bearing fluid environment.

## 2. Theoretical Basis

### 2.1. Introduction to Erosion Mechanism

Pipe erosion is caused by the mechanical wear of the sand particles on the inner wall of the pipe when the sand-bearing fluid flows through the pipe. This process is affected by many factors such as the particle size, shape, hardness, concentration of the sand particles, the speed of the fluid, the viscosity and the material properties of the pipe. The erosion mechanism mainly includes cutting action, fatigue action and compression action. The cutting action means that the sand particles hit the inner wall of the pipeline at a certain Angle, causing the material to be cut or stripped. The fatigue effect is due to the repeated impact of sand particles in the fluid on the inner wall of the pipeline, resulting in micro-cracks on the surface of the material, which gradually expand with the passage of time and eventually lead to material damage. Compression refers to the compression stress on the material when the sand particle hits the inner wall of the pipe, resulting in deformation or density increase of the material [1].

### 2.2. Erosion Rate Calculation Formula

Erosion rate is an important parameter to evaluate the erosion resistance of materials, which is usually defined as the material mass or volume loss caused by erosion in unit time [2]. The formula for calculating the erosion rate can vary according to the actual situation and research needs. The following are two common formulas for calculating the erosion rate:

(1) Mass loss method: This method measures the material mass loss due to erosion in a specific period of time [3]. The calculation formula is:

$$E_m = \frac{\Delta m}{\rho \times A \times t}$$

Where $E_m$ is the mass loss erosion rate (kg/(m²·s)), Δm is the mass loss (kg), ρ is the material density (kg/m³), A is the erosive surface area (m²) and t is the erosive time (s).

(2) Depth loss method: This method measures the depth loss of the material surface due to erosion in a specific time [4]. The calculation formula is:

$$E_d = \frac{\Delta d}{t}$$

Where $E_d$ is the depth loss erosion rate (mm/s), Δd is the depth loss (mm) and t is the erosion time (s).

### 2.3. Principles of Protection Technology

#### 2.3.1. Coating Protection Technology

Coating protection technology is a method to prevent erosion by applying a protective layer on the surface of the pipeline. This protective layer is usually made of wear-resistant and corrosion-resistant materials such as ceramics, metal alloys or polymer composite materials. The main function of the coating is to form a physical barrier to prevent sand particles from directly contacting and wearing the inner wall of the pipeline [5]. In addition, some coating materials can also provide chemical stability, resistance to corrosion components in the fluid, coating material selection, thickness and construction process are crucial to the pipe wall protection effect, reasonable design and construction of the coating can not only effectively extend the service life of the pipe but also improve the overall performance and safety of the system.

#### 2.3.2. Alloying Technique

Alloying technology is a method of changing the chemical composition of pipe materials and combining them with other metals or elements to improve their erosion resistance. This technology usually involves adding elements such as chromium, nickel and molybdenum to form alloys with excellent wear resistance and corrosion resistance [6]. Alloying can not only enhance the hardness and toughness of the material, so as to resist the impact and wear of sand particles, but also improve the corrosion resistance of the material and prevent damage caused by chemical reactions. The key of alloying technology is to select the appropriate alloying elements and proportions and ensure the uniformity and stability of the alloy. Through rational alloy design and preparation technology alloying technology can significantly improve the corrosion resistance of the pipeline and prolong its service life.

#### 2.3.3. Other Protection Methods

In addition to coating protection technology and alloying technology, there are other protection methods to improve the corrosion resistance of pipelines, these protection methods have their own characteristics, and can be selected and combined according to the actual application scenario and economic considerations to achieve the best protection effect. Thermal spraying technology can spray a layer of wear-resistant material, such as metal or ceramic, on the surface of the pipe to form a strong protective layer; Surface treatment such as carburizing, nitriding or laser can improve the hardness of the pipe surface and reduce wear; In some cases, the use of bimetal pipe is also an effective protection strategy, that is, the use of high wear-resistant materials in the inner wall of the pipe and the use of high strength materials in the outer wall; In addition, the optimization of fluid dynamic design such as changing the fluid flow path or using diversion devices can also reduce the occurrence of erosion [7].

## 3. Analysis of Influencing Factors of Pipeline Erosion

Before discussing the erosion mechanism and protection technology of sand-bearing fluid pipeline, it is necessary to deeply analyze the main factors affecting pipeline erosion, which include not only the physical characteristics of fluid and sand, but also the properties of pipeline materials and external environmental conditions. In-depth understanding of these factors is of great significance for designing effective protection measures and optimizing pipeline operation parameters.

### 3.1. Fluid Characteristic

The physical properties of the fluid such as density, viscosity and flow rate have a direct effect on the erosion process. Flow velocity is one of the most critical factors, which determines the kinetic energy of sand particles in the fluid. The higher the flow velocity, the greater the impact of sand particles on the pipeline, thus increasing the severity of erosion. Fluid viscosity will also affect the erosion process, and fluids with higher viscosity can mitigate the impact of sand particles on the pipeline to a certain extent [8].

### 3.2. Sand Characteristics

The particle size, shape and hardness of sand are important factors to determine the degree of erosion. The larger particle size sand has higher kinetic energy, so the wear effect on the pipeline is stronger. Sharp-shaped sand makes it easier to cut pipe materials and increase erosion losses; Sand with higher hardness will also increase the wear degree of the pipeline [9]. In addition, the concentration of sand will also affect the erosion rate, the higher the concentration, the more the impact of the pipeline surface, the more serious the erosion.

### 3.3. Pipeline Material Characteristics

The material properties of the pipeline such as hardness, toughness and corrosion resistance have an important impact on its erosion resistance. Materials with higher hardness usually have better wear resistance, but may lack enough toughness to resist impact. Although materials with better toughness can absorb a certain amount of impact energy, they may be more vulnerable to wear. Therefore, various performance indexes should be comprehensively considered in the selection of pipeline materials [10].

### 3.4. External Environmental Condition

External environmental conditions such as temperature and chemical media will also affect the erosion of the pipeline, and temperature changes will affect the performance of the material, which may lead to reduced performance of the pipeline material under high or low temperature conditions. Chemical media may cause corrosion of pipeline materials and increase the complexity of erosion. Therefore, these external factors should be considered in the design and operation of pipelines.

## 4. Application and Effect Evaluation of Erosion Protection Technology

In order to accurately evaluate the influence of sand particle size, concentration and flow rate on pipeline erosion rate, this study adopted experimental methods for detailed analysis, simulated the flow of sand bearing fluid in the pipeline by constructing a special erosion test device, and measured the pipeline erosion rate under different conditions of sand particle size, concentration and flow rate. In order to ensure the reliability of experimental results, the experimental design is strictly planned to ensure the accurate control of experimental conditions and the accurate adjustment of variables. High-precision measuring instruments and technologies are used to collect data to ensure the accuracy and reliability of data. In order to ensure the consistency and repeatability of the results, repeated experiments were carried out in each group of experimental conditions.

### 4.1. The Influence of Sand Particle Size and Concentration on Corrosion Resistance

**Table 1.** Pipeline erosion rate under different sand particle size and concentration

| ID | Sand particle size (μm) | Sand concentration (%) | Erosion rate (g/m²·s) |
|---|---|---|---|
| 1 | 100 | 1 | 0.2 |
| 2 | 100 | 5 | 0.8 |
| 3 | 200 | 1 | 0.5 |
| 4 | 200 | 5 | 2 |
| 5 | 300 | 1 | 0.7 |
| 6 | 300 | 5 | 2.8 |

Table 1 studies the influence of sand particle size and concentration on pipeline erosion rate, indicating that with the increase of sand particle size and concentration, the erosion rate increases significantly. When the sand particle size increases from 100μm to 300μm, no matter the sand concentration is 1% or 5%, the erosion rate shows an obvious upward trend, which indicates that larger sand particles have stronger impact capacity. It can cause more severe wear to the pipe material per unit time. Through the analysis of the data in the table, it can be seen that the possible sand particle size in the fluid should be considered in the design and selection of pipeline materials, and the materials with sufficient erosion resistance should be selected. For the sand containing fluid, the sand concentration should be controlled as much as possible to reduce the erosion damage, which provides an important basis for the formulation of pipeline protection measures, and helps to optimize the design of the pipeline and extend its service life.

## 4.2. The Effect of Flow Rate on Erosion

**Table 2.** Pipeline erosion rates at different flow rates

| ID | Velocity of flow (m/s) | Erosion rate (g/m²·s) |
|---|---|---|
| 1 | 1 | 0.5 |
| 2 | 2 | 1 |
| 3 | 3 | 1.8 |
| 4 | 4 | 2.5 |
| 5 | 5 | 3.2 |

Table 2 explores the influence of flow velocity on the erosion rate of the pipeline. The results show that the erosion rate increases significantly with the increase of flow velocity. When the flow velocity increases from 1 m/s to 5 m/s, the erosion rate increases by about 6.4 times. This result is consistent with the principle of fluid dynamics, that is, the kinetic energy of the fluid is proportional to the square of the velocity. When these high-speed sand particles hit the surface of the pipeline, stronger impact force will be generated, resulting in more serious erosion damage. In addition, the shear effect of fluid on the surface of the pipeline at high flow rate will be stronger, which will also aggravate the degree of erosion [11]. Flow rate is one of the key factors affecting the erosion rate of pipelines. In the process of transportation and treatment of sand-bearing fluids, the flow rate should be controlled within a reasonable range to reduce the damage of erosion to pipelines. For applications with high flow rate, pipeline materials with higher erosion resistance should be selected. Additional protective measures such as coating protection or alloying technology can be used to improve the durability and reliability of the pipeline.

## 4.3. Evaluation of the Effectiveness of Protective Techniques

**Table 3.** Erosion rate of pipeline under different protection techniques

| ID | Protection technique | Erosion rate (g/m²·s) |
|---|---|---|
| 1 | unguard | 2.5 |
| 2 | Coating protection | 1.2 |
| 3 | Alloying technique | 1.5 |

Table 3 evaluates the effect of coating protection and alloying technology on the erosion rate of the pipeline, and the results show that the pipeline samples with coating protection and alloying technology show a lower erosion rate. These results show that the appropriate protection technology can significantly improve the corrosion resistance of the pipeline. The selection of the protection technology in practical applications needs to consider the erosion environment, pipeline material, cost and maintenance factors. The coating protection technology is suitable for the situation that requires additional wear layers, while the alloying technology is more suitable for the application that has higher requirements for the performance of the pipeline material. The results also suggest that in the case of serious erosion threats, it may be necessary to combine a variety of protective measures to achieve the best protective effect. Reasonable selection and application of protective technology can effectively extend the service life of the pipeline and ensure the safe and stable operation of the sand-bearing fluid transport system.

# 5. Result Analysis and Discussion

## 5.1. Erosion Mechanism Analysis

In this paper, the effects of coating protection and alloying technology on the erosion rate of the pipeline are evaluated. It is shown that the samples using the protection technology show a lower erosion rate. The coating protection technology effectively prevents the sand from contacting the pipeline material directly by forming a protective layer of wear and corrosion resistance on the pipe surface, thereby reducing the erosion damage. Alloying technology by changing the chemical composition of the pipeline material, improve the wear resistance and corrosion resistance of the material itself to enhance its erosion resistance, this technology usually involves the addition of elements such as chromium, nickel, molybdenum and other elements to form an alloy with excellent properties. It can be seen that the coating protection technology shows a better protective effect, which may be related to the properties of the coating material and the thickness of the coating, but alloying technology is still an effective means of protection, especially for applications that need to improve the performance of the material itself [12].

## 5.2. The Mechanism of Protective Technology

The mechanism of the protection technology is mainly to enhance the wear resistance, corrosion resistance and impact resistance of the pipeline material to effectively reduce the wear and damage of the sand-bearing fluid to the pipeline. Coating protection technology reduces physical wear by forming a hard protective layer on the surface of the pipe, acting as a physical barrier to prevent sand particles from directly contacting the pipe material. The chemical stability of the coating material can resist the corrosive components in the fluid, prevent chemical corrosion damage to the pipe, and disperse the impact force to reduce local stress concentration. Reduce material fatigue and cracking due to stress concentration. Alloying technology by changing the chemical composition of the pipeline material, improve its hardness and wear resistance, so that it can better resist the wear of sand, adding anti-corrosion elements (such as chromium, nickel, etc.) to enhance the corrosion resistance of the material, reduce the impact of chemical corrosion on the pipeline, while alloying can change the grain refinement of the material, the second phase strengthening and another microstructure. Thus improve the comprehensive properties of the material.

# 6. Summary

In this study, the influence factors on the erosion of sand bearing fluid pipeline were deeply analyzed through experimental methods, and the effects of different protection technologies were evaluated. The experimental results showed that the particle size, concentration and flow rate of sand would significantly affect the erosion rate, and the coating protection technology and alloying technology could effectively reduce the erosion rate, providing an important reference for the design and protection of sand bearing fluid pipeline. In practical applications, suitable protective measures can be selected according to working conditions, and regular inspection and maintenance are carried out to ensure the safe and stable operation of the pipeline. These research results can also be applied to other fields such as oil exploitation and offshore engineering to provide reference for solving similar erosion problems. The subsequent research can further explore the application effect of other protection technologies and the erosion mechanism under different working conditions, to provide more comprehensive guidance for the safe operation and maintenance of pipelines.

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