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# Current Status and Progress of Research on Oil and Gas Pipeline Failure Analysis

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## Abstract

**With the development of social economy, the service mileage of oil and gas pipelines is increasing, and their service life is gradually extending. This article analyzes the types of pipeline failures and their solutions, including third-party mechanical damage, corrosion damage (external and internal corrosion), and the impact of natural disasters on pipeline safety. These issues directly threaten the stability and safety of pipeline operations. In terms of key technologies, it details the application of real-time monitoring technology, anti-corrosion coating technology, advanced materials, and new non-destructive testing technologies. These technologies are crucial for enhancing the stability and safety of pipeline operations.**

## Keywords

**Pipeline Transportation; Failure Analysis; Key Technologies.**

## 1. Introduction

With the development of social economy, the demand for oil and natural gas resources among the people and various enterprises is gradually increasing[1]. As one of the main modes of transportation in today's production and life, pipelines have significant advantages such as saving land resources, high transportation efficiency, low cost, and simple laying, making them highly suitable as carriers for the transportation of oil and natural gas.

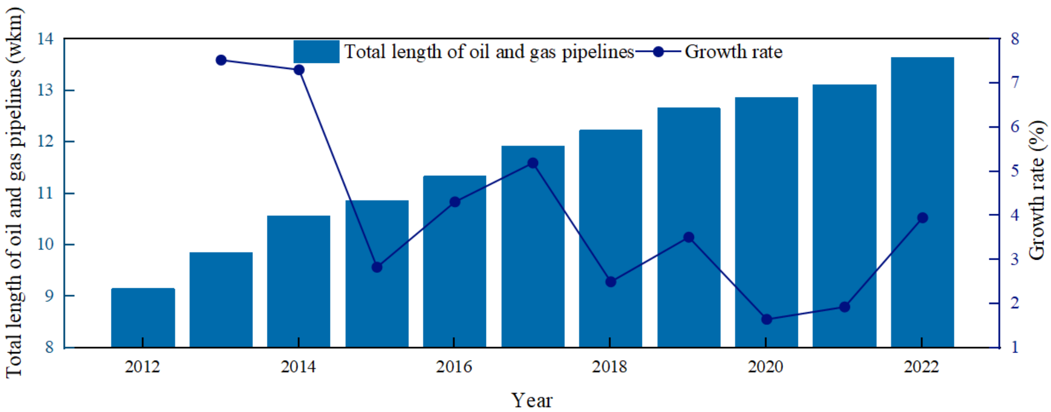


**Figure 1.** Total mileage of oil and gas pipelines in China from 2012 to 2022

According to data from the National Bureau of Statistics, the total mileage of oil and gas pipelines in China increased from $9.16\times10^4$ km to $13.64\times10^4$ km from 2012 to 2022 (Figure 1). The market size of China's oil and gas pipeline industry continues to expand, with investment scale and pipeline network coverage also increasing. By the end of 2023, among China's long-distance oil and gas pipelines, crude oil pipelines accounted for about 17%, refined oil pipelines accounted for about 17%, and natural gas pipelines accounted for about 64%, with the total mileage ranking third in the world[2]. However, pipeline failure can have severe consequences. In July 2016, the Sichuan-to-East Gas Pipeline suffered a rupture and explosion due to a

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landslide, resulting in two deaths and three serious injuries. On March 13, 2024, a third-party construction project in Sanhe City, Hebei Province, damaged a natural gas pipeline, leading to seven deaths and 27 injuries. According to relevant data from China's Ministry of Emergency Management, there were over 1,000 pipeline accidents nationwide from 2018 to 2023, with third-party construction accounting for over 70% of the incidents. Due to the wide range of areas the pipelines cross and the complex and variable service environments, there are various threats such as internal and external corrosion, external force damage, etc., making pipeline failure inevitable[3].

## 2. Types of Oil and Gas Pipeline Failures and Solutions

### 2.1. Third-Party Mechanical Damage

During the operation of pipelines, factors such as inadequate supervision by the user units, missing marker posts and warning signs along the pipeline, insufficient awareness of pipeline protection among third-party construction personnel who excavate blindly without verifying the direction of underground pipelines in advance, and operational errors by on-site construction personnel can lead to irreversible damage to pipelines during the construction process[4], including mechanical scratches, geometric deformations, and leaks caused by excavation. Therefore, higher requirements are placed on user units, such as increasing the density of marker posts and warning signs along the pipeline, enhancing the efficiency of pipeline patrols, or utilizing intelligent technologies such as intelligent inspection robots and drone patrols to achieve all-weather and full-coverage monitoring. User units should regularly conduct education and training for residents and construction personnel along the pipeline, clarifying the legal responsibilities for violations. Strengthen collaborative management of construction, impose mandatory supervision on third-party construction units, and require them to notify the pipeline user unit before construction and obtain accurate information on the location of underground pipelines.

### 2.2. Corrosion Damage

During operation, pipelines experience corrosion on their outer walls due to the corrosion of the internal transmission medium on the pipeline body, as well as external environmental factors and stray currents [5].

**Table 1.** Classification and Characteristics of Corrosion in Oil and Gas Pipelines

| Corrosion type | Name | Feature |
| --- | --- | --- |
| External corrosion | Soil corrosion | It is prone to pitting or ulcerative corrosion, which is related to soil resistivity, soil salt content, and soil texture |
| | Atmospheric corrosion | Currently, there is uniform corrosion and localized corrosion beneath the rust layer, which is related to atmospheric humidity, salt content, and pollution conditions |
| | Stray current corrosion | The corrosion rate is high, which can easily lead to pipeline perforation, and this is related to the interference from AC and DC stray currents near the pipeline, such as high-voltage power lines and high-speed railways |
| Internal corrosion | chemical corrosion | The pipeline surface undergoes direct redox reactions with the transmission medium, resulting in the formation of corresponding compounds |
| | electrochemical corrosion | The overall thinning or localized corrosion of the pipeline is caused by the electrolyte environment formed by the presence of water, sulfur, and carbon dioxide in the transmission medium |
| | microbial corrosion | Initiated by iron bacteria and sulfate-reducing bacteria, it can produce pitting corrosion products that are prone to clogging pipelines |
| | erosion | It manifests as groove-like or horseshoe-shaped corrosion, caused by high-speed medium scouring the inner wall of the pipeline, and often occurs in elbows, tees, and other parts |

### 2.3. Impact of Natural Disasters

During pipeline operation, natural disasters such as earthquakes, flash floods, and landslides can cause severe damage to underground pipelines[6]. Earthquakes are the most significant natural threat affecting pipeline operation, causing deformation, fracture, and displacement of pipelines, undermining the integrity of pipeline operation, leading to oil and gas pipeline leaks and even explosion accidents. Flash floods and landslides can result in reduced pipeline cover soil, heavy object impacts, and other factors that lead to deformation and displacement of oil and gas pipelines. Moreover, these natural disasters are difficult to predict and relatively challenging to manage. At the beginning of pipeline design, it is necessary to investigate past disasters in the pipeline burial area, adopt corresponding protective measures and reinforcement treatments, and enhance the pipeline's risk resistance capability.

## 3. Key Safety Technologies for Oil and Gas Pipeline Transportation

### 3.1. Real-time Monitoring Technology

Real-time monitoring technology plays a crucial role in oil and gas pipeline transportation. These technologies refer to systems and equipment capable of real-time monitoring of pipeline operating status, detecting anomalies, and responding promptly, which are key technologies to ensure the safe operation of pipelines. Smart sensors and monitoring devices are the core of achieving real-time pipeline monitoring. These devices can monitor pipeline operating pressure, temperature, flow rate, and other key parameters. They collect data in real time and transmit it to the monitoring center, enabling managers to understand the pipeline operating status in a timely manner and take corresponding measures when anomalies are detected. At the same time, the monitoring system should also have remote control and alarm functions. Once anomalies are detected in the pipeline, the system can promptly issue an alarm. Emergency management personnel can quickly respond and control the pipeline through remote control functions, such as closing valves or initiating emergency response measures, thereby minimizing the harm to the environment and personnel caused by accidents.

### 3.2. Anti-corrosion Coating Technology

Anticorrosion coating technology plays a significant protective role in oil and gas pipeline transportation. This technology aims to protect pipelines from corrosion, oxidation, and other environmental impacts by applying special coatings or paints on the pipeline surface, thereby extending the service life of the pipeline, reducing the risk of accidents, and ensuring the reliability of pipeline transportation[7]. Firstly, anticorrosion coating technology can effectively prevent pipeline corrosion. Pipelines are subject to corrosion caused by atmospheric, water, and soil chemicals or internal media in the environment. By applying special coatings such as epoxy resin, flexible ceramics, and succinic acid on the pipeline surface, it is possible to effectively isolate the pipeline from the internal and external environment, reduce the possibility of corrosion, and improve the pipeline's corrosion resistance. Secondly, anticorrosion coating technology helps reduce mechanical wear of pipelines. Pipelines are subject to erosion from internal media during transportation and use, with elbows and tees experiencing more severe erosion. Applying wear-resistant anticorrosion coatings can effectively reduce wear on the pipeline surface and extend the pipeline's lifespan. Regular inspection and maintenance of the coating can maintain its effectiveness and reduce the risk of corrosion and wear of the pipeline. With technological advancements, anticorrosion coating technology is constantly innovating. New anticorrosion coating technologies include high-temperature resistant coatings, nano coatings, multifunctional coatings, etc., which exhibit stronger corrosion resistance, wear resistance, and anti-aging capabilities, making their protection of pipelines more reliable.

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### 3.3. Application of Advanced Materials

The key factor influencing the safety of oil and gas pipeline transportation is the application of advanced materials. Different pipeline materials significantly affect the reliability, durability, and safety of operations under various pipeline media and operating conditions. With the development of technology, breakthroughs in the research, development, and application of pipeline materials continue to be made, providing reliable guarantees for pipeline safety. High-strength steel is an important choice in pipeline construction, with excellent compressive and tensile strength, capable of withstanding high-pressure transportation demands[8]. Pipelines operating in harsh environments for extended periods face a higher risk of failure. Selecting higher-quality materials that are more resistant to harsh environments for pipeline construction is highly effective and can extend the service life of pipelines. Furthermore, with the continuous development of technologies such as polymer nanotechnology and composite material technology, the performance of pipeline materials continues to improve. The application of nanotechnology can form a more uniform and dense structure on the pipeline surface, enhancing the pipeline's corrosion resistance and mechanical wear resistance during service. The use of composite materials also provides more options for pipelines, enhancing their tensile strength and durability, while reducing material weight and improving the convenience of construction and transportation.

### 3.4. New Non-destructive Testing Technology

Non-destructive testing (NDT) technology is an indispensable technical means in the maintenance and management of oil and gas pipelines[9]. This technology can determine the size, quantity, and location of cracks and other defects on the surface or inside of materials without altering their shape and performance. Currently, widely used NDT technologies in the petroleum industry include radiographic inspection, ultrasonic inspection, eddy current inspection, magnetic particle inspection, and penetrant inspection. These NDT technologies primarily utilize acoustic, optical, electrical, thermal, and magnetic methods to identify and detect pipeline defects, but they generally suffer from drawbacks such as cumbersome operation and time-consuming processes. Digital radiographic inspection technology and laser ultrasonic inspection technology have improved traditional radiographic inspection and ultrasonic inspection, offering advantages such as visualization, automation, high efficiency, and high precision. Infrared thermal imaging inspection can quickly identify failures such as insulation layer damage, localized corrosion, and medium leakage through temperature differences on the pipeline surface, and combined with drones, it can achieve large-scale, high-efficiency automatic inspection. Fiber-optic sensing detection, laid along the pipeline, can detect changes in pipeline stress and strain, operating temperature, etc. in real time. It can also monitor geological changes in the pipeline laying area, risks that may cause pipeline failure such as third-party construction, and possesses long-term online monitoring capabilities.

## 4. Summary and Outlook

The safety, reliability, and service life of oil and gas transmission pipelines are of great significance to the entire oil and gas industry. These pipelines are influenced by numerous factors and operate in complex environments, and their failure could potentially lead to severe consequences. This article provides a comprehensive overview and summary of the types and characteristics of failures in oil and gas transmission pipelines. The primary modes of damage are third-party mechanical damage, corrosion, and natural disasters. With the development of social economy, there is an increasingly urgent demand for safe, reliable, intelligent, and efficient pipeline transportation. Key technologies for the safe operation of oil and gas transmission pipelines will continue to be refined and developed. In the future, key technologies for the safety of oil and gas pipeline transmission will continue to evolve,

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encompassing multiple fields such as material innovation, real-time monitoring, and non-destructive testing. As technology continues to advance, we are witnessing rapid developments in intelligent monitoring, anti-corrosion coatings, advanced materials, and non-destructive testing technologies, providing a more reliable guarantee for the safe operation of pipelines. The continuous progress and application of these technologies will continuously enhance pipeline safety, ensure the stability of energy supply, and make significant contributions to society, the environment, and people's safety.

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