Engineering Application and Key Technologies of CIPP Rehabilitation for Natural Gas Pipelines

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Abstract. Traditional rehabilitation of natural gas pipelines often relies on large-scale excavation, which causes significant traffic disruption and notable environmental impact. As an efficient alternative, trenchless cured-in-place pipe (CIPP) lining technology can substantially reduce interference with surface activities. This paper focuses on a specific natural gas pipeline rehabilitation project to investigate the design and construction practices of CIPP lining technology. Through systematic engineering design, including the composite liner structure and wall thickness, key construction control parameters such as inversion speed, curing pressure, and temperature were determined. Engineering practice demonstrates that this technique offers strong adaptability, short construction duration, minimal environmental impact, and reliable rehabilitation quality, highlighting its broad potential for application in natural gas pipeline repair. To further enhance the adoption of this technology, future efforts should focus on refining relevant technical standards and material systems to promote its standardized and large-scale development.

Keywords: Cured-in-place pipe (CIPP) lining; Trenchless technology; Rehabilitation construction; Natural gas pipeline

1 Introduction

The rapid development of national industries has led to an increasing demand for oil and gas resources, driving the steady advancement of the integrated national oil and gas pipeline network. According to data from the National Bureau of Statistics, by the end of 2024, the total length of long-distance oil and gas pipelines in China had reached 195,000 kilometers[1], with natural gas pipelines accounting for over 128,000 kilometers[2]. Since 2025, the construction of oil and gas pipeline infrastructure in China has further accelerated, with an expected annual addition of over 2,000 kilometers of new pipelines, ensuring the successful completion of the objectives outlined in the "14th Five-Year Plan." To realize the "Two Centenary Goals" and provide a solid foundation

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for national energy security, advancing the construction and development of the oil and gas pipeline network remains of significant strategic importance in the coming years, representing a challenging and urgent task[3].

With the continuous expansion of natural gas pipeline construction and the increasing complexity of operation and maintenance, trenchless cured-in-place pipe (CIPP) lining technology has gained gradual application. This technique serves as an alternative to traditional excavation and pipe replacement by utilizing the existing pipeline material and spatial layout to invert and bond composite liner material to the inner pipe wall, which is then cured in situ to form a tightly integrated composite pipeline[4]. The trenchless CIPP rehabilitation method for natural gas pipelines offers advantages such as strong adaptability, short construction duration, energy efficiency, environmental friendliness, high durability, and good safety performance[5]. Given the increasingly complex network of underground pipelines and structures, trenchless CIPP technology demonstrates significant advantages. It can be implemented with minimal or no excavation, thereby substantially reducing damage to road structures and subgrades, preserving road aesthetics, lowering the costs associated with the removal and restoration of roadside greenery and other surface facilities, and mitigating traffic congestion and environmental pollution caused by construction activities.Therefore, through investigating the applicability of trenchless cured-in-place pipe (CIPP) lining technology to urban gas pipelines—with a focus on its introduction in the renewal and rehabilitation of aging gas pipelines—this study explores the analysis of key engineering issues, such as liner thickness calculation, resource allocation for operations, and repair acceptance, within an actual natural gas pipeline CIPP rehabilitation project. It aims to clarify the critical technical parameters and construction scheme design for trenchless CIPP lining, thereby providing necessary references for enhancing the sustainability of natural gas pipeline infrastructure, reducing maintenance and rehabilitation costs, and mitigating negative environmental impacts.

2 Project Overview

The in-situ rehabilitation section of the natural gas pipeline has a design pressure of 0.8 MPa. The pipeline body is a DN250 mm 20# seamless steel pipe, manufactured in accordance with the standard Seamless Steel Tubes for Fluid Transportation (GB/T 8163). The section has a total designed length of 800 m and an average burial depth of 1.5 m. Its corrosion protection system combines three-layer polyethylene (3LPE) reinforced insulation coating with sacrificial anode cathodic protection. Due to terrain constraints along the route, multiple factory-prefabricated hot-bent elbows are installed at horizontal and vertical turning points. These elbows have a curvature radius of R=5D, are made of the same material as the main pipeline, and comply with the requirements of Steel Induction Heating Bends for Oil and Gas Transportation (SY/T 5257).

The rehabilitation section is located at a vehicular intersection, where underground utilities such as water supply, electricity, and communication lines are densely interwoven, resulting in highly constrained underground space. Traditional excavation-based repair methods would face challenges including route selection difficulties and significant environmental disruption. Therefore, this project employs trenchless cured-in-place pipe (CIPP) lining technology to rehabilitate and protect the existing pipeline. The rehabilitated pipeline meets the load requirements of the site conditions, maintains gas transmission capacity consistent with the original design flow, and extends its service life.

3 Design of CIPP Rehabilitation Scheme

3.1 Pipeline Inspection

Commonly used pipeline inspection methods in China primarily include Quick View (QV) inspection, Closed-Circuit Television (CCTV) inspection, and Sonar inspection[6].

Quick View inspection is a rapid video-based pipeline assessment technique. Operators extend the device into the pipeline through an inspection shaft to conduct real-time observation and evaluation. Portable and easy to install, this method operates within a temperature range of 0–50°C and is suitable for quick screening of pipelines up to 50 meters in length. It can preliminarily identify internal conditions and structural defects, though its results are generally not used as the sole basis for pipeline rehabilitation decisions[6].

CCTV inspection is one of the most widely applied and technologically mature pipeline inspection methods. The system mainly consists of a crawler, camera equipment, lighting, power controller, and length measuring device. Its advantages include comprehensive observation of internal defects such as cracks, deformation, and corrosion, support for long-distance continuous inspection, and the ability to record video for professional analysis, providing reliable data for pipeline condition assessment.

Sonar inspection is based on acoustic detection technology and is particularly suitable for water-filled pipelines that cannot be drained. During inspection, the sensor probe pauses at preset intervals or at abnormal locations, emitting acoustic signals and collecting return data to plot longitudinal profiles of sediment accumulation. While widely used abroad and extended to municipal, oil and gas, and power sectors, its application is somewhat limited due to high equipment costs and the difficulty of using its results as definitive evidence of structural defects.

The three main inspection methods described above each have distinct characteristics in terms of accuracy, portability, cost, and visualization capability. A detailed comparison is presented in Table 1.

Table 1. Comparison of Pipeline Inspection Methods

No.	Inspection Method	Accuracy	Portability	Cost	Visualization
1	QV Inspection	Moderate	Good	Low	No
2	CCTV Inspection	High	Good	Moderate	Yes
3	Sonar Inspection	Moderate	Fair	High	No

Considering the on-site conditions, this project adopts the CCTV inspection method for video recording inside the pipeline. This approach provides a clear representation of the pipeline's actual condition and accurately documents its internal structural state, offering reliable data for subsequent rehabilitation. The selected inspection equipment is a color CCTV system with explosion-proof functionality. The camera should support rotation and zoom capabilities and be equipped with a CCD image sensor with a horizontal resolution of at least 460 lines.

3.2 Pipeline Cleaning

In trenchless CIPP rehabilitation, the cleaning quality of the natural gas pipeline directly determines the bonding effectiveness between the liner and the pipe wall. Primary cleaning methods include mechanical cleaning, high-pressure water jet cleaning, and abrasive blasting.

Mechanical cleaning employs devices such as cleaning pigs or rotating steel brushes. Cleaning pigs, made of corrosion-resistant materials like neoprene, have a long service life and are suitable for heavily corroded pipelines, though their effectiveness against high-hardness debris is limited. The rotating brush method, while cost-effective and efficient, may enlarge the pipe diameter and performs poorly around bends.

High-pressure water jet cleaning uses pressurized water flow to remove contaminants from the pipe wall. It allows pressure adjustment based on contamination levels, avoiding damage to the pipe body and effectively removing stubborn deposits. However, in complex pipelines, increased flow resistance may reduce cleaning effectiveness.

Abrasive blasting propels steel grit at high speed against the pipe wall, removing contaminants while improving surface roughness. Cleaning effectiveness depends on precise control of pressure, speed, and angle: excessive pressure can damage the grit, while insufficient pressure leads to incomplete cleaning; uneven speed results in inadequate surface roughness.

The characteristics of the three methods are compared in Table 2. Considering the project requirements, abrasive blasting is selected, utilizing a professional blasting system. The dust extraction equipment must achieve 100% recovery of abrasive dust. After cleaning, the pipe wall must be dry, free of residual contaminants, and completely derusted, exposing the bare metal substrate with a uniform metallic luster, complying with the Sa2.5 standard[7].

Table 2. Comparison of Cleaning Methods

No.	Cleaning Method	Cleaning Type	Portability	Cleaning Time	Cleaning Effect	Environmental Impact
1	Mechanical Cleaning	Simple Derusting	Low	Moderate	Moderate	Minor
2	High-pressure Water Jet	Derusting, Special Contaminant Removal	lower	Relatively Fast	Good	Small

3	Abrasive Blasting	Deep Cleaning, Surface Treatment	Moderate	Fast	Excellent	Moderate

3.3 Liner Thickness

The liner is a composite hose with a reinforcing interlayer, capable of carrying thermosetting resin. Upon expansion, it conforms to the pipe shape and cures in place. Current trenchless rehabilitation liners commonly utilize high-performance composite materials, typically composed of a base layer and an impermeable layer. The impermeable layer adopts a one-fabric-one-membrane composite structure, where the "fabric" refers to nonwoven fabric and the "membrane" is an impermeable film. Materials for the impermeable film may include linear low-density polyethylene (LLDPE), thermoplastic polyurethane (TPU), or other thermoplastic materials[8]. The mechanical properties of the composite liner material used for rehabilitation must meet the requirements specified in Table 3.

Table 3. Mechanical Performance Requirements for Composite Liner Materials

No.	Item Name	Performance Requirement	Test Method
1	Longitudinal Tensile Strength (MPa)	≥20	CJJ/T 210
2	Transverse Tensile Strength (MPa)	≥20	CJJ/T 210

Based on domestic and international engineering practices, CIPP liner repair is categorized into structural and semi-structural rehabilitation, with the core distinction lying in whether the liner can independently bear external loads after repair. Considering that the original pipeline in this project remains in overall good structural condition and no significant changes in external loads are anticipated, semi-structural rehabilitation has been adopted. In accordance with the Technical Specification for Trenchless Rehabilitation and Renewal of Urban Gas Pipelines (CJJ/T 210—2014), the structural design of the liner follows the buckling theory for circular pipes, and the minimum wall thickness of the liner is calculated using the formula provided below:

$$t = \frac{D}{\left[\frac{2KE_LC}{PN(1-\mu^2)}\right]^{\frac{1}{3}}+1} \tag{1}$$

Where:t is the calculated liner wall thickness (mm);D is the liner pipe diameter (mm), taken as 250 mm;K is the circumferential support factor, with a recommended value of 7.0;E_L is the long-term elastic modulus of the liner (MPa), taken as 1968 MPa (50% of the short-term modulus);C is the ovality reduction factor, taken as 1;P is the groundwater pressure above the pipe (MPa), taken as 0.02 MPa;N is the safety factor, taken as 2.0;$\mu$is Poisson's ratio, taken as 0.3. Based on these parameters, the theoretical minimum wall thickness t is calculated to be approximately 3.0 mm.

To verify design stability under worst-case conditions, a sensitivity analysis was conducted focusing on the impact of variations in groundwater pressure (P), long-term modulus (E_L), safety factor (N), and circumferential support factor (K) on the required wall thickness, as summarized in Table 4

Table 4. Sensitivity analysis of key variables

Variable	Range	Calculated wall thickness t/mm	Wall thickness variation rate
P	+50%	3.43	+14.3%
E_L	-20%	3.23	+7.7%
N	+25%	3.23	+7.7%
K	-15%	3.16	+5.3%

Wall thickness is notably sensitive to groundwater pressure. Under an extreme 50% water level rise, the theoretical requirement increases to 3.43 mm. Additional thickness may be required to account for long-term modulus degradation or structural decline of the host pipe (e.g., reduced K). While increasing the safety margin affects thickness, its sensitivity is moderated by nonlinear effects.Based on these analyses, a composite liner with a total thickness of approximately 4 mm was selected—representing a 16.7%–33.3% increase over the 3.0 mm baseline. This fully accommodates the combined worst-case effects of groundwater fluctuation (+50%), material creep (20% modulus reduction), and safety adjustments, while minimizing impact on flow capacity.The liner comprises a bilayer structure of polyurethane film and textile fibers: a 1.5 mm inner polyurethane layer, a 1.5 mm outer high-strength textile fiber layer (providing structural support and adhesive bonding), and a 1 mm impermeable membrane.

4 Key Procedures and Construction Guidelines for CIPP Rehabilitation

4.1 Pipeline Plugging and Abrasive Blasting Cleaning

Prior to rehabilitation, the upstream and downstream ends of the pipeline section to be rehabilitated must be plugged. Before plugging, forced ventilation and hazardous gas detection are conducted to ensure compliance with safety standards. Cleaning employs abrasive blasting, using compressed air to propel brown fused alumina (aluminum oxide grit) at high velocity onto the inner pipe surface (see Figure 1). The blasting nozzle rotates at a uniform speed under a spraying pressure of 1 MPa to ensure full coverage of the pipe wall, effectively removing surface sludge, loose deposits, and other contaminants, achieving complete derusting and producing a uniformly roughened surface. Simultaneously, the blasting and vacuum recovery systems operate in tandem, with the vacuum system continuously recovering dislodged debris in real-time. The process continues until the pipe wall is fully exposed, achieving 100% derusting and surface roughening, thereby providing a sound foundation for subsequent liner bonding.

Fig. 1. Pipeline Abrasive Blasting Cleaning

Upon completion of cleaning, a CCTV inspection system equipped with panoramic color imaging, defect annotation, and frame-by-frame playback capabilities was employed to record the entire interior surface of the pipeline before and after cleaning. The camera shall feature 360° rotation and zoom functionality with a resolution of no less than 460 TV lines to ensure image clarity.Using image analysis software, CCTV footage was subjected to grid-based sampling to calculate the percentage of the pipe wall area exhibiting exposed metallic luster after cleaning. Acceptance criteria strictly follow the Technical Specification for Trenchless Rehabilitation and Renewal of Urban Gas Pipelines (CJJ/T 210), requiring 100% derusting coverage, with the pipe wall displaying uniform metallic coloration and no localized residues.

4.2 CIPP Lining Installation

Prior to construction, approximately 50 cm of the pipeline end exterior must be cleaned, and the pipe opening and weld seams must be ground. Subsequently, flanges, blind plates, knife-gate valves, and other ancillary equipment are installed at the launching and receiving ends. The composite liner material is then cut according to design dimensions, and the adhesive is precisely mixed according to the specified ratio. The uniformly mixed adhesive is poured onto the liner material, and even rolling is achieved by adjusting the roller gap. After impregnation, the material is rolled into the inversion drum, and the drum opening is sealed.

On-site, the air compressor unit is activated to invert the liner hose from the drum into the existing gas pipeline using compressed air, as shown in Figure 2. The hose continuously advances under air pressure, during which the inversion drum temperature must be maintained below 20°C to prevent premature resin curing. The outer surface of the inverted liner is coated with adhesive, ensuring full adhesion to the original pipe inner wall under air pressure.

Fig. 2. CIPP Installation

Cured-in-place pipe (CIPP) lining technology demonstrates excellent bending performance, enabling it to traverse 90° elbows with a curvature radius greater than three times the pipe diameter ($R > 3D$) in a single, wrinkle-free pass. This confirms its full suitability for rehabilitating the curved sections of this project. However, given the presence of multiple consecutive bends in the repair segment, real-time monitoring of the inversion process is essential to ensure construction quality. Inversion speed must be strictly controlled within 2–3 m/min, while air pressure should be maintained between 0.05–0.1 MPa. These parameter settings align with the recommended ranges for similar projects documented in references [4–5], contributing to the stability and reliability of the rehabilitation process. Upon completion of inversion, the resin-impregnated liner hose shall extend beyond both ends of the pipeline by more than 1 meter to provide sufficient allowance for subsequent end treatment.

4.3 In-Situ Curing

After inverting the liner and installing the end flange blinds, the pipeline system was pressurized to 0.08 MPa, after which the knife valve and air compressor were closed. Adequate curing time is critical for quality rehabilitation, allowing the liner to fully expand and adhere tightly to the host pipe wall, thereby preventing gaps and wrinkles.Curing time is highly dependent on ambient temperature—lower temperatures require longer durations. A two-part epoxy resin system, comprising a resin base and a hardener, was used. The mixing ratio of resin to hardener ranged from 100:30 to 100:50 by weight, mixed using a low-speed agitator (<300 rpm) to avoid bubble entrainment. To accelerate curing, a catalyst may be added at 0.5%–2.0% by weight of the resin.

During curing, positive pressure must be maintained within the pipe to ensure full contact between the liner and the host pipe wall. The curing reaction is exothermic, with peak temperatures typically occurring 6–8 hours after initiation. Temperature distribution inside the pipe should be closely monitored to prevent localized heat buildup, which could compromise liner integrity or surface quality.Given a soil temperature of 20 °C, the curing period was set to 72 hours. Throughout this phase, an infrared thermometer recorded curing temperatures at 5-minute intervals to verify conformance with the prescribed curing curve, ensuring complete material reaction and attainment of design strength. After curing, the pipe must be allowed to cool naturally to ambient temperature before gradual depressurization, avoiding thermal-shrinkage cracks in the liner.

4.4 End Treatment and Corrosion Protection Rehabilitation

End treatment primarily involves sealing and trimming the liner ends. After removing the terminal equipment, specialized tools are used to cut off the liner material extending from the pipe ends. The cut should be smooth, with a recommended trimming length of 20 cm. Following trimming, a rapid-setting sealing material is applied at the interface between the pipe end and the inspection shaft to ensure a watertight, leak-free joint between the liner and the original pipe[9]. Subsequently, the short pipes at the working pits are sequentially connected by welding. During welding, protective measures must be implemented for the completed liner sections to prevent damage from welding operations[10]. Welding procedures and quality acceptance strictly comply with the relevant provisions of the Code for Construction of Field Equipment and Industrial Pipeline Welding Engineering (GB 50236).

After on-site excavation and verification, corrosion protection is restored on the reinforced pipe sections. First, the original coating is removed to expose clean steel pipe surfaces. Epoxy adhesive is then applied to the stripped areas, and carbon fiber sheets are bonded for reinforcement. Areas without carbon fiber reinforcement are protected by wrapping with polyethylene cold-applied tape. The wrap layer must overlap with the original coating by a minimum width of 100 mm. During wrapping, the tape edges must remain parallel and free of twisting or wrinkles, with a minimum overlap width of 25 mm between tape layers.

5 Acceptance of Rehabilitated Natural Gas Pipeline

5.1 Internal Inspection and Wall Thickness Verification

After trimming the liner ends, a CCTV system was used to inspect the full length of the rehabilitated pipe. The results showed that, apart from minor wrinkles permitted at bends, the inverted liner had a smooth and uniform internal surface—free from defects such as inadequate curing, bulging, delamination, cracks, or severe wrinkling. The trimmed ends were flush and tightly bonded to the host pipe wall. The entire inspection process and results were recorded as visual documentation, providing a direct view of the post-rehabilitation condition and serving as a digital record for project acceptance.

Additionally, wall thickness was measured at multiple points using an ultrasonic thickness gauge. At least four evenly distributed points were taken at each end, with measurements at bends intensified to one point every 45°. The measured values ensured that the average thickness at any cross-section was no less than the design thickness, and the minimum thickness at any point did not fall below 90% of the design value, as shown in Table 5.

Table 5. Wall thickness measurement data

Location	Point 1	Point 2	Point 3	Point 4	Section average	Pass/Fail
Starting point	4.02	4.05	3.98	4.01	4.02	Pass
Bend	3.95	3.92	3.88	3.91	3.92	Pass
End point	4.10	4.08	4.05	4.07	4.08	Pass

5.2 Pressure Testing

The rehabilitated natural gas pipeline undergoes strength testing followed by leak tightness testing. The strength test pressure is set at 1.5 times the design pressure of the rehabilitated pipeline. During the test, pressure is increased gradually—first to 50% of the test pressure for an initial leak and abnormality check, then raised to the full test pressure. After maintaining this pressure for 1 hour, the pressure gauge reading is observed for no less than 30 minutes. The test is deemed satisfactory if no pressure drop is recorded.

Leak tightness testing is conducted after the strength test is passed. The leak tightness test pressure is set at 1.15 times the design pressure, but not less than 0.1 MPa. Pressure is increased steadily and slowly. Recording begins once temperature and pressure stabilize. The test requires maintaining stable pressure for 24 hours, with recordings taken at least once per hour. A corrected pressure drop of less than 133 Pa is considered acceptable.

5.3 Long-Term Monitoring and Reliability Assessment Plan

To evaluate the long-term performance of the lined gas pipeline under actual service conditions, validate the durability of the semi-structural rehabilitation, and support the refinement of industry standards, a 10-year tiered monitoring program was established.

The monitoring schedule was divided into three phases based on material aging patterns and engineering experience: initial phase (Year 1) at three-month intervals, focusing on early defect development; intermediate phase (Years 2–5) at six-month intervals, tracking performance trends; and long-term phase (Years 6–10) annually, incorporating destructive sampling to refine life-prediction models. Monitoring covers structural integrity, gas tightness, and material properties. Structural integrity is assessed via high-definition CCTV for wrinkles, circumferential cracks, and end detachment, supplemented by ultrasonic thickness gauging to evaluate wall-thickness reduction and creep resistance. Gas tightness is monitored using an online pressure system, analyzing leakage trends through 24-h pressure-drop comparisons, with tracer gas employed for precise micro-leak localization when needed. Material performance is evaluated through sampled coupons for tensile strength retention, elastic modulus retention, and glass transition temperature shift, indicating resin aging.

Based on the collected data, the aging model recommended in ISO/TS 18289-1 was applied, using a 50 % reduction in long-term elastic modulus relative to the initial value as the end-of-life criterion. Under a constant 20 °C service temperature, the liner's service life is preliminarily estimated to be no less than 50 years. This projection, derived from short-term accelerated aging tests, will be dynamically updated with field measurements to align predictions more closely with actual engineering conditions.

6 Conclusion

With the continuous expansion of China's natural gas pipeline network, the demand for the operation, maintenance, and rehabilitation of in-service pipelines has been increasing. Trenchless Cured-in-Place Pipe (CIPP) lining technology demonstrates broad application prospects in this field. Taking a specific natural gas pipeline rehabilitation project as an example, this paper systematically analyzes the design approach, construction techniques, and acceptance standards for trenchless CIPP lining technology. The main conclusions are as follows:

(1) Trenchless CIPP lining technology is suitable for rehabilitating natural gas pipelines in areas with complex terrain and dense underground utilities. Through rational rehabilitation design, this project defined key construction parameters—such as inversion speed (2–3 m/min), curing pressure (0.08 MPa), and temperature control (<20°C)—achieving successful application in the natural gas pipeline rehabilitation.

(2) Liner thickness design is a core factor influencing rehabilitation effectiveness. Based on the CJJ/T 210 specification and using circular pipe buckling theory for structural calculations, a 4 mm composite liner structure was determined. This meets the strength requirements while ensuring maximum retention of the pipeline's flow capacity.

(3) Post-rehabilitation inspections, including endoscopic examination and pressure testing, verified that the internal wall quality, structural integrity, and sealing performance of the pipeline comply with regulatory requirements. This confirms the favorable feasibility and reliability of the technology in practical engineering applications.

Moving forward, further efforts should be made to refine relevant technical standards and material systems, promoting the standardized and large-scale development of trenchless CIPP lining technology in China's natural gas pipeline rehabilitation sector.

References

1. National Bureau of Statistics. National Data [EB/OL].[2025-02-11]. https://data.stats.gov.cn/easyquery.htm
2. National Energy Administration. China Natural Gas Development Report (2025) [R]. Beijing: Petroleum Industry Press, 2025.
3. Huang Weihe. Interpretation and Reflection on China's Medium- and Long-Term Oil and Gas Pipeline Network Plan [J]. Scientific Chinese, 2017, (27): 64–65.
4. Yun Y ,Xinxin W ,Zhongyi W , et al.Application of CIPP flipped lining method in the rehabilitation of old gas pipelines[J].Scientific Reports,2025,15(1):11167-11167. DOI:10.1038/S41598-025-95155-Y.
5. Wang Qing. Design and Research of a Skid-Mounted Automatic Inversion System [D]. Beijing Institute of Petrochemical Technology, 2019.
6. Yang Xiaohui. Research on the Applicability of Urban Drainage Pipeline Rehabilitation Technologies and Engineering Applications [D]. Xi'an Technological University, 2019. DOI:10.27391/d.cnki.gxagu.2019.000515.
7. Zhao Kun. Comparative Study on Different Cleaning Techniques in CIPP Rehabilitation of High-Pressure Gas Pipelines [D]. Beijing University of Civil Engineering and Architecture, 2014.
8. Wen Xue. Research on Sealing Composite Technology for CIPP Liner Hose [D]. Tianjin University of Science & Technology, 2022.DOI:10.27359/d.cnki.gtqgu.2022.000202.
9. Li Tao. Application of Trenchless Pipeline Rehabilitation Technology in Urban Underground Engineering [J]. Scientific and Technological Innovation, 2024, (23): 155–158.
10. Zhao Kun. Comparative Study on Different Cleaning Techniques in CIPP Rehabilitation of High-Pressure Gas Pipelines [D]. Beijing University of Civil Engineering and Architecture, 2014.