

# Study on the Oil Pipeline Design of R Oil Field

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## ABSTRACT

It's a compressive article consists of three parts, an overview of pipeline development in China, oil pipeline design for R oilfield and pipeline management suggestions. First, this article introduces the current status of pipeline construction, oil pipeline technology and gas pipeline technology in China in recent years. The current status of China's pipeline construction is divided into three stages. In terms of construction, pipeline construction is developing in the direction of intelligence and modernization. Long-distance oil pipelines require technical breakthroughs in two aspects. One is the sequential oil product delivery technology to improve the type of oil that can be delivered sequentially; the second is the viscosity reduction delivery technology for heavy oil. Gas transmission pipelines are developing in the direction of high pressure, large diameter and high steel grade. Secondly, based on all the pipeline development above, in order to meet the development of R oil field, an oil-water two-phase pipeline transportation design and a pipeline crossing river design were carried out. Under the condition of the design pressure of the pipeline of 5.5MPa, it is preferable to produce a pipeline of  $\phi 219 \times 6.5$ mm, and the steel grade of the pipeline is L360. A heating station and pumping station are needed in the transportation process, and the heating station and pumping station are combined for one construction. Considering that the strata of the river crossing section are mainly gravel sand layer, clay layer and non-lithological stratum, horizontal directional drilling (HDD) is adopted for river crossing, and suggestions are made for the construction process. Finally, after the pipeline was put into production, the corresponding auxiliary production system and supporting engineering suggestions were put forward.

## 1. Introduction

### 1.1 The Art of Pipeline Construction in China

#### 1.1.1 First Construction Phase

In the 1970s, the Northeast crude oil transportation pipeline network marked by the "August 3" pipeline project opened the prelude to the construction of China's long-distance oil pipelines. Welding and pipeline

installation are mainly carried by people. In the 1990s, the oil and gas pipelines represented by the Ku-Shan line and the Donghuang double-track line were first used in China with X65 steel grades (micro alloyed controlled steel, carbon content of 0.10% to 0.14%). The pipe diameter is 610mm and the pressure is 8MPa. Construction began to apply self-protected flux cored wire semi-automatic welding on a large area, and a centralized control system was adopted throughout the line. The first generation of pipeline construction technology (steel grade

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below X70, pipe diameter below 1000mm, and pressure not greater than 8MPa) was started, and a total of 2.6 pipelines were constructed.  $\times 10^4$ km, taking a new step in China's long-distance oil and gas pipeline construction technology to catch up with the world's advanced level [1].

### 1.1.2 Second Construction Phase

The West-East Gas Pipeline, which started construction in 2000, used X70 steel grade materials (multi-component micro alloy controlled rolling and controlled cold steel, carbon content 0.01% to 0.04%) for the first time, with a diameter of 1016mm and a pressure of 10MPa. Pipe end diameter expander and other technologies and equipment, make the pipe end dimensional accuracy, residual stress control and other indicators reach the international advanced level. The second West-East Gas Pipeline, which began construction in 2007, was the first large-scale use of domestic X80 steel grade materials with a diameter of 1219mm and a pressure of 12MPa. After unremitting research, China has made significant progress in the development of X80 pipeline steel pipes, successfully achieved precise control of micro alloy elements such as carbon and niobium, and achieved ultra-micro control of harmful elements sulfur and phosphorus, mastering the smelting and rolling of X80 high-strength steel Manufacturing process, formulated technical standards for high-strength pipes, developed high-strength and high-toughness X80 sheet; developed high-grade pipeline steel pipe forming process, and fully realized the localization of X80 large-diameter thick-walled steel pipes. The performance indicators of the second-line steel pipe meet the standard requirements, especially the excellent fracture toughness of the steel pipe, which can meet the crack arrest requirements of the 12MPa gas pipeline. In terms of welding process, we have successfully applied the fully automatic welding process, established automatic welding and semi-automatic welding construction systems, realized welding construction with a minimum ambient temperature of  $-45^{\circ}\text{C}$ , and established requirements for the toughness index of girth welding joints for the characteristics of China's welding process. Solved the problem of pipeline welding across the seismic fault zone and winter low temperature environment. It has developed a series of supporting equipment such as beveling machine, butt joint, internal welding machine and external welding machine, which represents the most advanced technical level of pipeline welding in China at that time. China's natural gas pipeline has generally adopted large-scale combustion and electric drive compressor units. The unit power of the combustion drive compressor unit is 30MW and the total power reaches 3300MW; the unit power of the electric drive compressor

unit is 18MW and the total power reaches 2400MW [2]. So far, the second generation pipeline construction technology has been formed (steel grade X70, X80, pipe diameter 1000~1219mm, pressure 10~12MPa, transmission volume  $100 \times 10^8 \sim 300 \times 10^8 \text{m}^3/\text{a}$ ), a total of  $8.3 \times 10^4$ km of pipeline construction, realized China's high-grade, large-caliber, high-pressure long-distance oil and gas pipeline construction technology has made a new leap from catching up to leading [3].

### 1.1.3 Third Construction Phase

Since the "Twelfth Five-Year Plan", focusing on the construction of key pipeline projects and adhering to the concept of safe and efficient operation, we have carried out key technical indicators such as steel grades X90 and X100, pipe diameters of 1219~1422mm, pressures of 12MPa, and throughput of  $300 \times 10^8 \text{m}^3/\text{a}$  and above. A major scientific and technological project represented by the "Key Technology Research on the Third Generation of Large-Volume Natural Gas Pipeline Project" has broken through a series of key technical difficulties restricting the construction and operation of pipeline engineering, and gradually formed the third generation pipeline construction technology. In order to realize China's large-capacity pipeline construction, technical reserves have been made [4]. As of the end of 2017, the total mileage of China's long-distance oil and gas pipelines has reached 131,400 km, of which natural gas pipelines are approximately 72,600 km, crude oil pipelines are approximately 30,900 km, and refined oil pipelines are approximately 27,900 km, accounting for 54.9%, 23.6%, and 20.5%. Major operators include PetroChina, Sinopec, CNOOC and provincial pipeline companies. Among them, the pipelines under the jurisdiction of PetroChina and Sinopec are 85,600 km and 34,000 km, respectively, and the national proportions are 64.8% and 25.9%, respectively. In recent years, China's gas pipeline technology has developed rapidly. As far as the engineering practice of high-pressure transportation and high-steel welded pipes is concerned, my country has become one of the international leaders. However, in terms of the overall technology of gas pipeline construction, especially the basic research on high-pressure transmission and the application of high-grade welded pipes, we are still in the tracking research stage, and there is still a certain gap with developed countries. In the flowing chapter, the development of pipeline transportation is introduced.

## 1.2 The Art of Pipeline Transportation

### 1.2.1 Product Oil Sequential Delivery Technology

The United States, Canada, Western Europe and oth-

er countries and regions have a variety of oil pipeline transportation technologies that are relatively mature. They have many varieties and large scales of transportation. The transportation network is relatively developed, which realizes the sequential transportation of chemical products, and the sequential transportation of crude oil and refined oil. Sequential transportation of light oil products such as gasoline, kerosene, diesel and other products such as liquefied petroleum gas, liquefied natural gas, chemical products and raw materials. The most famous is the Colonial Pipeline in the United States, which has 118 varieties to be transported, with a sequence period of only 5 days. Under normal delivery conditions, oil mixing is mainly along the way. The generation of mixed oil along the way is based on two mechanisms: convection transfer and diffusion transfer. The convective transfer process is caused by the uneven velocity field, which causes the axial extension of the mixed oil to increase continuously; the diffusion transfer includes axial diffusion and radial diffusion. Stretching has an inhibitory effect. The most basic factor leading to oil mixing in sequential transportation is diffusion transmission. For oil products operating under turbulent flow conditions, there is a laminar bottom layer and a buffer layer with a lower flow rate than the center area, so that the downstream oil product enters the front oil product in a wedge shape; at the same time, the turbulent diffusion causes the pipe section the concentration tends to be uniform. When the turbulent diffusion is weak, the radial diffusion plays a role, but due to the existence of the axial concentration gradient, there is both axial molecular diffusion and turbulent diffusion, which causes the concentration of mixed oil to increase continuously<sup>[5]</sup>. Sequential product oil transportation mixed oil cutting, and processing is a relatively complex, unified, and interactive process system, which is composed of mixed oil cutting time (cutting amount), mixed oil processing method and processing amount. The function of this system is to use the quality potential of oil products to reduce the depreciation loss of mixed oil and obtain the best economic benefits. The system contains the biggest contradiction between the processing method and the processing cost. How to deal with this contradiction is the main goal of studying the product oil sequential delivery mixed oil cutting and processing system<sup>[6]</sup>.

There are only 3 to 5 types of pipeline transportation in China, and the distribution flow is relatively balanced. The pipeline system batch arrangement, optimized operation, system automatic control and water hammer protection are relatively simple. Sequential product oil transportation and mixed oil treatment is not only an

important production link for long-distance sequential product oil transportation and oil storage, but also an important study to reduce pipeline transportation costs and improve the economic benefits of pipeline transportation. The key research direction should be: give full play to the advantages and potential of pipeline transportation, study more media sequential transportation technology, especially the transportation process control and optimized operation technology, oil quality control and quality inspection of complex working conditions such as multi-injection and multi-user full download Technology, mixed oil cutting and processing technology.

### 1.2.2 Heavy Oil Pipeline Transportation Technology

The major heavy oil producing countries in the world are mainly the United States, Canada, Venezuela and China. In recent years, foreign heavy oil mining technology has developed rapidly. In transportation technology, physical field treatment (magnetic treatment, vibration reduction) and water transportation (liquid ring), suspension, emulsification), device transportation (sliding box, film bag), aeration and viscosity reduction (saturated gas to increase the amount of transportation), mixed transportation and other processes have been carried out. The annual output of heavy oil and ultra-heavy oil in my country is kept above  $1000 \times 10^4$ t. In the international project, the ultra-heavy oil with the viscosity of  $28000 \text{ mPa} \cdot \text{s}$  at the temperature of  $20^\circ\text{C}$  in Sudan 5B pipeline will also be encountered. The main feature of heavy oil is high viscosity, and its transportation technology research mainly focuses on viscosity reduction and drag reduction<sup>[7]</sup>. The currently commonly used thick oil viscosity reduction conveying process can be summarized into three<sup>[8-12]</sup> based on the principle: ① chemical methods, which reduce the viscosity of the heavy oil by modifying the method; ② physical methods, will A certain proportion of water is mixed into the heavy oil, the pipeline is heated, and the low-temperature liquid ring is transported; ③ Physical and chemical methods, emulsifiers are added to the heavy oil to change the gel state of the heavy oil, thereby reducing the viscosity of the heavy oil.

#### (1) Thinner Blended to Reduce Viscosity

The viscosity of a typical heavy oil is too high, and heating alone often fails to meet the requirements of pipeline viscosity (otherwise the heating temperature is too high). Dilution of light oil (including natural gas condensate, crude oil distillate, waxy crude oil, etc.) has been the main method of viscosity reduction and drag reduction of heavy oil. When the source of light oil is convenient and sufficient, the dilution viscosity reduction and drag

reduction technology is the simplest and most effective. In order to solve the contradiction of light oil shortage, since the 1980s, foreign countries have vigorously carried out research on alternative thinners and other viscosity reduction and drag reduction technologies, for example, the viscosity reduction effect of MTBE (methyl tertiary butyl ether) on heavy oil has been studied<sup>[13]</sup>. The 25%-30% MTBE blended into the Canadian cold lake crude oil can reduce the viscosity to 270mPa·s at 4°C. MTBE can be recovered by simple distillation.

### (2) Emulsification, Viscosity Reduction and Drag Reduction

The oil-in-water emulsion viscosity reduction and drag reduction technology was developed as an alternative technology for the dilution and viscosity reduction of heavy oils. The viscosity-reducing principles of surfactants are generally classified into three types: ① Emulsification and viscosity-reducing, that is, the W/O emulsion is reversed into O/W emulsion under the action of surfactants to reduce the viscosity; ② breaking the emulsion to reduce the viscosity, That is, the surfactant breaks the W/O emulsion to generate free water, and forms a “water jacket oil core”, “suspended oil”, and “water float oil” according to the amount and flow rate of free water to reduce viscosity; ③ Adsorption and viscosity reduction, yes The surfactant aqueous solution is injected into the oil well, destroying the thick oil film on the surface of the tubing or sucker rod, inverting the surface wettability to hydrophilicity, forming a continuous water film, and reducing the resistance of crude oil flow during the pumping process. These three mechanisms often exist at the same time, but when the surfactants are different and the conditions are different, the viscosity reduction mechanism that plays a leading role is also different<sup>[14]</sup>. A small amount of emulsifier is used to prepare an oil-in-water emulsion called Orimulsion (Orimulsion Oil). Its viscosity at 50°C is 300 to 500 mPa·s (crude oil viscosity at the same temperature is 6 000 to 40 000 mPa·s), which can be stored stably. more than a year. Emulsifiers and emulsification processes are the key to this technology. Because the formation water has a high degree of mineralization, the emulsifier is required to be salt-tolerant, and non-ionic surfactants are often used. The emulsion must withstand various shear and thermal effects during storage and transportation without being destroyed. However, when applied to drag reduction in wellbore and oil field short distance gathering and transportation pipelines, the requirements for emulsion stability can be appropriately reduced.

### (3) Liquid Ring Drag Reduction

A stable low-viscosity ring is formed near the pipe

wall to separate the heavy oil from the pipe wall, which has a very significant drag reduction effect. The key to its technology is the stability of the liquid ring. Adding appropriate polymer in water has viscoelasticity, which is convenient for liquid ring stability. Tests show that<sup>[15]</sup> water accounts for 8% to 12% of the pipeline’s transport volume (88% to 92% is crude oil), and its transport friction is about 1.5 times that of the same volume. Therefore, trying to inject a low-viscosity fluid between the heavy oil and the pipe wall will effectively reduce the lifting resistance of the heavy oil well<sup>[16]</sup>. Isaacs et al.<sup>[17]</sup> first proposed a drag reduction method for the lubrication interface of heavy oil pipelines. Prada et al.<sup>[18]</sup> studied the flow characteristics of the heavy oil-water central flow in the riser and confirmed the significant drag reduction effect of the water ring. Silva et al.<sup>[19]</sup> found that the oxidation or roughness of the inner wall of the pipeline can reduce the adhesion of heavy oil on the wall of the pipeline. The injection of microbubbles between the aircraft and the liquid flow wall is considered by the shipbuilding community as one of the most effective drag reduction methods<sup>[20]</sup>. McCormick et al.<sup>[21]</sup> first used hydrogen bubbles produced by electrolysis to study the drag reduction of microbubbles on a towed rotor. Ortiz-Villafute et al.<sup>[22]</sup> found that the injection of 5v% microbubbles in the turbulent boundary layer of the square channel can significantly reduce drag. Jing et al.<sup>[23]</sup> noticed that the production of “foam oil” was several times higher than that of ordinary heavy oil and the phenomenon of microbubbles drag reduction, and proposed a new idea of water-based foam drag reduction in the flow boundary layer of heavy oil.

In summary, the direction of continued research is: continue to pay attention to the tracking and application research of high viscosity crude oil additives modified viscosity reduction transportation technology, viscosity reduction treatment transportation technology, high viscosity crude oil pipeline transportation energy saving technology to adapt to the crude oil pipeline construction market demand.

## 1.2.3 Gas Pipeline

### (1) High Steel Grade

As early as the mid-1980s, the development of X100 pipeline steel was completed abroad, but because there was no real project demand at that time, X100 steel grade pipelines have not been vigorously developed. In recent years, TransCanada of Canada conducted research on the X100 test section in 2002, 2004, and 2006, respectively, including steel pipe manufacturing, on-site cold bending welding, and winter construction, as well as the X120 steel grade conducted in 2004,

although just the study of the test section. After the successful application of X70 steel from the first West-East Gas Pipeline in China and the large-scale application of X80 steel on the second West-East Gas Pipeline, China has gradually achieved a major development from catching up to surpassing in the manufacture and use of large-caliber and high-grade pipelines. In recent years, the steel plant and the pipe plant have cooperated to complete the development of X100 pipeline steel. In 2007, the first domestic trial production of the first  $\phi 914 \times 16$  mm X120 welded pipe was successfully produced<sup>[24]</sup>. However, the performance and quality of the X100 steel pipes trial-produced in my country are still unstable, and the worldwide problem of crack toughness has not been solved well. From the perspective of development, the performance of many steel pipes is closer to X90. For the research on the fracture criteria and parameters of ultra-high-strength X90 steel pipes, Europide Company has conducted a small amount of X90 development and conducted two full-scale gas blasting tests. In 2013, driven by the major scientific and technological projects of China National Petroleum Corporation, the research work of the relevant steel mills and pipe plants focused on the development of X90 steel pipes that meet the basic requirements of API<sup>[25-26]</sup>, and the problem of fracture control has not been involved. Only China National Petroleum Institute of Petroleum Engineering Technology conducted a pilot study, conducted two physical gas blasting tests on X90 steel pipes in 2014, and built Asia's first pipeline fracture control test site in Shanshan, Xinjiang in 2015, with plans for 2016 Continue the X90 pipeline blasting test with a view to revising the empirical formula based on the CVN index, but because the number of physical blasting tests is too few, the project has not yet reported public research results<sup>[27]</sup>.

## (2) Improve Design Factor

In the 1980s, the ASME B31.8 committee recommended that natural gas pipelines use a design factor above 0.72, and a series of studies were conducted on pipeline design, reliability assessment, pipeline pressure test, and pipeline fracture control; in 1990, the 0.8 design factor was officially adopted Incorporated in ASME B31.8<sup>[28]</sup>, has been used until ASME B31.8-2007. As early as 1973, Canada changed the maximum allowable operable pressure of the pipeline in CSA Z184-1973, and the design coefficient of the first-level area was increased to 0.8, which was extended to CSA Z184-2007. The famous Union pipeline in North America, the Rocky Express Line, and the Alaska gas pipeline all use a design factor of 0.8 in the first-level

region. The strength design coefficient increased from 0.72 to 0.8 is a trend. On the one hand, if the wall thickness is kept constant, the pipeline operating pressure can be increased, thereby effectively increasing the pipeline throughput and transmission efficiency; on the other hand, if the pipeline design pressure is kept unchanged, the pipeline can be effectively reduced. Wall thickness requirements, which will significantly save pipeline construction costs. In engineering applications, 0.8 design factor pipelines require high-intensity hydraulic tests to verify the pipeline's pressure-bearing capacity and system reliability.

Relative to the design factor of 0.72, the use of a design factor of 0.8 means that the operating pressure can be increased when the pipeline specifications remain unchanged, thereby increasing the pipeline throughput. On the other hand, if the design pressure of the pipeline is kept constant, the 0.8 design factor can be used to a greater extent to take advantage of the strength properties of the pipe itself, thereby reducing the requirements for the pipe wall thickness, which will significantly reduce the production cost of line pipe. Taking the West-East Gas Pipeline as an example, the design coefficient of the gas pipeline in the first-level area is 0.72. The grid is  $\phi 1219$  mm  $\times$  18.4 mm. If the design factor is increased to 0.8, the wall thickness of the pipeline can be reduced to 16.6 mm under the condition that the design pressure and delivery volume remain unchanged, and the demand for steel will be reduced by 9.7%. Pipes used in the first-tier area of the West-East Gas Pipeline are about  $195 \times 10^4$  t. If the design coefficient is increased from 0.72 to 0.8, the construction cost can be saved by about 1 billion CNY. Based on this, in the construction of the Third West-East Gas Pipeline, a design factor of 0.8 was adopted in the 300 km test section<sup>[29]</sup>. 0.8 design factor Two key problems that need to be solved for high-strength pressure test of pipelines: ① Determine a reasonable pressure test pressure, so that the pipeline can increase the test pressure as much as possible within the acceptable risk range; ② adopt a reliable pressure test monitoring method, so that Once an abnormal situation occurs during the pressure test, it can be stopped immediately.

After the introduction to the art of pipelines in China, it comes to the design part of R oilfield in aspects of A-B pipes and the method for pipelines to cross the river.

## 2. Basis for R Oil Field Pipeline Design

### 2.1 Project Overview

When R oil field was put into development, the initial

crude oil was transported out by car. In order to meet the needs of oilfield development and production, and reduce the cost of automobile oil pulling, the design of crude oil pipelines and train loading programs is required.

The starting point of the main oil pipeline is Joint Station A, passing the first station outside B, and the ending point is the C loading station. The crude oil of this station is shipped to users by train. There is a river 40km away from Union Station A. The proposed oil pipeline crosses the river and enters the first station of B external transmission. The length of the crossing channel is about 1000m. The riverbed is relatively flat, and the terrain on both sides of the riverbank is relatively high.

## 2.2 Design Basic Information

### 2.2.1 Basic Data

**Table 1.** Basic data of R oil field oil pipeline

Pipeline start point	Pipeline end point	length(km)
A United Station	B First Outbound	86.0
The first station of B	Loading station C	84.0

**Table 2.** production from 2016-2025

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Oil production (10 <sup>4</sup> t)	49.6	45.7	39.2	34.1	29.9	26.5	23.6	21.2	19.2	17.4
Liquid production (10 <sup>4</sup> t)	86.7	83.6	77.3	72.6	68.8	65.6	63.1	61.4	59.8	58.7
Water content (%)	42.7	45.3	49.2	53.0	56.5	59.6	62.5	65.4	67.9	70.3

A dehydration station and an oily sewage advanced treatment station have been built at the first station of B foreign transportation to meet the needs of receiving watery oil from A united station.

The data of the longitudinal section of the external pipeline is shown in the table 3.

**Table 3.** Pipeline profile data

mileage (km)	0	20	38	50	72	86	110	136	158	170
Elevation (m)	562	560	572	541	556	584	568	525	536	578

### 2.2.2 Crude Oil Properties

**Table 4.** Crude Oil Properties

No.	Item	Test results
1	Density (20°C, kg/m <sup>3</sup> )	856.07
	Density (50°C, kg/m <sup>3</sup> )	835.1
2	Freezing point (°C)	30
3	Pour point (°C)	26
4	Wax precipitation point (°C)	42.7
5	Abnormal point (°C)	38
6	Colloid (%)	3.38
7	Asphaltene (%)	0.28
8	Wax content (%)	20.2
9	Salt content (mgNaCl/L)	30
10	Initial boiling point (°C)	67
11	Sulfur content (%)	0.07
12	Closed flash point (°C)	<10
13	Saturated vapor pressure (37.8kPa)	25.2(37.8°C)
		31.5(45.0°C)
14	Viscosity	see viscosity and temperature data table 5
15	Specific heat kJ/(kg·°C)	2.24
16	Fuel calorific value (MJ/kg)	4.56

**Table 5.** Crude Oil Viscosity and Temperature Data Table of Union Station

Temperature (°C)	Viscosity at different shear rates (mPa·s)					
	8 1/s	13 1/s	25 1/s	40 1/s	80 1/s	100 1/s
27	150.819	111.311	78.7296	67.1498	52.8343	49.6133
30	88.2348	81.1386	65.939	55.1189	41.9696	38.7763
32	32.4525	50.9479	46.2511	40.9102	33.3782	31.2303
34	38.8484	36.31	32.819	30.4226	26.6783	25.5444
36	21.7525	21.6544	20.991	20.4856	19.3058	18.8751
38	14.4267					
40	13.7385					
42	13.5475					
45	11.9492					
50	10.4973					
55	8.1666					
60	6.8706					
65	5.5753					
70	6.2058					

### 2.2.3 Design Environment

#### (1) Soil Condition

The buried depth of the center of the pipeline is 1.6m;

the annual minimum monthly average temperature of  $-4^{\circ}\text{C}$  and the highest monthly average temperature of  $20^{\circ}\text{C}$ ; the thermal conductivity of the soil is  $1.3\text{W}/(\text{m}\cdot^{\circ}\text{C})$ ; the thermal conductivity of the asphalt anticorrosion layer is  $0.15\text{W}/(\text{m}\cdot^{\circ}\text{C})$ .

(2) Railway Support Conditions

The C loading station is flat, the station is located 8km east of the railway marshalling station.

(3) Meteorological Conditions

The project area belongs to a mid-temperate semi-humid and semi-arid continental monsoon climate. How much wind and little rain in spring, large evaporation; cool and short in summer, concentrated precipitation; rapid fall in temperature, early frost; long cold in winter, long snow area. The monthly minimum temperature is  $-37.8^{\circ}\text{C}$ , and the monthly maximum temperature is  $32.9^{\circ}\text{C}$ . The annual sunshine hours are 2049.5 hours, and the frost-free days are 126 days.

### 3. Process Design of Oil Pipeline

#### 3.1 Conveying Process

When the freezing point of high-wax oil products is higher than the ambient temperature, or the viscosity of the oil flow is very high at ambient temperature, the normal temperature delivery method cannot be used directly. The high viscosity of the oil flow causes the pressure drop of the pipeline to increase sharply, which is often difficult or uneconomical and unsafe in engineering. Therefore, measures such as condensation and viscosity reduction must be adopted. Heated conveying is currently the most commonly used method. When heating and conveying, increasing the conveying temperature will reduce the viscosity of the oil, reduce the friction loss, reduce the pipeline pressure, or maintain the minimum oil temperature of the pipeline above the freezing point to ensure safe transportation<sup>[30]</sup>.

Use OILGA software to perform simple temperature drop calculation on the four groups of pipelines with 6in, 8in, 10in, and 12in diameters, divided into AB oil transfer section and BC oil transfer section. The following assumptions are made: ① The pipeline is transported at normal temperature without heating; ② The starting temperature of oil flow is  $70^{\circ}\text{C}$ . The calculation results are shown in Figure 1 and Figure 2.

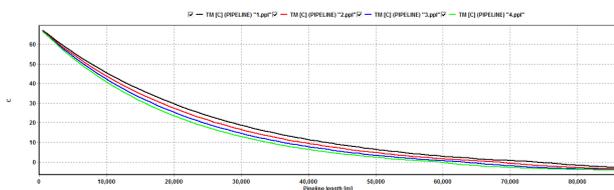


Figure 1. Temperature drop along the A-B oil transfer

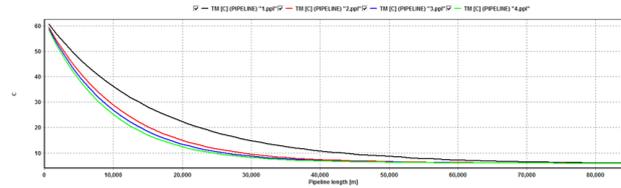


Figure 2. Temperature drop along the B-C oil transportation section

It can be seen from Figure 1 and Figure 2 that even when the starting oil temperature is  $70^{\circ}\text{C}$ , the normal temperature non-heating conveying process is adopted, and the final oil temperature is lower than the freezing point of the oil ( $30^{\circ}\text{C}$ ), which cannot guarantee the safe flow of oil. The heating conveying method can be used.

For waxy crude oil, the physical method of heating and transportation can effectively reduce the viscosity and improve the efficiency of pipeline transportation. Years of practice have shown that heating and transportation is effective, but it has high transportation energy consumption, high operation and management costs, and difficulty in restarting after stopping transportation. And other inherent defects. The emulsification viscosity reduction method and suspension transportation method in the chemical method require a large amount of water, which is difficult to achieve in remote or water-scarce areas and sites. The most widely used chemical method is mainly to add pour point depressant to reduce pour point and reduce viscosity. The chemical agent depressurization method is to change the shape, size and aggregation structure of wax crystals in crude oil by adding chemical treatment agents such as oil-soluble polymer polymers or some surfactants, and delay the wax crystals to form a three-dimensional space grid structure, thereby Lower temperature is required to form the network structure of crude oil, so as to lower the freezing point and improve the low-temperature fluidity of crude oil.

Comprehensive feasibility and economy, the AB section should be heated and insulated, and the BC section is planned to use the heating transfer process without pour point depressant and the delivery process with pour point depressant for program optimization and economic evaluation, and select the one that is suitable for the crude oil pipeline process design the best solution.

### 3.2 Design Parameters

#### 3.2.1 Pipe Design Parameters

(1) Design Throughput

There are three definitions of liquid pipeline transportation in North America, which are design transportation,

operation transportation and annual transportation. Designed output refers to the maximum output of pipeline-related equipment under ideal working conditions; operating output is the maximum output of pipelines under normal operating conditions; annual output is the shipper's hope that the pipeline will actually Completed loss. In general, the annual output is 90% of the designed output, and the operational output is 95% of the designed output.

According to relevant definitions, the maximum annual oil production in the 10-year production forecast of the area under the jurisdiction of United Joint Station A is 496,000 tons, which should be the maximum output of the pipeline under normal operating conditions, that is, the operational output. When considering the design output, 5% is taken as the design safety margin, and the design annual output should be 522,000 tons.

When calculating the amount of oil transported in the design of oil pipeline engineering, considering the factors such as pipeline maintenance and accidents, the annual working days should be calculated as 350d (4800h). The relevant design parameters are shown in Table 6.

**Table 6.** Design throughput

Operational output (10 <sup>4</sup> t)	Designed output of A-B section (10 <sup>4</sup> t)	Designed output of B-C section (10 <sup>4</sup> t)	Working days of pipeline (d)
49.6	91.1	52.2	350

(2) Design Pressure

There are two options for piping design pressure: conventional design and optimized design. The conventional design is based on the operating pressure in ASME/ANSI B16.5 for piping system pressure design, that is, MAOP (maximum allowable operating pressure) cannot exceed the rated stress limit of the valves and accessories used in the system, and the design pressure is based on the pressure level of the valve or accessories And design temperature. Although this method simplifies program selection, it increases investment and transportation costs. Because the pipeline is rarely carried out at the maximum working pressure, its conveying capacity is not fully utilized. Therefore, in order to rationally design the pipeline transportation capacity and reduce the pipeline transportation cost, the design pressure is planned to adopt the optimized design method<sup>[31]</sup>.

The optimal design is to determine the MAOP according to the technological calculation results of the design conditions and consider a certain margin as the design pressure. GB50253-2014 also specifies that MAOP should be less than or equal to the design pressure.

(3) Optimization of Pipe Diameter

For oil pipelines with a certain design capacity, as

the pipe diameter increases, the investment in steel pipe and line engineering increases, but the number of pumps and the total investment in the pumping station decrease. With the increase in pipe diameter, the cost of oil-transmission power decreases, while depreciation, management, labor, and maintenance costs are calculated according to a certain percentage of the total investment in the design. The change trend of these costs and pipeline engineering investment vary with the pipe diameter. The trend of change is similar, so it also has a minimum. The designed output is the economic output corresponding to the selected pipe diameter, and the flow velocity in the tube at this time is the economic flow velocity.

Different pipe diameters have an economic transport range with the lowest transportation cost. The current economic flow rate of oil pipelines in my country is 1.0-2.0m/s. The corresponding economic pipe diameter is calculated by equation (1). The calculation results are shown in Table 7.

$$d = \sqrt{\frac{4Q}{\pi v}} \tag{1}$$

Where d is pipe inner diameter in m, Q is volume flow of designed output in m<sup>3</sup>/s, v is economic flow rate in m/s.

**Table 7.** Pipe diameter corresponding to economic flow rate

A-B pipe diameter (mm)	A-B economic flow rate(m/s)	B-C pipe diameter (mm)	B-C economic flow rate(m/s)
201	1.5	128	1.5

According to GB-T17395 (2008) in China, six groups of similar pipe diameters were selected for preliminary optimization calculation, see Table 8.

**Table 8.** Pipe diameters for preliminary optimization calculation

Cases		I	II	III	IV	V	VI
Nominal diameter (mm)	A-B	180	194	203	219	232	245
Nominal diameter (mm)	B-C	127	140	159	168	180	194

(4) Steel Pipe Type Selection

Steel is divided into seamless steel pipe and seamed steel pipe according to different pipe making methods, and seamed steel pipe can be divided into straight seam pipe and spiral welded seam pipe. Due to the small diameter range of the seamless steel pipe, the complicated manufacturing process and the high price, it is rarely used

on long-distance oil pipelines.

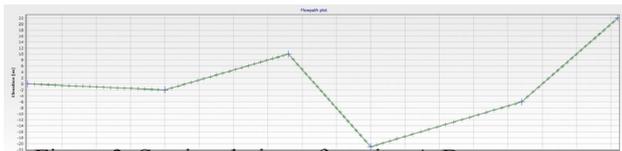
Straight seam pipe and spiral welded steel pipe have their own advantages and disadvantages. In principle, as long as the pipes that are produced and inspected according to the specifications can meet the requirements of oil and gas pipeline engineering. According to statistics from foreign sources, in high-pressure large-diameter oil and gas pipelines, the production and use of straight-seam pipes occupy a considerable advantage and dominant position. Considering the economics and safety of pipelines, in the design of China's long-distance oil and gas pipelines, spiral welded pipes are mostly used in general areas with low population density. Therefore, combined with the regional characteristics of the project, spiral welds are used for oil pipelines tube.

(5) Pipeline Longitudinal Section

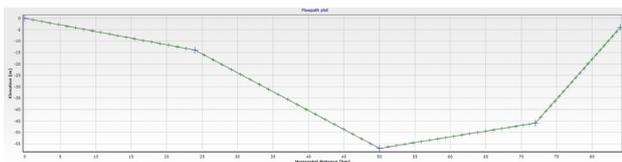
**Table 9.** Pipeline profile data

Mileage (km)	0	20	38	50	72	86	110	136	158	170
Elevation (m)	562	560	572	541	556	584	568	525	536	578

Use OLGA software to draw the topographic relief slopes of sections A-B and B-C, see Figure 3 and Figure 4.



**Figure 3.** Sectional view of section A-B



**Figure 4.** Sectional view of section B-C

It can be seen from Figure 3 and Figure 4 that the terrain along the pipeline has a relatively smooth terrain, but there are two points with a large drop. It is necessary to check the corresponding hydrostatic pressure to ensure the safe transportation of the pipeline.

(6) Pipeline Depth Parameters

The buried depth of the center of the pipeline is 1.6m; the annual minimum monthly average temperature of the pipeline is -4°C, the highest monthly average temperature is 20°C; the soil thermal conductivity is 1.3W/(m·°C).

(7) Pipeline Coating

The anti-corrosion layer is the main barrier for pipeline protection. The selection of anti-corrosion layer should be based on the topography and soil quality of the specific laying environment of the pipeline, combined with the use

of domestic mature anti-corrosion layer. The principle of selection. At present, the commonly used anticorrosion process for the external wall of pipelines usually includes anticorrosion of petroleum asphalt, anticorrosion of three-layer PE structure and anticorrosion of polyethylene adhesive tape.

① The three-layer PE is formed by the combination of epoxy resin and extruded polyethylene coating. It combines the advantages of two-layer PE and sintered epoxy, overcomes their respective shortcomings, and makes the three-layer PE have various excellent The performance and adaptability are wider, so that the corrosion resistance of the pipeline is further improved, and the service life of the pipeline is increased, but the cost is high.

② Petroleum asphalt anti-corrosion, the main advantages are relatively simple prefabricated technology, mature construction technology, rich experience, low cost, strong construction adaptability, but large water absorption rate, poor aging resistance, not resistant to bacteria, which is a relatively backward anti-corrosion process.

③ The anti-corrosion layer of polyethylene adhesive tape is a non-heating anti-corrosion layer. It has the characteristics of convenient and flexible construction, dense anti-corrosion layer, small water absorption rate, and resistance to chemical erosion. However, it has the characteristics of poor resistance to soil stress. Peel strength should be the focus of the adhesive tape performance indicators. Generally, adhesive tape with release paper should be used, and the peel strength of the primer steel should reach 40 N/cm.

Based on the above analysis, the common grade PE with the best comprehensive performance is recommended as the anti-corrosion layer of the oil pipeline, in which the fused epoxy layer: 50 μm, the adhesive layer: 50 μm, and the polyethylene layer: 2.7 μm.

**3.2.2 Physical Properties of Crude Oil**

(1) Oil Density

The relative density of crude oil is approximately linear with temperature, and its temperature coefficient is related to density. The relative density of crude oil at a certain temperature T can be obtained from equations (2) and (3). The calculation results are shown in Table 10:

$$d_4 = d_4^{20} - \xi(T - 20) \tag{2}$$

$$\xi = 1.825 \times 10^{-3} - 1.315 \times 10^{-3} d_4^{20} \tag{3}$$

where  $d_4$  is relative density of crude oil,  $d_4^{20}$  is relative density of crude oil at 20°C,  $\xi$  is temperature coefficient.

**Table 10.** Relative density of oil at different temperatures

Temperature(°C )	relative density
10	0.863063
20	0.85607
30	0.849077
40	0.842085
50	0.835092
60	0.828099
70	0.821107

(2) Oil Viscosity

For waxy crude oil, when the temperature drops to the wax precipitation point, as the temperature further decreases, the wax crystals precipitated from the crude oil increase continuously, and the rheological properties of the crude oil also change from Newtonian fluid to non-Newtonian fluid, that is, the crude oil also has a constant temperature No longer has a unique viscosity, but an apparent viscosity related to shear rate. The temperature at which the transition from Newtonian fluid to non-Newtonian fluid is called the anomaly point. Considering that before and after the anomalous point, the fluid behaves as Newtonian fluid and non-Newtonian fluid respectively, with different viscosity-temperature characteristics. Therefore, when fitting the viscosity-temperature curve, it is divided into two parts for fitting.

In the temperature range of Newtonian fluid, below the initial boiling point, above the temperature of the wax precipitation point, and between the wax precipitation point and the abnormal point, the viscosity temperature curve can be generally fitted by equation (4).

$$\lg\mu = a - bT \tag{4}$$

Where  $\mu$  is oil viscosity in mPa·s, T is oil temperature in °C.

When the waxy crude oil drops to an abnormal point with temperature and turns into a non-Newtonian fluid, the waxy crude oil is generally a pseudoplastic fluid, and the relationship between shear stress and shear rate can be well described by the power law equation. For non-Newtonian fluids, based on the definition of Newtonian hydrodynamic viscosity, the shear stress can be calculated according to formula (5), and the calculation results are shown in Table 11.

$$\tau = \mu_a \cdot \dot{\gamma} \tag{5}$$

Where  $\tau$  is shear stress in mPa,  $\mu_a$  is apparent viscosity in mPa·s,  $\dot{\gamma}$  is shear rate 1/s.

**Table 11.** Crude oil shear stress at A United Station

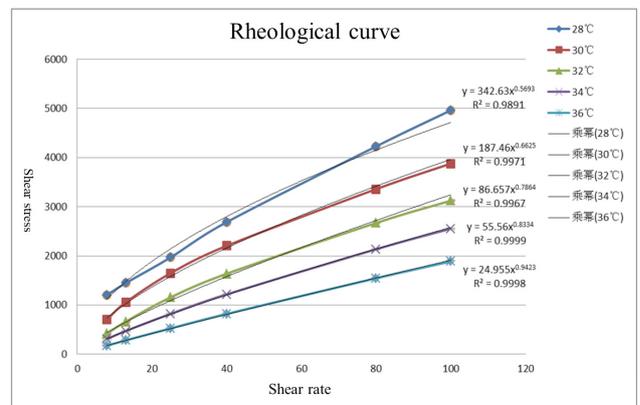
Temperature (°C )	Shear stress at different shear rates (mPa)					
	8 1/s	13 1/s	25 1/s	40 1/s	80 1/s	100 1/s
27	1206.552	1447.044	1968.24	2685.992	4226.744	4961.33
30	705.8784	9031.627	1968.24	2204.756	3357.568	3877.63
32	419.62	4133.841	1156.278	1636.408	2670.256	3123.03
34	310.7872	1849.918	820.475	1617.064	2134.264	2554.44
36	174.02	786.2713	524.775	819.424	1544.464	1887.51
38	115.4136	187.5471	360.6675	577.068	1154.136	1442.67

Pseudoplastic fluids are generally solid-liquid and liquid-liquid dispersion systems and polymer solutions that do not form an overall network structure. After the wax precipitation of waxy crude oil increases to a certain degree and becomes a non-Newtonian Newtonian fluid, it is a pseudoplastic fluid. The relationship between fluid shear stress and shear rheology is called rheological equation, or rheological model. There are many rheological models that can describe pseudoplasticity, among which the most commonly used is the power law model of formula (6).

$$\tau = K\dot{\gamma}^n \tag{6}$$

Where K is the consistency factor to indicate the viscosity of the fluid in mPa·s<sup>n</sup>, n is the flow characteristic index, indicating the degree to which the flow characteristic of the fluid deviates from Newtonian fluid in dimensionless.

According to the crude oil shear stress and formula (6) power law model formula provided in Table 9, the rheological curve when the crude oil behaves as a non-Newtonian fluid is fitted. The fitting results are shown in Figure 5.



**Figure 5.** Rheological curve fitting

It can be seen from Figure 5 that the result of fitting the rheological curve of the waxy crude oil according to

the power law fluid model is basically consistent with the actual situation. When the fluid is converted into a non-Newtonian fluid, the calculation can be performed according to the power law fluid.

(3) Crude Oil Emulsification

Section A-B is the oil-water two-phase mixed transportation section. When considering the phase state of oil and water, it is considered to be the emulsification of crude oil, and referring to Daqing crude oil (because the nature of the oil in this article is similar to Daqing crude oil), the inversion point is 65% water content. That is, when the hydraulic calculation of section A-B is performed, the water content is 65% before W/O emulsion; after the water content 65% is O/W emulsion.

The mixed viscosity of emulsified crude oil is calculated by the WOELFLIN mixed viscosity formula of OLGA software. The viscosity of crude oil with different water content is shown in Figure 6. Oil viscosity is in mPa·s.

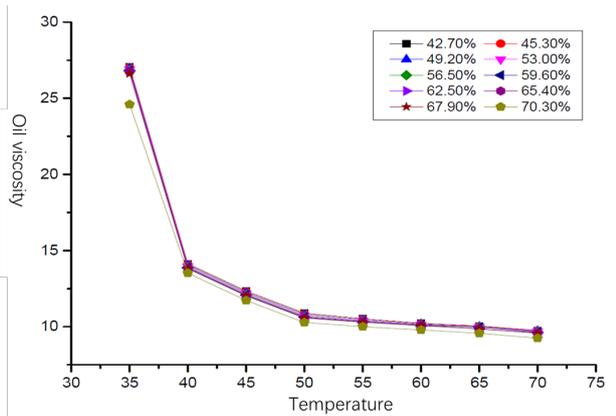


Figure 6. Viscosity of emulsified crude oil at different water contents

3.2.3 Thermal Design Parameters

(1) Outlet Oil Temperature of Heating Station

Because waxy crude oil tends to have a steep viscosity-temperature curve near the freezing point, when the temperature is higher than the freezing point by 30-40 °C, the change of viscosity with temperature is small. Because the hot waxy crude oil pipeline is usually in the turbulent smooth area, the friction resistance is proportional to the viscosity of 0.25 power, increasing the oil temperature has little effect on the friction resistance, but the heat loss is significantly increased, so the heating temperature should not be too high, And considering that the heating temperature should not exceed the thermal stress of the pipeline, the maximum exit temperature is taken as 65 °C.

(2) Oil Temperature of Heating Station

The inlet oil temperature of the heating station depends mainly on the needs of economic comparison and operational safety. For waxy crude oil with a higher freezing point, the viscosity entry temperature curve is very steep near the freezing point, so its economic inlet temperature is slightly higher than the freezing point, which can be higher than the freezing point 3-5 °C.

Under normal operating conditions, the oil temperature at the next station should be 35°C and the minimum oil temperature at the station should be 33°C.

(3) Medium Temperature T<sub>0</sub> around the Pipeline

For buried pipelines, T<sub>0</sub> takes the natural temperature of the soil at the depth of the pipeline. When designing hot oil pipelines according to “GB50253-2014 Oil Pipeline Engineering Design Code”, the temperature drop, and heat load should be calculated according to the average temperature of the coldest month. And formulate the operation plan under the highest monthly average temperature and carry out the plan design in different seasons. According to the basic data of the competition, the minimum and maximum monthly average temperature of the soil is taken as the temperature T<sub>0</sub> of the medium around the pipeline (see Table 12).

Table 12. Medium temperature T<sub>0</sub> around the pipeline

The lowest monthly average temperature (°C )	The highest monthly average temperature (°C )
-4	20

(4) Design of Pipeline Insulation

Since the freezing point of crude oil is 30°C and the wax precipitation point is 42.7°C, if the pipeline is not provided with an insulation layer, the temperature of the fluid in the pipe will rapidly decrease when the starting temperature is 65°C under the simulation of OLGA software. When the flow length reaches 350 meters, the temperature is reduced to 30 °C, which means that the temperature of the fluid in the tube is below the freezing point temperature. At this time, a large amount of wax crystals will be precipitated to form a network structure, which makes the crude oil have strong thixotropy and high yield stress, and the crude oil loses its fluidity, which eventually leads to “Condensation tube accident. Therefore, this scheme adopts two methods of heating transportation and heat preservation transportation to ensure the crude oil fluidity.

The thermal conductivity of the steel pipe is very strong, and its thermal conductivity is about 45-50 W/(m·°C). Commonly used thermal insulation materials are polyurethane foam, foamed diatomaceous earth, vermiculite cement, slag wool, and foam concrete rock wool pipe, glass wool tube, rubber and plastic sponge, polyethylene

insulation material, composite silicate insulation material, aluminum silicate insulation material. The thermal conductivity of several commonly used insulation materials is shown in Table 13.

**Table 13.** Thermal conductivity of commonly used insulation materials

Material name	Polyurethane foam	Foam diatomaceous earth	Vermiculite cement	Slag wool	Foam concrete
Thermal ConductivityW/(m·°C)	0.035-0.047	0.07-0.093	0.08-0.13	0.047-0.07	0.12-0.21

This design uses polyurethane foam as the thermal insulation layer because it has the advantages of low bulk density, low thermal conductivity, low water absorption, high compressive strength, good adhesion to the steel surface and convenient construction.

After the insulation layer material is determined, the thickness of the insulation layer is an important parameter that affects the technical and economic indicators. As the thickness of the insulation layer increases, the heat transfer coefficient of the pipeline decreases, which can reduce the investment in the heating station or heat pump station, reduce energy consumption, and save operating costs, but the material cost and construction cost of the insulation layer increase. And after the insulation layer is increased to a certain degree, the improvement of the insulation effect is not obvious. The thickness of the insulation layer should be determined through technical and economic comparisons. It is proposed to choose different thicknesses of insulation layers, perform thermal and hydraulic process calculations on them, determine the pumping station, heating station and operating parameters, calculate their investment and operating costs, and then carry out technology on each program. Economic comparison to determine the best insulation thickness.

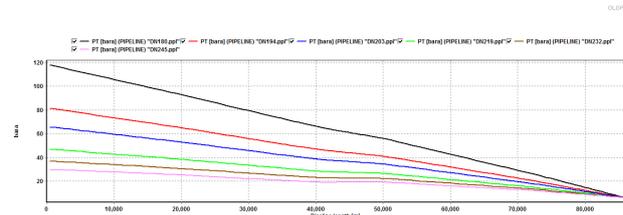
### 3.3 A-B Process Design

The process design mainly considers the influence of pipe diameter, thermal insulation layer, design pressure, and wall thickness (steel level) on pipeline investment and operation. The above parameters are combined and optimized. Hydraulic and thermal calculations are performed at the same time, and each set of schemes is determined based on the design output. The hydraulic scheme and the minimum output under the following schemes determine the thermal scheme under each group of schemes. The 54 groups of schemes are combined. The 54 groups of schemes are analyzed for eco-

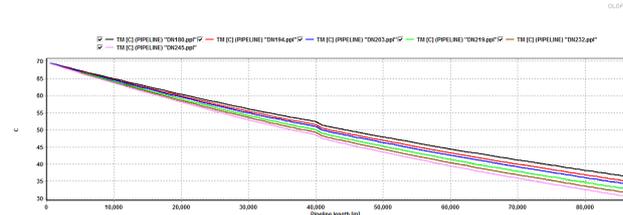
nomical and low-flow adaptability, and the best scheme is selected. According to the thermal calculation, the thickness of the heat preservation layer is 30mm, 40mm and 50mm.

### 3.3.1 Design Scheme under Design Throughput

#### (1) Plans Under 30mm Insulation

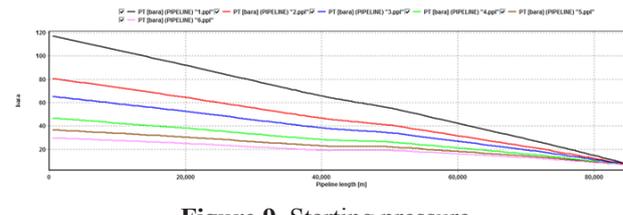


**Figure 7.** Starting pressure

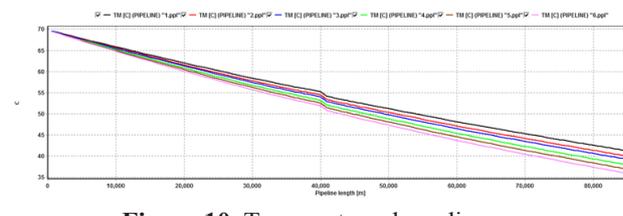


**Figure 8.** Temperature drop diagram

#### (2) Plans Under 40mm Insulation

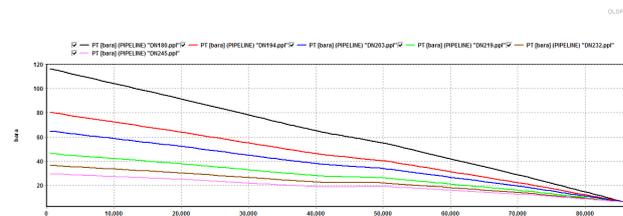


**Figure 9.** Starting pressure



**Figure 10.** Temperature drop diagram

#### (3) Plans Under 50mm Insulation



**Figure 11.** Starting pressure

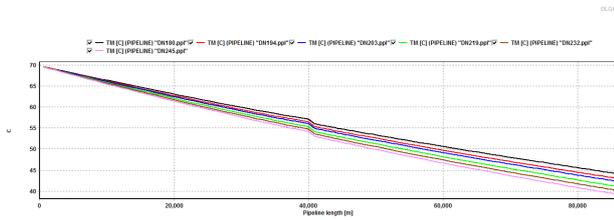


Figure 12. Temperature drop diagram

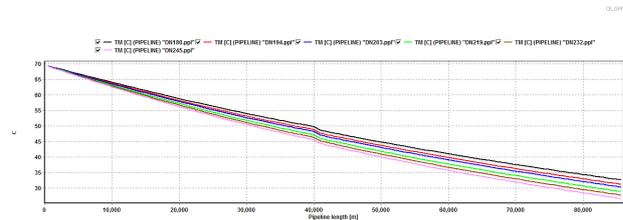


Figure 14. Temperature drop diagram

Table 14. Design scheme under design throughput

Scheme		A-B				
Pipe diameter scheme	Insulation (mm)	Outbound temperature(°C)	Incoming temperature(°C)	Starting point pressure(M-Pa)	Number of thermal stations	Number of pumping stations
D180	30	70	36.6	11.9	1	2
	40	70	41	11.8	1	2
	50	70	44	11.7	1	2
D194	30	70	35.2	8.2	1	2
	40	70	39.8	8.1	1	2
	50	70	43	8	1	2
D203	30	56	34.4	6.6	1	2
	40	51.8	39	6.5	1	2
	50	48	42	6.4	1	2
D219	30	59	35	4.7	2	1
	40	56	37.7	4.6	1	1
	50	53	41	4.5	1	1
D232	30	70	35	3.7	2	1
	40	70	36.7	3.67	1	1
	50	70	40	3.64	1	1
D245	30	70	35	3	2	1
	40	70	35.7	2.97	1	1
	50	70	39	2.94	1	1

(2) Plans under 30mm Insulation

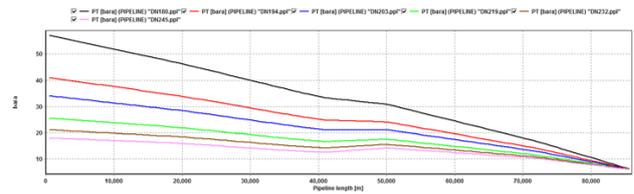


Figure 15. Starting pressure

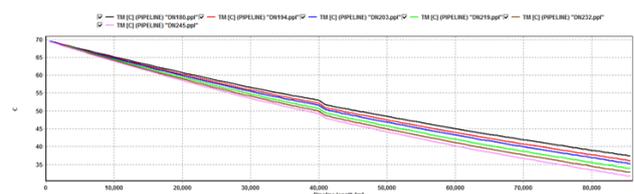


Figure 16. Temperature drop diagram

(3) Plans under 40mm Insulation

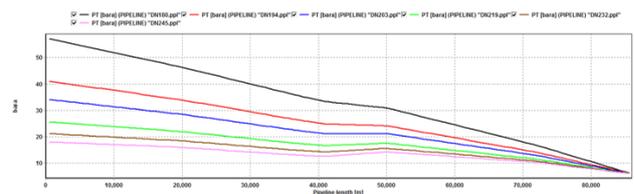


Figure 17. Starting pressure

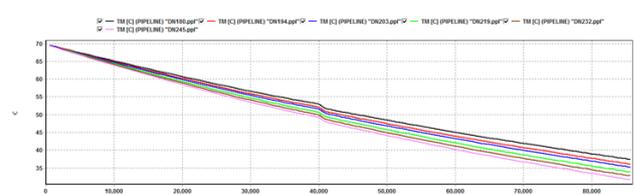


Figure 18. Temperature drop diagram

(4) Plans under 50mm Insulation

### 3.3.2 Design Scheme at Minimum Throughput

(1) Plans Under 30mm Insulation

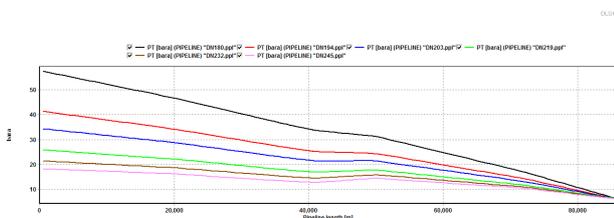


Figure 13. Starting pressure

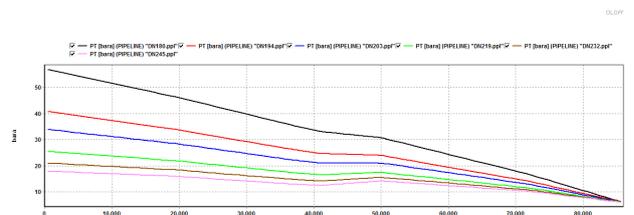


Figure 19. Starting pressure

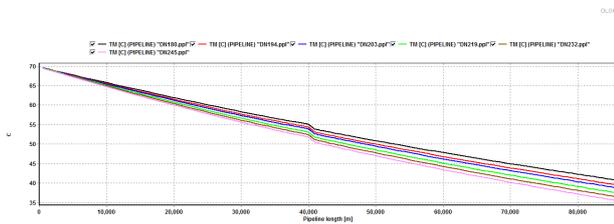


Figure 20. Temperature drop diagram

Table 15. Design scheme at minimum throughput

Scheme		A-B				
Pipe diameter scheme	Insulation (mm)	Outbound temperature(°C)	Incoming temperature(°C)	Starting point pressure(MPa)	Number of thermal stations	Number of pumping stations
D180	30	70	35	5.75	2	2
	40	70	37.4	5.72	1	2
	50	70	40.8	5.7	1	2
D194	30	70	35.2	4.12	2	2
	40	70	36.1	4.1	1	2
	50	70	39.6	4.1	1	2
D203	30	70	35	3.43	2	2
	40	70	35.3	3.4	1	2
	50	70	38.8	3.4	1	2
D219	30	59	35	2.59	2	1
	40	56	33.4	2.57	1	1
	50	53	37.5	2.56	1	1
D232	30	70	35	2.1	2	1
	40	70	35	2.1	2	1
	50	70	36.5	2.1	1	1
D245	30	70	35	1.82	2	1
	40	70	35	1.81	2	1
	50	70	35.5	1.8	1	1

3.3.3 Design Pressure and Pipe Wall Thickness

According to the hydraulic calculation results under the design throughput, a set of design pressure and three sets of steel grades are selected, and the design wall thickness is calculated by considering a certain corrosion allowance. Among them, the strength design factor of oil pipeline is 0.5. Pipe wall thickness should be calculated according to

the following formula (3.7).

$$\delta = \frac{pD}{2\sigma_s F \phi t} + C \tag{7}$$

Where  $\delta$  is wall thickness of steel pipe in mm, P is pipe design pressure in MPa, D is outer diameter of steel pipe in mm, F is strength design factor,  $\sigma_s$  is minimum yield strength of pipeline in MPa,  $\phi$  is welding coefficient (0.9 for seamless pipeline and 0.8 for welded pipeline), C is additional value of corrosion allowance in mm, here taken as 3 mm, T is temperature reduction coefficient taken as 1.0.

Due to the high-water content of section A-B, considering the safe transportation of the pipeline, the corresponding internal anti-corrosion measures should be taken, and the wall thickness corrosion allowance should be 3mm.

(1) L245 steel pipeline

Table 16. Selection of design pressure and wall thickness under L245 steel grade

Cases		A-B Section			
Diameter	Insulation (mm)	Design pressure(MPa)	Number of pumping stations	Corrosion allowance (mm)	Design wall thickness (mm)
D180	30	6	2	3	8.5
	40	6	2	3	8.5
	50	6	2	3	8.5
D194	30	9.4	1	3	13.5
	40	9.3	1	3	13.5
	50	9.2	1	3	13.5
D203	30	7.4	1	3	10
	40	7.3	1	3	10
	50	7.2	1	3	10
D219	30	5.7	1	3	9
	40	5.6	1	3	9
	50	5.5	1	3	9
D232	30	4.7	1	3	8.5
	40	4.7	1	3	8.5
	50	4.6	1	3	8.5
D245	30	4	1	3	8.0
	40	4	1	3	8.0
	50	4	1	3	8.0

(2) L290 Steel Pipeline

**Table 17.** Selection of design pressure and wall thickness under L245 steel grade

Cases		A-B Section			
Diameter	Insulation (mm)	Diameter	Insulation (mm)	Diameter	Insulation (mm)
D180	30	6	2	3	7.5
	40	6	2	3	7.5
	50	6	2	3	7.5
D194	30	9.4	1	3	10
	40	9.3	1	3	10
	50	9.2	1	3	10
D203	30	7.4	1	3	8.5
	40	7.3	1	3	8.5
	50	7.2	1	3	8.5
D219	30	5.7	1	3	7
	40	5.6	1	3	7
	50	5.5	1	3	7
D232	30	4.7	1	3	6.5
	40	4.67	1	3	6.5
	50	4.64	1	3	6.5
D245	30	4	1	3	6
	40	4	1	3	6
	50	4	1	3	6

(3) L360 Steel Pipeline

**Table 18.** Selection of design pressure and wall thickness under L360 steel grade

Cases		A-B Section			
Diameter	Insulation (mm)	Diameter	Insulation (mm)	Diameter	Insulation (mm)
D180	30	6	2	3	6.5
	40	6	2	3	6.5
	50	6	2	3	6.5
D194	30	9.4	1	3	9
	40	9.3	1	3	9
	50	9.2	1	3	9
D203	30	7.4	1	3	8
	40	7.3	1	3	8
	50	7.2	1	3	8

D219	30	5.7	1	3	6.5
	40	5.6	1	3	6.5
	50	5.5	1	3	6.5
D232	30	4.7	1	3	6
	40	4.67	1	3	6
	50	4.64	1	3	6
D245	30	4	1	3	6
	40	4	1	3	6
	50	4	1	3	6

**3.3.4 Economic Evaluation**

The total investment of each plan should include pipeline investment, insulation layer investment, station investment, operation investment. After the economic comparison and selection of 54 sets of schemes, the “φ219×6.5mm” scheme was selected, the specific parameters of which are shown in Table 19 below.

**Table 19.** A-B pipeline design parameters

Nominal diameter	Insulation	design pressure	Wall thickness	Steel grade	thermal-pump station	Independent thermal station	Independent pumping station
D219	50	5.5	6.5	L360	1	no	no

**4. Crossing River Design**

**4.1 Comparison of Methods for River Crossing**

The crossing scheme adopted is selected to determine the most economical, reasonable and feasible technical scheme. The general principle of river crossing and crossing scheme selection is the main, crossing is the secondary. The specific principles are as follows:

(1) Due to the large investment in pipeline crossing projects, the construction is relatively complicated, and the maintenance workload is large after completion, it is preferable to use the crossing method when the pipeline passes through the river.

(2) In the selection of the crossing plan, the reasonable width of the project pipeline crossing the river, the flow rate, the flow rate, the navigable grade, the levee grade of the river bank, etc. should be determined according to the comprehensive consideration of the river shape, hydrological parameters, engineering geology, etc. Way through. For large rivers, it is advisable to exclude the underwater excavation and crossing method that has a large amount of construction work on the wa-

ter and affects navigation and try to use the non-excavating method.

(4) In the case of geological conditions that do not meet the directional drilling crossing, tunnels, shields, pipe jacking and other crossing methods or crossing methods can be considered for large and medium-sized rivers, and the optimal crossing and crossing scheme can be determined through comprehensive technical and economic comparison and selection.

(5) The crossing of small rivers mainly includes excavation, horizontal hole drilling rig (with casing) or small directional drilling. The appropriate crossing construction method can be selected according to the specific conditions of river hydrology and geology.

(3) Directional drilling crossing is an advanced trenchless pipeline crossing construction method. The construction is completely carried out on the land on both sides of the water. It has no damage to the river embankment or water embankment, does not disturb the riverbed, does not affect navigation, and has a short construction period. The advantages of safe pipeline operation and low comprehensive cost should be given priority to large and medium-sized rivers under geological conditions.

In summary, considering that the strata of the river crossing section are mainly gravel sand layer and clay layer, and no rock formation, adhering to the design concept of "safety, economy and environmental protection", the construction period is selected to be short, the environmental damage is small, and the project investment is low. The horizontal directional drilling crossing (HDD) is the preferred scheme for the pipeline crossing the river.

## 4.2 Horizontal Directional Drilling Crossing Design

### 4.2.1 HDD Drillability Evaluation

#### (1) Cross-Site Stratigraphic Lithology

According to the comprehensive analysis of drilling results, in-situ testing and laboratory test results, the characteristics of each rock and soil layer of the site are described below from top to bottom as follows:

Within the depth range revealed by the exploration, the site stratum is divided into 6 main layers and 3 sublayers.

1) Silty clay: gray-gray-black, the cause of silt. The soil is uneven, and the layout is mixed with thin layers of silt, silt, and clay. No shaking response, slightly smooth, medium dry strength, medium toughness. Flow plastic-soft plastic. This layer is only distributed on the floodplain, with a thickness of 0.8-2.0m.

2) Medium sand: yellow, formed by impact. The particles are uniform, with a thin layer of silt and silt locally. The main mineral components are quartz, feldspar and a small amount of dark minerals. Slightly dense-medium dense, slightly wet-saturated. This layer is distributed in the west of the river channel and has a thickness of 2.0-3.0m.

3) Silt: yellow, formed by impact. The particles are uniform, with a thin layer of silt locally. The main mineral components are quartz, feldspar and a small amount of dark minerals. Slightly dense-medium dense, dry-slightly wet, only distributed on both sides.

4) Clay: yellow, the cause of siltation, the soil quality is relatively uniform, with a thin layer of plastic silty clay locally, no shaking response, slightly smooth, high dry strength and high toughness. Plastic.

5) Gravel: gray, formed by alluvial deposits. The particles are uneven, and there are thin layers of sand and coarse sand in the local area. The main mineral components are quartz, feldspar and a small amount of dark minerals. Slightly dense-medium dense, saturated.

① Medium sand: yellow, formed by impact, with uniform particles, and a thin layer of silt. The main mineral components are quartz, feldspar and a small amount of dark minerals. Medium density, saturated, this layer is only distributed in some holes.

② Silt: yellow, formed by alluvial deposits. The particles are uniform, with a thin layer of silt locally. The main mineral components are quartz, feldspar and a small amount of dark minerals. Medium density, saturated, this layer is only distributed in some holes.

6) Clay: gray-yellow-gray, the cause of siltation, the soil quality is relatively uniform, and a thin layer of plastic silty clay is locally sandwiched. No shaking response, slightly smooth, high dry strength and high toughness. Hard plastic hard. Silt: gray, alluvial origin, relatively uniform soil quality, no shaking response, shiny, low dry strength, low toughness. Medium density, wet, this layer is only distributed in part of the borehole.

It should be noted that the geological profile is a projection profile of the borehole strata on both sides of the pipeline under the pipeline location. Since the borehole is not in the pipeline location, there is a problem that the borehole elevation is higher or lower than the topographic line.

#### (2) Physical and Mechanical Properties of Soil across the Site

The R oil field gives the main physical and mechanical properties of each soil layer, including the natural water content of each layer, soil density, pore ratio, liquidity index, compression coefficient ( $\text{MPa}^{-1}$ ), compression mod-

ulus (MPa), 5 types of indicators for standard penetration test (hit).

Natural water content: an important physical indicator reflecting the humidity of the soil. The water content of the soil layer in the natural state is called the natural water content, and its variation range is very large, which is related to the type of soil, the burial conditions and the natural geographical environment in which it is located. Generally, the value of dry coarse sand is close to zero, and saturated sand can reach 40%; the water content of hard cohesive soil is less than 30%, while that of saturated soft clay (such as silt) can reach 60% or more. Generally speaking, when the water content of the same type of soil increases, the strength decreases.

Liquidity index: It is an index to judge the soft and hard state of the soil, indicating the relative relationship between the natural water content and the limit water content. According to the Geotechnical Investigation Specification (GB50021-94), the liquidity index is shown in the table 20.

**Table 20.** The softness and hardness of the soil divided by liquidity index

Liquidity Index $I_L$	$I_L < 0$	$0 \leq I_L \leq 0.25$	$0.25 \leq I_L < 0.75$	$0.75 \leq I_L < 1$	$I_L \geq 1$
Soft and hard state	Hard	Hard plastic	Plastic	Soft plastic	Flow plastic

Porosity ratio: refers to the ratio of the volume of pores in the material to the volume of particles in the material and is an important physical property index that reflects the compactness of the material. The compactness of natural soil layers can be evaluated [7]. Generally, the soil with  $e < 0.6$  is dense low-compression soil, and the soil with  $e > 1.0$  is loose high-compression soil.

Soil compressibility coefficient  $a_{1-2}$ : A physical quantity used to describe the compressibility of soil, defined as the slope of the secant of a pressure segment on the  $e-p$  curve obtained from the compression test.  $a_{1-2} < 0.1$  MPa-1 belongs to low compressive soil;  $0.1$  MPa-1  $\leq a_{1-2} < 0.5$  MPa-1 belongs to medium compressive soil;  $a_{1-2} \geq 0.5$  MPa-1 belongs to high compressive soil [8].

The compressive modulus of soil is one of the important indicators to judge the compressibility of soil and calculate the compression deformation of foundation. The greater the compression modulus, the harder the soil [9].

Standard penetration test (hit): It is a method for determining the bearing capacity of sand or cohesive soil on site [10]. According to "Code for Design of Building Foundation Foundation" (GB50007-2011), the classification of the density of natural sand is shown in the table 21.

**Table 21.** Classification of the density of natural sand

Standard penetration test hammer number N	Compactness
$N \leq 10$ loose	$N \leq 10$ loose
$10 < N \leq 15$ slightly dense	$10 < N \leq 15$ slightly dense
$15 < N \leq 30$ medium density	$15 < N \leq 30$ medium density
$N > 30$	$N > 30$

1- Layer, silty clay layer, natural water content  $\omega=73\%$ , liquidity index  $IL=1.61$ , this layer is a high-water-bearing, fluid-plastic layer, which is liquified easily by vibration during the directional drilling process.

2-Layer, medium sand layer, natural water content  $\omega = 8.9\%$ , standard penetration test (strike) = 4.6, this layer is low water content, loose formation.

3- Layer, silt layer, natural water content  $\omega=12\%$ , which is water-bearing stratum.

4- Layer, clay layer, natural water content  $\omega=36\%$ , soil density  $\rho_0=1.81g/cm^3$ , porosity ratio  $e=1.059$ , liquidity index  $IL=0.22$ , soil compression coefficient  $a_{1-2}=0.655MPa-1$ . The compressive modulus of the soil  $E_s=3.15MPa$ , the layer is a hard plastic, loose and highly compressive soil layer.

5- Layer, gravel sand layer, natural water content  $\omega=11.2\%$ , standard penetration test (strike)=14.9, this layer is water-bearing, slightly dense soil layer.

5-1-Layer, middle sand layer, natural water content  $\omega=17.5\%$ , water-bearing stratum.

5-2-Layer, silt layer, natural water content  $\omega=18.8\%$ , water-bearing stratum.

6- Layer, clay layer, natural water content  $\omega=35.4\%$ , soil density  $\rho_0=1.86g/cm^3$ , porosity ratio  $e=1.004$ , liquidity index  $IL=0.24$ , soil compression coefficient  $a_{1-2}=0.24MPa-1$ . The compression modulus of soil  $E_s=9.93MPa$ , standard penetration test (strike)=11.2, the layer is a hard plastic, loose-slightly dense, loose medium compressive soil layer.

6-1-Layer, silty layer, natural water content  $\omega=22.3\%$ , soil density  $\rho_0=1.95g/cm^3$ , porosity ratio  $e=0.693$ , liquidity index  $IL=0.24$ , soil compression coefficient  $a_{1-2}=0.24MPa-1$ , soil compression modulus  $E_s=7.20MPa$ , this layer is a hard plastic, medium compressive soil layer.

(3) Drillability Evaluation of Rock and Soil Layers across the Area

Engineering survey results show that: the clay 6-layer is a hard soil layer with good mechanical properties and is easy to be drilled by directional drilling; the 5-layer of gravel sand,  $N=14.9$ , is slightly dense and the mechanical properties are average, but the particles larger than 2mm are unknown about the content and cement ability between particles. The stable groundwater level across the section is higher, the elevation is (Yellow Sea Elevation System), the

elevation is 566m, and the depth is 1.2m-7.8m.

Existing problems:

① The silty clay 1-layer with high water content is fluid and plastic, which is liquified easily by vibration during the process of directional drilling;

② Due to the high groundwater level, sand in 2-layer, silt in 3-layer, gravel sand in 5- layer, and sublayers 5-1-layer and 5-2-layer are sandy formations, which are often exposed to water. Saturation is easy to dilute and dissipate. During the drilling process, the sand layer is encountered, and the stability of the shaft wall is poor. It often occurs that the cross-hole collapses and the hole cannot be formed, which causes difficulties in drilling, reaming, and dragging. It is prone to accidents such as buried drilling.

In response to the above problems, in addition to crossing below the maximum scouring line of the riverbed, the silt, silt and silty soil layer should be avoided as far as possible. The mud ratio must be strictly controlled during drilling, the mud formula must be adjusted, and the straight-line section of the access point should be set. The casing adopts effective measures such as a pre-expanding process and enhanced hole washing operations to ensure high hole formation quality and good stability of the shaft wall, to ensure that no backhauling difficulties, stuck pipes, buried pipes and other vicious accidents occur, and to ensure pipeline backhauling One-time completion success rate.

In summary, it is recommended:

- ① Crossing from hard clay with good self-stability;
- ② HDD entry and exit points avoid the 1-layer of silty clay that is liable to vibration and liquefaction, and choose embankments on both sides of the river (mainly sandy formations) capable of HDD construction;
- ③ The collapsible sand layer located near the unearthed point and the unearthed point, such as 2-middle-layer sand, can be solved by the construction method of setting casing during construction.

(4) Evaluation of Construction Conditions

According to the site conditions, the left bank and the right bank of the river have a certain inclination angle, which is not conducive to on-site construction. After the site is leveled and the foundation is tamped, the design of equipment such as drilling rigs can enter the site.

(5) Evaluation of Underground Obstacles

According to the survey data, there are no underground obstacles in the river crossing section that will affect the construction of the crossing pipeline.

### 4.2.2 HDD Crossing Curve Design

The drill ability evaluation of the HDD stratum shows that: the clay 6-layer is mainly penetrating the stratum, so the horizontal section of the crossing curve should be located

at 551.65m-557.20m in the Yellow Sea elevation system; the silty clay 1-layer is liable to liquefaction due to vibration and is not suitable for selection. As the point of entry and exit of the pipeline, the point of entry and exit of the crossing track is set on the banks of both sides of the river; in order to ensure the shortest distance of the pipeline passing through the bad stratum, the coordinates of the point of entry are initially selected as (9.36,573.86), and the coordinates of the point of entry are (1073.18 , 570.15). Establish a mathematical model to solve the objective function of the shortest crossing trajectory. Each design parameter is represented on the simplified drawing of the crossing curve, as shown in Figure 21.

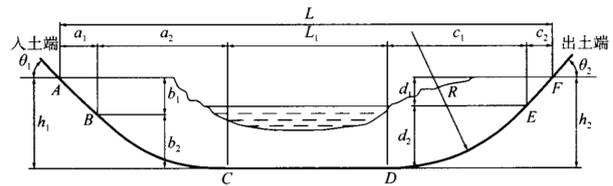


Figure 21. Simplified diagram of the crossing curve

Mathematica is used to solve the function by programming, and the calculation interface is shown in Figure 22. The detailed HDD trajectory design parameters are listed in Table 24. Figure 23 is the design drawing of the trajectory.

```

In[ ]:= Ds = 0.273;
R = 1500 * Ds;
Laf = 1063.82;

f[h_, theta_] := Module[{b2, b1, a1, a2, Lab, Lcd}, b2 = R - R * Cos[theta];
b1 = h - b2;
a1 = b1 / Tan[theta];
a2 = R * Sin[theta];
Lab = a1 / Cos[theta];
Lcd = R * theta;
{a1 + a2, Lab + Lcd}];

L[h1_, h2_, theta1_, theta2_] := Module[{leftPair, leftArc, leftSeg, rightPair, rightArc, rightSeg},
leftPair = f[h1, theta1];
leftSeg = leftPair[[1]];
leftArc = leftPair[[2]];
rightPair = f[h2, theta2];
rightSeg = rightPair[[1]];
rightArc = rightPair[[2]];
Laf = leftSeg - rightSeg + leftArc + rightArc];

ArgMin[{f[h1, h2, theta1, theta2], (16.26 <= h1 <= 22.21, 12.55 <= h2 <= 18.50, 8 Degree <= theta1 <= 20 Degree, 4 Degree <= theta2 <= 12 Degree)}, {h1, h2, theta1, theta2}]

L[8]
Out[ ]:= {16.26, 12.55, 0.139626, 0.0698132}
Out[ ]:= 1065.29
    
```

Figure 22. Program calculation interface

Table 22. Detailed design parameters of HDD river crossing

Entry point coordinates	(9.36,573.86)	Unearthed point coordinates	(1073.18,570.15)
Entry angle	8°	Unearthed corner	6°
Entry point mileage pile number	K40+30	Unearthed Mile Number	K41+148
Through the maximum depth H <sub>max</sub>	14m	Curvature radius of curvature	1500D=328.5m
Horizontal length	725.72m	Total length of pipe section	1065.30m



Figure 23. Crossing track design

According to the “Code for Design of Horizontal Directional Drilling Crossing of Oil and Gas Transmission Pipeline Engineering” (SYT 6968-2013), it is determined that the crossing engineering grade is medium-sized, and the strength design factor is 0.5.

Table 23

Engineering level	Crossing pipe section parameters		Strength design factor
	Crossing length (m)	Crossing pipe diameter (mm)	
Large	≥1500	Excluding pipe diameter	0.5
	Excluding Length	≥1219	
	≥1000-<1500	≥711	
Medium	1000	≥711-<1219	0.6
	≥800-<1500	<711	
Small	<800	<711	0.6

### 4.2.3 Selection of HDD Equipment

#### (1) Type Selection of Drilling Rig

The maximum stress during horizontal directional drilling and towing is calculated according to (4.1).

$$F_t = \mu_{soil} L \left| \frac{\pi D_s^2}{4} \gamma_{mud} - \gamma \delta \pi D_s - W_p \right| + \pi D_s \mu_{mud} L \quad (4.1)$$

Where  $F_t$  is the maximum tension in KN, L is the length of the crossing pipe section in m,  $\mu_{soil}$  is friction coefficient taken as 0.3,  $D_s$  is the outer diameter of steel pipe in m,  $\gamma_{mud}$  is the weight of the mud in  $\text{kN/m}^3$  taken as 10.5-12.0,  $\gamma$  is the weight of the steel pipe in  $\text{kN/m}^3$  taken as 78.5,  $\delta$  is wall thickness of steel pipe in m,  $W_p$  is counterweight per unit length in the process of dragging back in  $\text{kN/m}^3$ ,  $\mu_{mud}$  is the viscosity coefficient in  $\text{kN/m}^2$ .

According to the “Code for Design of Horizontal Directional Drilling Crossing of Oil and Gas Pipeline Engineering” (SYT 6968-2013), the recommended value of the viscosity coefficient is  $0.175 \text{ kN/m}^2$ , because the effective gravity of the pipeline in the borehole does not reach the buoyancy of  $2\text{kN/m}$ , Therefore, counterweight buoyancy control measures are not adopted. The calculated maximum pulling force of the towed pipeline is  $=417.37\text{kN}$ .

According to GB 50423-2013 “Code for Design of Oil and Gas Transportation Pipeline Crossing Engineering”, the maximum pullback force of the drilling rig is selected based on 1.5-3.0 times of the calculated pulling force. Therefore, the pullback force provided by the selected drilling rig should be greater than or equal to  $1252\text{kN}$ . It is a medium-sized drilling rig.

Because the GD1600-L horizontal directional drilling rig has the advantages of high cost performance, strong adaptability and convenient transition, this solution recommends the use of the GD1600-L horizontal directional drilling rig. The main parameters of the rig are shown in Table 224.

Table 24. Main parameters of GD1600-L horizontal directional drilling rig

Machine quality	29000kg	Dimensions (L×W×Hmm)	10300×2500×3100
Maximum pushing force	1700kN	Torque	70000N•m
Maximum push and pull speed	37m/min	Maximum swing speed	92r/min
Engine power	2*194kW	Crawler walking speed	3.0-6.0km/h
Entry angle	8-18°	Maximum grade	20°
Maximum back expansion aperture	Φ1600	Maximum construction distance	1200m

#### (2) Drill Tool Selection

Drilling tools mainly include drill bits, power drilling tools, drill collars, drill rods, reamers, centralizers, whipstocks and rotary joints. The key equipment: drill bit, drill pipe and reamer are selected as follows.

##### 1) Drill bit selection

The working performance of the drill bit directly affects the drilling quality, the drilling capacity under different formation conditions, the drilling cost and efficiency, and the direction change and control method. The drill bit is divided into inclined plate drill bit (generally used for small directional drill), roller cone bit, PDC drill bit and diamond drill bit (for hard rock formation conditions). According to the preliminary geological exploration results, the stratum crossing the river does not contain hard rock formations, so the mud motor combined with hydraulic jet bit is used.

##### 2) Selection of drill pipe

The drill pipe is the hub connecting the ground drilling equipment and the underground drilling tools. Drilling rods in complex drilling conditions are subjected to complex alternating stresses and are the weakest link in drilling tools and equipment. Therefore, the rational design of the drill string is of great significance for achieving fast and high-quality drilling.

**Table 25.** Working load status of drill pipe string

Axial compression and tension	It is applied by the drilling rig when drilling pilot holes, reaming holes, and towing, which is the main cause of drill pipe fatigue
Torque	Maximum torque at the entry point and minimum at the hole end Bending moment and centrifugal force
Bending moment and centrifugal force	The curved drill rod receives the bending moment under the action of axial force, and the self-rotation generates centrifugal force to aggravate the bending deformation of the drill rod string.
Longitudinal vibration, torsional vibration and pendulum vibration	Causes serious wear on the drill string

Considering the complex and changeable load of the drill pipe string in operation, the pipe material needs to have high axial strength, torsional strength and toughness, so the steel pipe with high steel grade is selected to ensure safe drilling. The arc curve of the oblique section is regarded as its projected straight line on the horizontal plane. This approximation simplifies the calculation. The error can be corrected by enlarging the calculated n value. The total length of the traversing pipe section is 1065.29m, and a total of 372.66 drill rods are required, rounded to 373 drill rods of steel grade DZ75.

3) Selection of reamer

The reamer can be divided into barrel reamer, plate cutter reamer, fly spin reamer, roller cutter reamer, etc. The main function is to cut and ream the guide hole along the curve of the guide hole. Different reamers should be selected according to different geological conditions.

According to the results of the geological survey, the strata crossing the river are mainly sand and hard clay layers, and the method of squeezing and expanding the holes is of high quality. Therefore, the use of plate reamers is more suitable for the formation conditions and is beneficial to improving the quality and expansion hole efficiency.

**Table 26.** Relationship between minimum reaming diameter and crossing pipe diameter

Diameter of crossing pipe section (mm)	Reaming diameter (mm)
< 219	Pipe diameter+100mm
219-610	1.5 times the diameter
> 610	Pipe diameter+300mm

Take the minimum reaming diameter of 330mm according to the table above. According to the “Code for Design of Oil and Gas Transportation Pipeline Crossing Engineering” (GB 50423-2013), pipelines with a diameter of less than 400mm can be directly expanded and with-

drawn when the rig’s capacity permits. Therefore, this scheme adopts a pre-reaming and dragging construction process.

**4.2.4 Design of Crossing Pipeline**

(1) Wall Thickness Design of Crossing Section

The wall thickness of the pipeline is designed according to the specifications of the oil pipeline and the large and medium-sized crossing projects of the “Specifications for the Design of Horizontal Directional Drilling Crossing of Oil and Gas Transportation Pipeline Engineering”. The pipeline strength calculation of this project adopts the SYT 6968-2013 medium wall thickness calculation formula.

$$\delta = \frac{PD}{2\sigma_s\psi F}$$

Where D is outer diameter of steel pipe in mm,  $\sigma_s$  is yield strength of steel pipe in MPa,  $\psi$  is weld coefficient taken as 1.0, F is strength design factor. The grade of the crossing project is medium, so F is 0.5.

After calculation, under the pressure of 5.5MPa and 7.0MPa, the wall thickness of different steel grades is calculated as follows:

**Table 27.** Wall thickness calculation table for different steel grades

Steel grade	Calculated wall thickness (mm) (5.5MPa)	wall thickness (mm)	Weight (t/km)	(Ten thousand yuan/km)	Calculated wall thickness (mm) (7.0MPa)	wall thickness (mm)	Weight (kg/km)	price (Ten thousand yuan/km)
L245	4.92	8.0	41.61	21.64	8.96	9.0	5800	24.23
L290	4.15	7.5	37.01	20.03	7.83	8.0	5400	22.47
L360	3.35	6.5	34.05	19.75	7.00	7.0	5200	21.22

The calculated price of L245 in the table is calculated at 5200 yuan/t; the price of L290 is 5400 yuan/t; the price of L360 is calculated at 5800 yuan/t. From the calculations in the above table, we can see that after the design pressure is increased from 5.5MPa to 7.0MPa, the corresponding increase in investment is more than 30%; at the same pressure, the steel grade is increased, the pipe cost is reduced accordingly, and the adjacent steel grades are reduced by 6%. Considering the importance of the river-crossing project and the reasons for earthquake resistance, the steel pipe of L360 grade was selected for this crossing. This can not only reduce the cost of the pipe in this project, but also improve the yield strength and tensile strength of the crossing pipeline, and the requirements for welding conditions are not very high, and the domestic

supply is sufficient.

#### (2) Corrosion Protection and Protection of Pipelines Crossing

The three-layer structure polyethylene (3PE) anticorrosion coating with strong corrosion resistance, water vapor permeability resistance and good mechanical properties is selected for the crossing pipeline, and the selected anticorrosion layer is an enhanced level. The filler material of the pipeline should match the material of the anti-corrosion layer of the pipe body, and directional drilling should be used to traverse the special heat-shrinkable belt. The outer protective layer adopts modified epoxy glass or glass fiber reinforced material compatible with three-layer structure polyethylene as the protective layer.

After determining the traversal plan, the next step is the specific implementation process of the traversal.

### 4.3 Construction Technical Measures

#### 4.3.1 Construction Preparation

(1) Before the project starts, organize technical personnel to review drawings and participate in design technical briefing; conduct safety education and on-the-job training for all employees and make technical quality briefing for all employees.

(2) Go through the procedure of handing over the piles of the project and make marks and records;

(3) Contact the owner, supervision and relevant departments to obtain information on the pipeline crossing the river, optical cables, ground and underground obstacles, and measure the pay-off.

(4) According to the requirements of pipeline construction and directional drilling for the width of the construction area, use the bulldozer or manual to clean up the debris in the occupied area. The trenches, ridges and steep slopes should be leveled, and the width of the operation area should be Meet the design requirements, meet the needs of construction equipment operation and pipeline installation.

(5) Leveling across the site: the operating site of the side-drilling rig needs to occupy 60×60m of the temporary operating site. The area unearthed is 100×30m. After the site investigation, the site of the excavation site and the crops on the access road are cleaned up, and the site is leveled and compacted with an excavator.

(6) Use an excavator to excavate the mud pool. Under normal circumstances, excavate a 15×10×2.0m mud pond at the entry point, and excavate a 15×10m×2.0m mud pit at the excavation point. At the soil entry point, two 3×2.5m×2m mud must be excavated to return to the pit. After the excavation of the mud pit is completed, a layer

of geotextile is placed on the bottom and all around the mud pit to prevent mud leakage.

(7) The size of the excavation cross-section is 0.8m wide and 0.8m high, and the bottom of the ditch should be excavated longitudinally to a certain arc to ensure that the pipeline enters the hole smoothly when the pipeline is towed back.

#### (8) Site equipment layout

Equipment for rig work site layout includes: directional drilling rig, mud pump, mud mixing and recycling system, diesel generator set, driller's operation control room, tool accessory room, crane, mud sloping soil storage site, diesel storage tank, drill rod storage site, Drilling tool stacking site, mud surplus soil feeding site, mud sedimentation tank, mud return tank, etc.

#### (9) Equipment installation and commissioning

The installation of equipment into the field is smooth: rig installation → rig operation control room installation → mud system installation → mud pump installation → drill rod placement in place → other equipment in place. The centerline of the rig coincides with the centerline of the pipeline crossing; adjust the height of the rig according to the angle of entry provided by the design drawings, so that the angle between the walking track of the rig and the horizontal plane coincides with the designed angle of entry.

#### 4.3.2 Mud Preparation

In the guide hole and hole expansion process, the loose sand layer cannot form an arch, it is difficult to maintain the shape of the channel, and it is easy to cause collapse. In the construction, high dispersion mud is used to increase the density and viscosity of the mud.

(1) The mud should be environmentally friendly mud, and it can be recycled. It is recommended to use a positive electric glue mud system, and bentonite to use high-efficiency bentonite. The basic formula of mud is recommended as: high-efficiency bentonite + positive gel + CMC + soda ash + appropriate amount of caustic soda. Lubricants can be added when pulling back, as appropriate. If slurring occurs, add a plugging agent to the mud.

(2) The directional drilling crossing of the project requires that the mud should mainly consider low fluid loss and good slag carrying performance, and the thin mud cake thickness forms a good wall protection and should also have a low friction coefficient and good Lubrication performance. According to the change of stratum conditions, the requirements for mud performance adjustment in each construction process are as follows:

##### ① Diagonal hole section of pilot hole

In order to ensure the carrying of drill cuttings and

the cleaning of the hole, to control the water loss of the mud and prevent the collapse of the hole, it is necessary to increase the content of the wall fixing agent and the tackifier.

② Horizontal hole section of guide hole

It is necessary to increase the content of debris removal agent and lubricant in a timely manner, appropriately reduce the viscosity and cutting force, ensure the good rheological performance of the mud, make the cuttings return to the ground smoothly, enhance the lubricity of the mud, and reduce the rotation and propulsion resistance of the drilling rig.

③ Reaming section

In order to enhance the wall-building performance of the mud and prevent the hole wall from collapsing and reducing diameter, it is necessary to increase the content of the wall-fixing agent and tackifier.

④ Drag back section

In order to improve the lubricity of the mud, reduce frictional resistance, and enhance the effect of carrying chips, it is necessary to increase the content of the cleaning agent and lubricant.

(3) The mud for directional drilling crossing should be prepared with clean water. Before the start of construction, the water samples on site must be used, and the mud formula must be modified according to the specific conditions of the stratum. The calcium and magnesium ions should be avoided. Impact.

(4) The performance of the prepared mud should be determined according to the geological conditions laboratory test. It is recommended that the mud performance meet the following conditions:

**Table 28.** Mud performance conditions

Slurry loss	Density	Viscosity	Dynamic plastic ratio	Back slurry carrying sand	PH value
12 mL/min	1.02-1.10	25-30s	1-1.5	Above 10%	10-11

(5) The mud should be recovered and recycled, and the sand should be removed by vibrating screen. The mud content of the mud used for recycling after treatment by the mud recovery system should not be greater than 0.5%.

(6) The mud displacement in the process of hole expansion should not be less than 2.5m<sup>3</sup>/min, and the mud displacement in the process of pilot hole drilling and towing should not be less than 1.0m<sup>3</sup>/min.

(7) In order to avoid slurring, a mud pressure sensor should be installed near the drill bit to monitor the mud pressure in the cave throughout the process. If the slurry pressure is too high and the slurry is splintering or the

pressure suddenly rises abnormally, the drill bit will be drawn back and washed Continue drilling after the hole.

**4.3.3 Drilling pilot holes**

Check whether the drill bit water hole is clogged, and after the mud is prepared, you can start the drilling rig for trial drilling. The drilling tools used in this project are: the drill pipe adopts the standard S135 internal thickened oil drill pipe, the drill bit uses the tri-cone bit and the non-magnetic drill collar; the real-time tracking of the steering system and the MGS system for tracking and positioning can be Make sure the unearthed location is accurate.

Drill pilot holes according to the design curve, and determine the angle of each drill rod according to the curvature radius of the design curve. Before starting drilling, first draw a 1:1 design curve (drawn on the computer) according to the design curve, and design the drilling angle of each drill rod according to the design entry angle, draw the drilling curve according to the design angle, and compare it with the design curve Compare, after repeated comparison, determine the final pilot hole drilling angle.

During the drilling of pilot holes, real-time tracking and measurement should be performed and records should be made. Data control points are set every other drill rod on the crossing curve. In order to increase the measurement frequency, a measurement can be performed at a certain distance in the middle of a drill rod. This controls the drilling of pilot holes. Measurement record data includes: initial azimuth, linear azimuth, initial tilt, drilling azimuth, drilling tilt, left and right offset, tool face, geomagnetic angle, total geomagnetic field, total gravity field, etc.

During the drilling of pilot holes, the steering personnel should communicate with the driller at any time to determine the angle of the tool face and the length of advancement or drilling.

During the drilling of pilot holes, the steering personnel should communicate with the driller at any time to determine the angle of the tool face and the length of advancement or drilling.

The steering personnel should draw the steering curve in time and compare it with the design curve, the design drilling inclination angle and the azimuth angle. Identify problems in time so that appropriate measures can be taken to correct them.

If it is found that the curve deviates from the design curve, the corrective plan is determined according to the deviation.

During the drilling of the pilot hole, the drilling direction must be strictly controlled to ensure that the drilling curve matches the design crossing curve.

#### 4.3.4 Pre-Reaming Process

After the pilot hole is drilled, remove the drill bit, non-magnetic drill collar and direction control system, install a  $\Phi 330\text{mm}$  reamer, make sure that the reamer and mud spray hole are not blocked, and then start reaming. In order to avoid the phenomenon of hole collapse, the mud pressure, mud viscosity and mud displacement should be strictly controlled according to the formation geological conditions during the hole expansion process, and the viscosity of the hole collapse area should be appropriately increased.

Collapse generally occurs at the front end of the towing pipe section. If collapse occurs, the amount of mud pumping should be increased at this time to properly reduce the viscosity of the mud and replace the mud at the collapsed hole.

When reaming, according to the size of the hole diameter. Reaming speed should be strictly controlled during hole expansion, and the hole expansion speed should be controlled within  $450\text{mm}/\text{min}$ .

#### 4.3.5 Pipeline Drag Back

The towing is the last step of directional crossing, and it is also the most critical step. After checking the correctness, the towing can be carried out. Perform continuous operations during backhauling to avoid increased resistance due to shutdowns. In order to ensure the smooth towing and the anti-corrosion layer is not damaged, the following measures will be taken: before connecting the tube to the towing, to ensure the consistency of the prefabricated pipeline and the crossing axis, reduce the lateral friction of the pipeline when entering the hole, and ensure that the anti-corrosion layer is intact Holes.

The pipeline is towed back in the way of sending trenches. The transmission ditch adopts single bucket operation, and its size is  $1.5\text{m}$  wide at the upper mouth,  $0.8\text{m}$  wide at the lower mouth, and  $0.8\text{m}$  deep; when the transmission ditch is dug, calculate the slope of the transmission ditch, especially the slope of this section of the transmission ditch where the pipeline enters the hole, Make sure that the distribution trench, especially the section of the pipeline that enters the hole, is smooth and smooth.

In order to reduce the friction of the pipeline during towing, ensure the pipeline to be smoothly towed and protect the pipeline anticorrosion layer, during the towing process, keep the pipeline suspended in the hole as much as possible, take floating measures to reduce the pipeline during towing Friction reduces the direct contact between the pipeline and the hole wall. As long as the pipeline is completely suspended in the hole, the drag resistance of

the pipeline during dragging will be reduced to a minimum, which can ensure the smooth dragging of the pipeline.

The stress factors in the pipeline dragging process mainly include: the friction between the pipeline and the sending ditch wall, the pipeline and the hole wall; the viscosity resistance between the pipeline surface and the mud or water. The calculation formula of directional drilling crossing construction design experience, taking the middle value of the recommended multiple, the maximum pulling force of the towing pipeline is  $417.37\text{kN}$ .

#### 4.3.6 Pipeline Welding Inspection and Pressure Test

Welding across the pipe section uses manual downward welding or semi-automatic downward welding welding process. Welding process evaluation should be carried out before welding. For specific requirements and operations, please refer to "Method for Welding Process Evaluation of Oil and Gas Pipelines" (SY/T4052-92) and "Steel Relevant regulations of Pipe Welding and Acceptance (SY/T4103-2006).

Downward welding root welding uses high cellulose sodium type E6010 electrode, electrode diameter  $4.0\text{mm}$ ; hot welding uses high cellulose sodium type E8010 electrode, electrode diameter  $3.2\text{mm}$ ; filling welding and cover welding use iron powder low hydrogen type E8018 electrode, The electrode diameter is  $3.2\text{mm}$ . The root welding of the semi-automatic welding E6010, the cover surface is B71T8-K6 electrode diameter  $2.0\text{mm}$ ; the performance of E6010 should meet AWS A5.1; E8010 meets the requirements of AWS A5.5, B71T8-K6 meets the requirements of AWS A5.29. Welding should be in accordance with the current national standard "Code for Construction and Acceptance of Field Equipment and Industrial Pipe Welding Engineering" (GB50236-98). Each welding port must be welded once. When the previous welding layer is not completed, it is not allowed to enter the welding of the next layer. When welding downward, the root welding should be penetrated, and the convex part in the weld bead should be polished to avoid slag inclusions.

The circumferential welding of the entire crossing section is first inspected using 100% ultrasonic flaw detection, and then 100% X-ray flaw detection is reviewed. X-ray inspection is carried out "Radiography and Quality Classification of Butt Welds of Oil and Gas Steel Pipelines" (SY4056-93). Welds above level II are qualified. Ultrasonic flaw detection implements "Ultrasonic flaw detection and quality classification of butt welds of oil and gas steel pipelines" (SY4065-93). Welds of grade I and

above are qualified.

The test pressure of the pipeline should be clean, non-corrosive water as the test medium.

Piping and pressure test of the entire crossing section pipeline, the strength test pressure is 1.5 times the design pressure is 7.2MPa, and the pressure is maintained for 4 hours; when the strength test pressure does not leak, the tightness test pressure is 6.0MPa, and the pressure is not less than 24 hours; the pressure drop during the pressure stabilization period is not more than 1% and the test pressure is qualified. After the hydrostatic test, the accumulated water in the pipe should be drained, and the drying process in the pipe should be carried out to achieve that the humidity of the air in the pipe is consistent with the humidity of the external environment. If the crossing section cannot be connected to the general line section immediately, temporary blind plates should be welded on both ends of the crossing section to prevent debris from entering the pipe.

#### 4.4 Impact on Hydrogeology and Environment

##### 4.4.1 Impact on Landform

Directional drilling does not destroy the landform, there is no water or underwater operation in the construction, and the pipeline is buried in the underground stable layer. Pipeline excavation construction must take measures such as precipitation and slope support, while the use of directional drilling reduces the amount of excavation works, will not cause damage to crops on both sides of the bank, reduce environmental pollution, and save a lot of investment.

##### 4.4.2 Impact on Riverbed Structure

Directional drilling does not damage the dam and riverbed structure. There are no construction access roads and construction machinery in the entire width of the crossing river surface. There is no need for land acquisition and reinforcement of the river embankment, which reduces project investment.

Compared with other construction methods, the construction cycle of directional drilling is short, the equipment enters and exits the field quickly, and has little impact on the surrounding environment and residents' lives.

At the same time, due to the buried depth of the pipeline about 12m below the river bed, the buried stratum is deep, and the internal corrosivity of the stratum is relatively small, which plays a role in anti-corrosion and thermal insulation of the pipeline, which can extend the service life of the pipeline and reduce the annual maintenance fee and man-made damage.

Using modern construction equipment with high construction accuracy, easy to adjust the burial depth and arc to ensure the accuracy of directional drilling construction.

##### 4.4.3 Impact on Biology

Directional drilling construction will cause the increase of suspended solids in the local area, which will have an adverse effect on the organisms. The increase of suspended solids will affect the growth of fish and slow down the reproduction rate of fish. Since the distance between the crossing section of the project and the shore is greater than 100m, the impact of suspended matter is limited.

##### 4.4.4 Impact of the Construction Process on the Environment

The main environmental pollution generated during the construction period is dust, noise, wastewater, channel occupation and ecological loss.

###### (1) Air Pollutants

During the construction period, the main sources of atmospheric pollution are the tail gas and dust emitted by engineering vehicles and transportation vehicles. The tail gas emitted by vehicles during operation is unorganized emissions. The main pollutants are NO, CO and TSP. The main pollutant in the construction process is TSP, and its pollution complies with the second-level standard of the National Comprehensive Air Pollution Emission Standard (GB 3095-96).

###### (2) Noise

In construction operations, drilling rigs and excavators are used for construction. Due to the noise generated by construction machinery (pneumatic picks, excavators, mixers, and loaders) and vehicles, some nearby residents will be affected temporarily.

###### (3) Wastewater

The water pollutants during construction are mainly domestic sewage of construction personnel and engineering wastewater discharged after pressure test of pipelines. Pipeline pressure test generally uses clean water. The pollutants in the discharged water after pressure test are mainly suspended solids, which are collected and discharged into the urban sewage system.

The main pollutant of domestic sewage during construction is COD, and domestic sewage cannot be discharged anywhere. After collection, it is required to be regularly extracted by the environmental sanitation department.

###### (4) Solid Waste

The solid waste in construction mainly comes from waste materials (such as welding rods, anti-corrosion materials, etc.), domestic garbage and waste mud. After the construction is completed, the waste mud in the mud

pool will be cleaned up and transported to the designated dump.

#### (5) Impact on Ecology

The impact on the ecology is mainly manifested in the destruction of the surface protective layer, the change of the soil structure, the loss of soil nutrients, and the soil erosion caused by adverse geological conditions, etc.

### 4.5 Fire and Safety

#### 4.5.1 Safety and Fire Protection Measures Adopted in the Design

Under normal production conditions, fires are generally not easy to occur. Only under operational errors, violations of regulations, improper management, and other abnormal production conditions or accidents can various factors lead to fires. Therefore, in order to prevent fires or reduce the losses caused by fires, according to the policy of “prevention first, combination of prevention and elimination”, the project has adopted corresponding preventive measures in design.

The design of pipeline weld requires 100% radiographic flaw detection and 100% ultrasonic re-inspection to ensure the quality of welding construction.

After detailed geological survey of the crossing river section, detailed geological survey data and detailed understanding of the conditions of the underground pipeline shall be obtained before construction drawing design.

Before construction, the construction unit shall formulate a perfect construction organization plan. After approval by the relevant departments, and before the crossing, the first step is to carry out geophysical prospecting and obtain the actual geological data of the crossing point before crossing.

#### 4.5.2 Main Safety Measures during Construction

(1) The construction plan for crossing should be approved by the local water conservancy department before construction;

(2) The unit undertaking construction must hold the corresponding qualification level certificate and pressure pipeline installation license, and the welder and non-destructive testing personnel must have the special operation personnel qualification certificate frequently issued by the technical supervision department;

(3) Pipes and pipeline components must have quality certificates, and their quality should not be lower than the current national standards;

(4) The pressure vessels and pressure pipes in this project are manufactured by the manufacturing unit with the corresponding manufacturing license and are manu-

factured, inspected, tested and accepted according to the corresponding standards;

(5) Hire a qualified and experienced construction team, and at the same time hire a supervising engineer of a qualified unit to control the whole process of the installation of the device, prevent the occurrence of non-compliance with the regulations, and avoid remaining hidden dangers. And invite a qualified third-party testing team to perform non-destructive testing on all welded joints to ensure their quality;

(6) Welding operators should be trained and qualified. When welding, you must wear protective glasses with color filters, wear protective clothing, protective gloves and other supplies. Barriers should be set around the work site to prevent injury to other personnel;

(7) According to relevant national regulations, provide site workers with safety helmets, anti-static overalls and other protective equipment to prevent casualties;

(8) Cutting and welding hot work must meet the “hot work requirements” and have practical safety facilities;

(9) Strict management in accordance with the relevant provisions of the State Council Decree No. 393, “Regulations on Construction Engineering Safety Management”.

### 4.6 Construction Risks and Countermeasures

#### 4.6.1 Emergency Response Plan for Construction

When drilling pilot holes, when the torque increases and the drill breaks, the construction should be stopped immediately. First look for the fracture collision situation. If the fracture rule collision situation is good, remove the drill rod on the side of the working rig, put a small drill rod into the drill rod to connect the broken drill rod together, and then use a special drill the rod salvage tool salvage the broken part out of the ground, and then reorganize the construction.

#### 4.6.2 Emergency Plan for Stuck, Held and Broken Drills in the Process of Hole Expansion

(1) The first step to be carried out when sticking and holding drills is to withdraw the reamer out of the hole: when the torque does not reach the limit of the rig, use the rig to rotate to withdraw the reamer, and then proceed to the next step; If relying on the power of one drilling rig cannot make the reamer exit the hole, we will transfer the other drilling rig to the excavation point and keep in touch with the driller on the other side after connecting the drill rod to keep the two rigs at the same speed And the steering, using the method of pushing into the soil drilling rig, pulling the drilling rig. If the above method fails to withdraw the reamer, contact the pulley block and use a com-

bination of certain pulleys and one-motion pulleys. Each pulley is worn with 8 strands of steel rope. Reinforce the ground anchor at the unearthed point. The power of this pulley block can use a hoist or an excavator to continuously increase the force until the reamer is pulled out. The combined straight drag force reaches more than 500t.

(2) In an emergency situation where the drill pipe breaks during the reaming operation, first determine whether the drill bit is at the front end or the rear end of the drill pipe break. When the drill bit is at the front end of the broken drill rod, first use the excavator to pull out the rear drill rod, and then use the drill to rotate back to slowly withdraw the drill bit, replace the broken drill rod, and re-expand the hole; when the drill bit is broken. When the drill pipe is at the rear end, first use an excavator to drag the rear drill pipe. If the supporting force is large, adjust another drill to the unearthing point. After the ground anchor is strengthened, the drill is rotated and pulled back to extract the drill. The tool and drill bit are used to replace the broken drill rod after drawing out the drill rod, and then re-drill the drill rod from the original hole to re-expand the hole.

#### 4.6.3 Emergency Plan for Pipeline Jamming During Towing

(1) Once the dragging force of the pipeline gradually increases during the dragging process, the speed gradually slows down until it locks up. First, analyze the curve and mud to quickly find out the reason;

(2) If the towed pipeline is within 50m from the drilling rig, consider the method of large excavation to dig out the pipeline and then connect the head. If the distance is beyond 100m or large excavation is not possible, the pipeline should be withdrawn;

(3) Pulley sets are used for the withdrawal pipeline, and the excavator or winch is used for the power, and the force is gradually increased until the pipeline is pulled back;

(4) Because the angle of the hole formation in the backhaul pipeline section of the crossing project is gentle, the whole drill pipe curve is bound to be gentle when the pipeline is towed, and the drill pipe at the entry point is covered with thin floating soil, which is likely to cause the drill pipe to move up. Adopt the method of adding floating weight on the overlying floating soil to prevent the drill pipe from falling and moving upwards.

#### 4.6.4 Spilling Emergency Plan

(1) First of all, arrange special personnel to monitor the entire project for the occurrence of spattering, especially near geological prospecting holes that are prone to spat-

tering. Once a small range of slushing is found, the cofferdam will be carried out immediately to prevent the spread of the slushing area.

(2) In the case of large-scale slurry pouring and failure to stop the leakage, dig the diversion channel to lead the mud to the mud pit or dig the mud pit on the spot, and arrange the mud truck to pump out.

(3) If it is found that there is a slurry hole along the line, due to the slurry leakage, the mud in the hole is lost and the debris in the hole cannot be discharged out of the hole. A certain amount of water glass agent can be used to block the slurry hole.

(4) Control the haulback force and haulback speed of the rig to prevent pipeline instability. When pulling back through the pipe section, the maximum pullback force of the drilling rig must be controlled. Excessive pullback force will affect the strength of the pipeline. When pulling back the pipeline, the speed should not be too fast, and the time should be greater than 12 minutes per root.

#### 4.6.5 Treatment Plan for Collapsed Holes

(1) Improve the viscosity and shear force of the mud, increase the density properly, control the low water loss of the mud, wash or drill with a small displacement cycle, so that the annulus mud is flat laminar or plug flow, and the slump and The cuttings are carried out;

(2) When the collapsed hole is serious and the size of the collapsed block is large, under the premise of maintaining the annulus laminar flow state, the drill bit eye hole can be increased, and the high pump pressure and appropriate displacement can be used to flush the collapsed large rock fragments. Take out the ground and can be equipped with a certain amount of high-shear, high-viscosity mud to clean the hole bottom and drill cuttings during flushing.

### 5 Auxiliary Production System and Supporting Engineering

#### 5.1 Communication

The construction of the communication system of this project is to provide a bearing network for the SCADA data, voice and video transmission of the process stations related to crude oil long-distance transportation, and at the same time set up video surveillance camera front ends and amplified broadcast telephone terminals for each process station.

At present, there are three commonly used transmission methods at home and abroad: optical fiber communication, wireless broadband communication and satellite

communication.

The selection of the technical solution of the engineering system should save investment as much as possible on the premise of meeting the technical requirements, and the satellite communication method has a large investment, the capacity is relatively small compared to the optical fiber communication, and the performance-price ratio is at a disadvantage. Therefore, the satellite communication method is not suitable for this project. No further discussion will be made in this design. The optical fiber communication mode has large transmission capacity, long relay distance, stable transmission quality, and is not disturbed by external factors. The wireless broadband communication method has flexible networking, high transmission rate, and easy expansion.

According to the actual needs of this project, the communication system must not only be safe and reliable, but also save investment as much as possible. Therefore, comprehensive analysis is considering the actual situation of the project, but higher requirements for transmission quality, optical cable communications in the formal development stage can be easily incorporated directly into the new optical fiber communication transmission network. Based on the comprehensive situation, the design recommends the use of optical fiber transmission communication as the communication transmission scheme of this project.

Considering the actual situation of this project, the optical fiber transmission system considers the use of multi-service uncompressed video optical transmission equipment networking. Install light receiving equipment at the loading station and light emitting equipment at the remaining stations. The system carries SCS data, video and control signals and voice transmission services from the joint station to the loading station.

## 5.2 Power Supply and Distribution

### (1) Power Supply System

This design builds a 110kV substation near the first station of the overseas transmission to provide power for the entire project area.

### (2) Lightning Protection and Static Grounding

According to the requirements of "Code for Design of Lightning Protection of Buildings" (GB50057) and "Code for Design of Grounding of Industrial and Civil Power Installations" (GBJ65), all structures, stations and process pipelines shall be provided with necessary lightning protection and anti-static grounding according to the specifications, Working ground and protective ground.

Each station's transformation and distribution room is provided with a ring-shaped closed common grounding

grid, the grounding resistance is less than  $1\Omega$ , and the metal shell and process equipment of all live equipment are grounded for protection.

For buildings that need protection against direct lightning strikes,  $\Phi 10$  galvanized round steel is used as the lightning protection belt, and  $\Phi 10$  galvanized round steel is used as the downline. The metal pipes and devices protruding from the roof are reliably connected to the roof lightning protection device.

There shall be no less than 2 connection points between grounding trunks and grounding devices for lightning protection in all buildings. The metal pipes introduced into and out of the building should be connected to the lightning protection grounding device at the entrance and exit, and the overhead metal pipes should be grounded once at a distance of about 25m from the building. The impact ground resistance is not greater than  $100\Omega$ .

The main metal objects such as equipment, framework, pipelines in the house should be connected to the lightning protection grounding device or the protective grounding device of the electrical equipment. All pipes and equipment that may be exposed to static electricity in the outdoor are connected into a continuous electrical path and grounded. The grounding resistance is not greater than  $30\Omega$ .

Bare metal brackets are placed outside the entrance of the explosion hazardous environment as anti-static facilities and there should be obvious signs, and the metal brackets should be grounded. In the production process, anti-static shoes, anti-static work clothes, anti-static gloves and other personal static protection facilities should be used; static test equipment should be provided to grasp the amount of static electricity carried by yourself before entering an explosion-proof place to take measures. The antistatic grounding resistance is not greater than  $100\Omega$ .

### (3) Laying Method of Distribution Lines

The power distribution adopts copper core insulated cable, the indoor part is laid underground through steel pipes, and the outdoor part is laid directly buried with armored cables. The lighting circuit adopts copper-core insulated wires through steel pipes and is dark-matched along the wall and the roof insulation layer. The lighting circuits in explosion and fire hazard locations are equipped with steel pipes. The selection of the cross-section of insulated wires and cables shall comply with the relevant regulations and be determined through calculation.

### (4) Electric Lighting Distribution Design

Install emergency emergency lighting in substations and power distribution rooms. Electrical lighting in explosion and fire hazard locations should meet explosion-proof requirements. The illuminance standard imple-

ments “Building Lighting Design Code” GB50034 2004. According to different lighting requirements, the light source of the lighting fixture is selected to comply with the relevant national standards and standard equipment products. Among them, the road lighting in the station is planned to use a mixed sodium and mercury light source, the light pole uses a steel column, and PVC power. Buried cable laying, photoelectric automatic control and manual control.

#### (5) Communication

The power distribution of instrument automation system and instrument automation do not allow uninterrupted power supply. Therefore, non-interruptible power supply (UPS) is used. For UPS power supply, see the communication and automatic control section.

### 5.3 Building Structure

In order to improve the level of earthquake resistance, the seismic intensity of this design is 7 degrees, and the basic earthquake acceleration value is 0.1g. In general, buildings take earthquake-resistant fortification measures according to the corresponding fortification intensity. First, select a structural system that meets the requirements of seismic fortification intensity. The plane and floor layout and shape treatment of buildings should avoid and reduce the seismic weak links as much as possible. Energy absorption and dissipation structure. For class B buildings, the “Classification Standards for Seismic Fortification of Construction Projects” (GB50223-2008), and according to the “Code for Seismic Design of Buildings” (GB50011-2010), take seismic measures in accordance with the requirements to increase the seismic fortification intensity of the region by one degree. Except for the control center building, compressor room, and empty torch tower, the seismic fortification category is Category B, and the other buildings and structures are considered as Category C.

Because the project area belongs to the mid-temperate semi-humid and semi-arid continental monsoon climate. How much wind and little rain in spring, large evaporation; cool and short in summer, concentrated precipitation; rapid fall in autumn, early frost; long cold in winter, long snow area. The monthly minimum temperature is  $-37.8^{\circ}\text{C}$ , and the monthly maximum temperature is  $32.9^{\circ}\text{C}$ . The annual sunshine hours are 2049.5 trivial, and the frost-free days are 126 days. The architectural design focuses on thermal insulation in summer and thermal insulation in winter. According to the “Code for Thermal Design of Civil Buildings” (GB50176-93), the building should not be too large from the direction, shape factor, unevenness of the flat facade, the area of the external window of the building should not be too large, double-layer windows,

stucco insulation coating Consider thermal insulation of buildings.

### 5.4 Heating and HVAC

#### (1) Design Principles

Strictly follow the current national standards of thermal engineering and HVAC, and the compromise documents formed by the current national standards, and design in accordance with the principles of practicality, advancedness and economy. Adopt high-efficiency, low-consumption, low-pollution equipment, implement the “safe and reliable” guiding ideology, simplify the technological process, achieve the purpose of saving investment and reducing operating costs. Fully consider environmental protection, soil and water conservation and energy conservation.

#### (2) Heating

According to the heat load requirements for the production of process devices in each station of the block, the heating load of individual building heating in winter in the plant area, and the heat load for process heat tracing, etc., the automatic heat conduction oil furnace heating system is used for the whole plant. Heating. The scale of the heating station is 2 automatic heat conduction oil furnaces, with a single heat load of 8000kW, and the operation mode is 1 for 1 standby; according to the requirements of the heating parameters for the domestic base hot water for the operation base and the winter heating load of the building unit, etc. . It is planned to use a hot water boiler to heat the operation base. The design scale of the boiler room is 2 hot water boilers, with a single heat load of 1.4MW, and the operation mode is 1 set for 1 use.

#### (3) Keep the Room Warm

The control room uses a heat pump type cabinet air conditioner with auxiliary electric heating to meet the requirements of cooling in summer and heating in winter. In order to meet the environmental temperature and humidity requirements of process equipment and instruments in the duty room, air conditioners and electric heating devices are installed.

#### (4) Ventilation

The ventilation of the plant is a combination of mechanical ventilation and natural ventilation. Some production plants will emit toxic gases during production operation. In order to reduce the concentration of toxic gases to the allowable range of hygienic requirements or to eliminate indoor residual heat, forced ventilation with natural air intake and mechanical exhaust may be adopted. Axial fans or the roof fan is fully ventilated to remove harmful gases and indoor residual heat.

## 5.5 Automation Control

The SCADA system should be used for production and operation management in this project area. In order to ensure safe production and improve management level, this project sets up a production monitoring system (e.g. SAC-DA system) for the entire block. The production monitoring system (SACDA system) is divided into three layers from the logical structure:

The first layer is the production management, decision-making, dispatch and command system, which is the production monitoring system with the SCADA central control system as the core; the second layer is the monitoring system located in each station, which is the control and management of each production operation area; The third floor is a small station control system located in each intermediate station and valve room.

The central control system of SCADA system (that is, the management, scheduling, and decision-making system of the central processing plant) is located in the production dispatching command center of the loading station, with a complete and unified production database and application database, and centralized production monitoring of each station under its jurisdiction, Scheduling and management. The station control system of the SCADA system is a monitoring system set up in the station yards along the line. Responsible for the data collection and processing of the production process and the automatic control and process management of the production process; and collect and monitor the production operation to realize the centralized scheduling and management of the production operation area. At the same time, upload the production data and production information to the central control system, accept the production command and scheduling instructions of the control center, and complete the specific realization of the production plan.

## 5.6 Fire and Explosion Protection

### 5.6.1 Causes of Fire and Explosion

The subjective cause of the fire in the oil tank area is often due to the lack of attention of the personnel concerned, paralysis, inadequate system, poor management, and violation of operating rules. The objective reasons are:

① When the electrical equipment is short-circuited, the contacts are separated, the shell is poorly grounded, etc., the arc and spark are caused, or the heating part of the electrical equipment exceeds the maximum allowable temperature;

② Sparks caused by metal impact;

③ Static electricity and lightning;

④ Spontaneous combustion of combustibles, such as sulfur-containing oil deposits in oil tanks spontaneously ignited during removal, and accumulated oily garbage spontaneously ignited;

⑤ Fire spread around the oil depot, etc.

### 5.6.2 Fire and Explosion Prevention Measures

The oil tank in the ground oil tank area is exposed above the ground, the target is obvious, and it is greatly affected by external factors, especially the risk of fire is large. After the accident, the oil products are easy to flow, causing damage and involving a large area. Therefore, it is necessary to enclose the fire dike around the oil tank or oil tank group. According to the requirements of GB50074-2002 "Code for Design of Petroleum Depots", the fire separation distance between oil tanks should meet the requirements, the oil tanks in the group should be arranged in a row or two lines, and the distance between the slopes of the two oil tank firewalls should be greater than 9.5m.

In addition to setting up fire dikes, it is also necessary to avoid fire and explosion by establishing a sound management system:

(1) Formulate Relevant Rules and Regulations

Establish a mass fire-fighting organization, formulate fire-fighting regulations and fire-fighting plans, divide fire-fighting areas, specify fire alarm signals, regularly organize fire-fighting education and fire-fighting exercises, and be skilled in using fire-fighting equipment.

(2) Cut off the Fire Source

① It must be strictly managed in the fire restricted area (oil storage area, receiving and sending operation area), and strictly abide by the relevant rules and regulations. No fires, such as matches and lighters, are allowed in the fire restricted area; smoking is not allowed; steam locomotives are not allowed to enter the warehouse. The front chimney should be covered with a fire hood, fly out with a fire star, and close the gray door; it is forbidden to open the blower and put down the gray box baffle in the warehouse, and do not open the steam door and remove the water from the furnace; when the locomotive enters the warehouse, there must be several isolation vehicles between the tank truck and the locomotive; the locomotive should be reversed into the warehouse; the locomotive should leave the tank truck as soon as possible after entering the tank area; the vehicle is not allowed to drive in the restricted area;

② Prevent sparks caused by metal impact, and do not wear iron spiked shoes for storage; mules and iron wheels are forbidden to enter the storehouse. Because the horse-shoes and iron wheels of the horses collide with gravel or cement roads on the road, sparks are prone to occur; use

metal tools and When handling oil drums, avoid collisions to avoid sparks;

③ No open flames (such as oil lamps, candles, etc.) should be used for lighting, nor should ordinary electrical equipment be used for lighting. In order to prevent electrical equipment from causing sparks due to short circuits, contact separation, etc., explosion-proof electrical equipment must be used in the restricted area;

④ In the event of thunderstorms, do not load, unload, measure and sample gasoline, kerosene and diesel fuel.

(3) Do a Good Job in Fire Prevention of Dangerous Operations

Open flame operations such as electric welding, gas welding, and forging in the oil depot area are the most stringent safety requirements and relatively dangerous operations. Therefore, they must be carried out in strict accordance with regulations. Before conducting an open flame operation, a fire application must be submitted. After approval, effective fire safety measures should be taken before the fire can be used. When working with fire, firefighters who are able to cope with any situation should be assigned to be on duty, and be prepared for first aid in the event of an accident.

(4) Handle Combustible Materials

The treatment of combustibles in the oil depot includes the treatment of the oil itself and other combustibles that cause the oil to catch fire.

① Prevent oil vapor accumulation and oil leakage and splashing. When the oil vapor concentration exceeds the safety regulations, mechanical ventilation or natural ventilation should be used to remove the oil vapor, or measures should be taken to collect oil and gas so that it will not escape into the air as much as possible. When oil is spilled, cover with sand or shovel clean;

② Fire dike or firewall should be built on the ground oil tank;

③ In order to prevent the spontaneous combustion of sulfur-containing materials, when removing the sediments of sulfur-containing crude oil tanks, the sulfur-containing sediments should be continuously wetted with water. After the sulfur-containing sediments are taken out, they must be transported away and buried in the soil while wet. Oily gauze and rubbish should be placed in covered iron drums and removed in time. Do not stack them in a place where there is no wind to prevent spontaneous combustion;

④ Dispose of other combustibles in time. It is forbidden to store and remove combustible materials, such as wood shavings, cotton yarn, hay, garbage, etc. around oil tanks, warehouses, pump rooms, etc.

(5) Ensure that Firefighting Equipment Is in Good Condition and Reliable

① The oil depot should have sufficient fire extinguishing equipment. In the warehouse, pump room, barrel room, laboratory, loading and unloading station, cavern and other places, sufficient fire extinguishing equipment and firefighting pool or fire hydrant shall be arranged. And set up fire-fighting points in appropriate places, equipped with all rescue equipment, such as buckets, fire hooks, shovel, axe, etc.;

② Fire equipment should be intact and reliable. It is necessary to check and maintain at ordinary times, and it is forbidden to use it for other purposes. Fire trucks and fixed firefighting equipment should be launched regularly. Always maintain good technical status.

## 5.7 Fire Protection at Station

### 5.7.1 Fire Extinguishing Principles and Methods

The principle of fire suppression is to destroy the combustion conditions. According to the three conditions of combustion and the chain reaction that constitutes flame combustion, three basic physical methods of cooling, suffocation and isolation are often used in firefighting technology to extinguish fire and chemical interruption.

(1) Cooling Method

The purpose of the cooling method is to absorb the heat released during the oxidation of combustibles. For burned substances, the temperature can be lowered to below the ignition point, while the decomposition process of combustibles is suppressed, and the speed of combustible gas generation is slowed down, causing the fire to be extinguished due to the “supply shortage” of combustible gases. For other combustibles in the vicinity of the combustibles, they can be protected from the threat of flame radiant heat and destroy the combustion temperature conditions.

(2) Asphyxiation

The suffocation method is to eliminate the combustion aid oxygen O<sub>2</sub>, so that the combustion extinguishes itself when it is isolated from fresh air. The methods of using this method to extinguish fires are:

1) Use non-combustible or incombustible materials to directly cover the surface of the combustible materials to isolate fresh air;

2) Use water vapor or refractory gas to spray on the combustion products to dilute the oxygen in the air and reduce the oxygen content in the air to less than 9%. For example, the steam in the pump room extinguishes the fire;

3) Try to seal the holes and gaps of the burning container, so that the flame will extinguish after the air in the container is exhausted. For example, after a fire in a cavern, closing a closed door is one of suffocation.

### (3) Quarantine

The isolation method is to isolate the fire source from combustible materials to prevent the spread of combustion. The specific methods are:

- 1) Quickly remove combustibles, combustibles, and explosives near the fire;
- 2) Demolition of combustible buildings and fire debris adjacent to the fire site in time;
- 3) Cut off combustible and flammable substances into the burning zone;
- 4) Limit the flow and splash of burning materials;
- 5) Move the movable combustibles to an open place, so that the combustibles burn under human control. For example, the tank truck caught fire and quickly dragged out of the warehouse.

### (4) Chemical Interruption Method

Chemical interruption method is also called chemical suppression method to extinguish fire. It is a new fire-extinguishing technology developed rapidly in modern times. The new combustion theory believes that combustion is a chain reaction maintained by certain active groups. Chemical fire extinguishing means spraying a chemical fire extinguishing agent into the flame. With the help of chemical fire extinguishing agents, the generation and existence of these active groups are inhibited, and the chain reaction of combustion is prevented to stop the combustion, thereby achieving the purpose of extinguishing the fire. Commonly used chemical fire extinguishing agents include dry powder fire extinguishing agent and high-efficiency halogenated fire extinguishing agent.

## 5.7.2 Fire Extinguishing Methods and Equipment

Foam fire extinguishing facilities and fire cooling water system should be installed in the oil tank area in the station.

### (1) Fire Extinguishing with Foam

According to the design of fire extinguishing equipment, it is divided into fixed, semi-fixed and mobile fire extinguishing systems.

1) Fixed air foam fire extinguishing system it is a semi-automatic foam fire extinguishing device. This system means that all equipment is fixed. There is no need to connect other equipment when extinguishing the fire. When the oil tank fires, just start the water pump (prior to prime the pump before starting), open the pump outlet valve, rotate the foam proportion mixer pointer to the required foam liquid volume index, and mix. The device mixes the foam liquid automatically with water in proportion and transfers it to the foam generator through pumps and pipelines. After inhaling the air, the foam is formed and sprayed into the oil tank to cover the oil surface and

extinguish the fire.

The fixed air foam fire extinguishing system has the advantages of no need to lay pipelines and installation equipment during fire extinguishing; rapid start-up, fast foam output; simple operation, saving manpower; low labor intensity and so on. The basic disadvantage is that the equipment has a large investment at one time, such as the collapse or explosion of the oil tank, and when the fire fighting equipment installed on the oil tank is damaged, the entire system loses the ability to extinguish the fire. Therefore, when the fixed air foam fire extinguishing system is used, a head is often left on the foam pipe network close to the oil tank area, so that when the fire fighting equipment on the oil tank fails, the mobile fire extinguishing equipment is replaced.

The fixed air foam fire extinguishing system is mainly suitable for oil tanks where the oil tanks are relatively concentrated, the number of independent oil depots and the oil tanks with few fire fighting lines required is relatively small, and the oil depots with complex terrain.

### 2) Semi-fixed foam fire extinguishing system

This system is equipped with a fixed foam generator on the oil tank and some auxiliary pipelines underneath (it should be connected to the fire dike of the oil tank, about 1 m above the ground, and the end should also be installed with an interface, usually equipped with a boring cover) Outside, cover), other equipment is removable. In case of fire, drive the fire truck with foam liquid to the scene, take water from the reservoir or fire hydrant, and supply the foam mixture to the foam generator fixed on the oil tank with a temporarily installed hose.

Since the water for preparing the foam mixture comes from the cooling water pipe network, there is no need to set up a special foam pipe network, so the construction investment and maintenance cost of this system are lower than the former, but it requires a motorized fire truck and a water pump, and a certain amount Operator. It is suitable for oil depots with relatively flat terrain.

### 3) Mobile foam fire extinguishing system

The mobile foam fire extinguishing system is to replace the foam generator on the fixed oil tank by foam guns, foam guns or foam hook pipes, foam pipe racks and other equipment. The equipment and equipment are movable, so it is called the mobile foam fire extinguishing system. It has the advantages of good safety, flexible use, low investment, etc., but the operation is complicated and the preparation time for fire extinguishing is long. It is suitable for oil depots with many oil tanks, scattered layout and relatively flat terrain.

According to the requirements of GB50074-2000 "Code for Design of Petroleum Depots", since the loading sta-

tion uses three 3000m<sup>3</sup> floating roof tanks, the foam fire extinguishing facility uses a fixed foam fire extinguishing system.

### (2) Fire Cooling System

For firefighting of oil tanks, two systems should be considered, namely fire extinguishing system and cooling system. The cooling system is set to prevent the fire tank steel plate from softening and to protect the adjacent tank; on the other hand, it is also necessary for the fire extinguishing with foam. Because of the fire in the oil tank, the flame temperature is generally 1050-1400°C, and the temperature of the oil tank wall reaches above 1000°C. When the temperature of the tank wall exceeds 600°C, the foam cannot extinguish the tank fire. After the oil tank catches fire, the tank wall should first be cooled with water. When the temperature of the oil surface drops below 147°C, it is possible to cover the fire with foam. Under normal circumstances, when the foam enters the combustion liquid surface, the foam evaporates and bursts very quickly. Because the foam evaporates, the oil is cooled. When the oil surface temperature drops below 147°C, the foam layer can advance on the combustion liquid surface to burn. The surface continues to decrease, and finally covers the entire combustion liquid surface to extinguish the fire. At this time, the foam continues to burst (evaporate) until the oil temperature drops below 98°C, the foam evaporation is gradually reduced, and then, the oil surface temperature continues to drop until it reaches the liquid surface temperature before combustion.

According to the requirements of GB50074-2000 "Design Specification for Petroleum Depot", since the loading station uses three 3000m<sup>3</sup> floating roof tanks, the fire-fighting cooling water system adopts a mobile cooling water system or a combined fire-fighting cooling water system with a fixed water gun and a mobile water gun.

### 5.7.3 Fire water supply

The oil tank area of this loading station belongs to a class 4 oil depot, and an independent fire water supply system shall be provided. Normally, the fire water supply system should be kept filled with water, but since the lowest monthly temperature in the project area is -37.8 degrees Celsius, it will not be filled with water in winter.

The fire-fighting water pipeline is laid in a branch shape. The scope of supply of fire cooling water for oil tanks shall meet the following requirements: The fixed oil tank above the ground on fire and the adjacent above-ground oil tanks within 1.5D (D is the diameter of the oil tank on fire) from the tank wall should be cooled. When there are more than 3 adjacent oil tanks on the ground, the cooling water volume shall be calculated according to the

larger 3 adjacent oil tanks.

The fired floating roof and inner floating roof oil tanks should be cooled, and the adjacent oil tanks may not be cooled. When the fired floating roof oil tank and inner floating roof oil tank are made of shallow plates or floating tanks made of fusible materials, the adjacent oil tank should also be cooled. Adjacent oil tanks within the range of the distance between the fired floating roof oil tank and the inner floating roof oil tank wall are less than 0.4D (D is the diameter of the larger oil tank between the ignition oil tank and the adjacent oil tank). The parts with greater heat influence should be cooled.

The fire-covered earth-covered oil tank and its adjacent earth-covered oil tank may not be cooled, but the amount of protective water used when extinguishing the fire (referring to the amount of water for personal shielding and cooling the ground and oil tank attachments, etc.) should be considered.

When the oil tank adopts the fixed fire-fighting cooling method, the installation of cooling water pipes shall meet the following requirements:

① When there is no diversion facility for the wind resistance ring or the reinforcement ring of the oil tank, a cooling water spray pipe shall be provided below it.

② Membrane spray nozzles should be installed on the cooling water spray ring, the spacing between the spray nozzles should not be greater than 2m, and the outlet pressure of the nozzle should not be less than 0.1MPa.

③ The lower end of the intake riser for the cooling water of the oil tank is to be provided with a cleaning port. The lower end of the cleaning port should be higher than the top surface of the tank foundation, and the height difference should not be less than 0.3m.

④ Control valves and anti-aircraft valves should be installed on the cooling and fire water pipelines. The control valve should be located outside the fire dike, and the vent valve should be located outside the fire dike. When the fire-fighting cooling water uses ground water as the water source, the fire-fighting cooling water pipeline is provided with a filter.

### 5.8 Lightning Protection

A large number of flammable and combustible fuels are stored in the oil tank. Once a lightning strike occurs, serious fire and explosion accidents may occur. Therefore, the problem of oil tank lightning protection has attracted people's attention.

The current commonly used lightning protection devices to prevent oil tanks from direct lightning strikes include lightning rods, lightning protection lines, lightning protection nets, lightning protection belts, and lightning

arresters. A complete set of lightning protection devices includes air-termination devices, down conductors and grounding devices. The above needles, wires, nets, and belts are actually just lightning receptors, and the lightning arrester is a special lightning protection device. The lightning rod is mainly used to protect open-air substation equipment and protect buildings (structures). Lightning conductors are mainly used to protect power lines. Lightning protection network and lightning protection belt are mainly used to protect buildings. Lightning arresters are mainly used to protect electrical equipment. In short, the lightning protection device can prevent direct lightning strikes or the introduction of lightning currents to the ground to ensure the safety of people and buildings (structures). There are generally two types of floating roof oil tanks: an outer floating roof oil tank and an inner floating roof oil tank. Three 3000m<sup>3</sup> outer floating roof tanks are installed in this loading station. The outer floating roof oil tank is tightly sealed, and the oil product has a small area of contact with the atmosphere and direct contact with the atmosphere. The mixed gas of oil vapor and air on the floating roof is not easy to reach the explosion limit, even if a lightning strike catches fire. It also happens only when the sealing ring is not strict, and it is easy to extinguish. Lightning rods are not required. In order to prevent the induction of lightning and the static charge from the oil away to the metal floating roof, two soft copper strands with a cross-sectional area of not less than 25mm<sup>2</sup> should be used to make a good electrical connection between the metal floating roof and the tank, and ground.

## 5.9 Anti-static

The generation of static electricity control is mainly to control the process and the selection of all materials in the process; the accumulation of static electricity is mainly to try to accelerate the leakage and neutralization of static electricity so that the static electricity does not exceed the safety limit. Grounding and the addition of antistatic additives are all methods of accelerating electrostatic leakage; methods of using static elimination devices to eliminate electrostatic hazards are methods of accelerating electrostatic neutralization.

### (1) Reduce the Generation of Static Electricity

Impurities in oil products are important factors for electrostatic charging, however, it is difficult and uneconomical to achieve high precision in oil products. From the current state of technology, there are no measures that can completely prevent the generation of static electricity. Therefore, in order to prevent the damage of petroleum static electricity, the generation of electrostatic charge cannot be eliminated, and only the technical measures to

reduce the generation of static electricity are available.

#### 1) Control flow rate

It is known that the saturation value of the flowing current and charge density generated by the oil flowing in the pipeline is proportional to the square of the oil flow rate. Controlling the flow rate is an effective way to reduce the generation of static electricity. When the oil is in laminar flow, the amount of static electricity generated is only proportional to the flow rate and has nothing to do with the inner diameter of the pipeline; when the oil product is turbulent, the amount of static electricity generated is proportional to the 1.75th power of the flow rate.

The flammable and combustible liquid flowing in the pipeline, even with a higher average charge density, often does not show a higher electrostatic voltage due to the larger capacitance in the pipeline, and because there is no air in the pipeline, So it will not cause burning and explosion. In this case, although static electricity does not constitute a danger inside the pipeline, its serious harm is mainly at the outlet of the pipeline, which must be paid attention to. For example, China's oil tanker loading test shows that when the average flow rate is 2.6m/s, the measured oil surface potential is 2300V; when the average flow rate is 1.7m/s, the oil surface potential is 580V (because the tanker is on the ground) The capacitance is constant, the greater the charge, the higher the potential). Therefore, controlling the flow rate becomes an effective measure to reduce the generation of static electricity in oil products.

According to GB50074-2002 "Code for Design of Petroleum Depot", the filling flow rate of gasoline, kerosene and light diesel oil is not more than 4.5m/s. Some national regulations. When oil is injected from the top, before the oil injection pipe mouth is submerged, before the oil inlet pipe inlet at the top of the oil tank is not submerged, before the floating roof oil tank is not floated, when water or air is trapped in the product oil or flammable liquid, install The oil speed is limited to less than 1m/s.

#### 2) Control the fueling method

This loading station adopts the method of upper oil loading, in order to reduce the impact of oil loading on the tank wall, reduce the agitation of crude oil in the tank, and reduce the accumulation of static electricity. When loading oil, the crane pipe should be extended close to the bottom of the tank truck. This is okay:

① Reduce oil splashing and foaming to avoid the generation of new charges;

② Reduce the atomization and evaporation of oil, and avoid the ignition of oil when it reaches the flash point temperature;

③ Avoid oil flow through the middle of the oil tank

with the smallest capacitance, so as not to generate a large oil surface potential;

④ It can avoid the formation of high oil surface charge density due to the concentrated drop of oil column in a local range;

⑤ In the later stage of oil filling, when the oil surface potential reaches the maximum value, there is no protruding metal grounded on the upper part of the oil surface, which can avoid the increase of local electric field and prevent spark discharge.

3) There is enough leakage time when passing through the filter

The filter is a source of static electricity. The oil passing through the filter, due to the dramatic friction with the filter, greatly increases the strength of contact and separation, which may increase the voltage of the oil by 10-100 times.

In order to avoid injecting large amounts of charge into the container. In the oil pipeline connected with the filter, a certain length should be left at the outlet or flowed for a certain time, the ground charge will be leaked out, and then injected into the container. This length should be  $L \geq 3L_b$  is called the relaxation length, if it is calculated as time, it is  $t \geq 3\tau$ , which is called the relaxation time or residence time.

When the length of the pipeline is limited and cannot meet  $L \geq 3L_b$ , consider designing a container so that the oil has a temporary relative residence in the container, and its residence time  $t \approx 3\tau$ . This container is called a moderator. General engineering only requires that the amount of charge leak to a level that does not cause danger, so it can be considered that the residence time  $t \approx 2\tau$  can meet the requirements. It is generally stipulated that the oil passing through the filter must have a relaxation time of more than 30s. Therefore, the oil passing through the filter must continue to flow through the pipe length of more than 30s in the grounding pipeline before it is allowed to enter the container.

In order to avoid static electricity accidents. The reasonable arrangement of equipment pipelines has a great relationship with the control of static electricity. For example, the filter should not be close to the oil tank or the oil loading platform, and a certain length of relaxation should be left; the pipeline should be free of bends and diameter changes. Where rubber hoses must be used, conductive rubber tubes or conductive plastic tubes are preferred.

(2) Accelerate Static Electricity Leakage and Reduce Static Electricity Accumulation

The generation of static electricity itself is not dangerous. The actual danger is the accumulation of electric

charge, because this can store enough energy to generate sparks to ignite the combustible gas mixture. It is generally believed that when the resistivity of the insulator is less than  $108\Omega \cdot m$ , there will be no dangerous static electricity accumulation. However, the resistivity of oil products is almost greater than  $108\Omega \cdot m$ , and the charge in the oil products is not easy to leak, so the more static charges that are generated in the oil products are accumulated. In order to accelerate the leakage of oil charge, it can be grounded, bridged and increased the conductivity of the oil.

(3) Eliminate Spark Discharge

In order to eliminate spark discharge, the bottom of the tank must be cleared before filling the tank, and no floating conductors and other debris that fall into the tank, such as liquid level gauge floats, measuring cylinders, gaskets and other metal objects. Testing and sampling must be carried out in the oil measuring tube. If no special oil measuring tube is installed, such as conducting a simple sampling, dipstick, etc., these metals are also equivalent to spark initiators on the oil surface. According to relevant information, when oil tank cars are refueled, the discharge phenomenon will occur when the oil surface potential reaches about 28kV, but when there are free insulating metal objects on the oil surface, that is, there are quite a few charge collectors, as long as 1~2kV. There will be a discharge.

When the oil in the oil tank is finished, it must not be tested. This is because the maximum value of the oil surface potential sometimes occurs after the oil tank is stopped during the oil tank filling process. For safety, when it is necessary to directly measure the liquid level or oil temperature, the leakage time of the static charge in the tank should be avoided. Generally, it takes about 30 minutes to allow the settling charge in the oil to leak before it can be detected. The crane pipe of the tank truck is also a promoter of spark discharge. The crane pipe is well grounded to avoid the spark discharge of the crane pipe and the inner wall of the tank truck. However, the spark discharge of the crane pipe and the oil surface may still occur. Therefore, before changing to bottom filling, the crane pipe should be extended to the bottom of the tank truck to fill the oil; the oil injection pipe that extends into the oil tank should be as close as possible to the bottom to avoid the end of the oil filling (At this time, the oil potential is the highest) the oil surface and the protruding part of the crane pipe (oil injection pipe) are discharged. Therefore, when carrying out the oil filling operation, do not stand on the tank top, let alone do other operations.

## References

- [1] Lei F., Wang W., Cao Y., Wang F. Leapfrogging

- China's Oil and Gas Storage and Transportation Construction Technology and Future Trends[J]. Petroleum Technology Forum, 2016 (3):44-51.
- [2] Li H., Ji L., Tian W. Significant Technical Progress in the West-East Gas Pipeline Projects in Line One and Line Two[J]. Natural Gas Industry, 2010, 30(4):1-9. DOI: 10.3787/j.issn.1000-0976.2010.0.001
- [3] Xiang B. Design Features of West-East Gas Pipeline Project[J]. Petroleum Engineering Construction, 2010 (S1): 1-5. DOI: 10.3969/j.issn.1006-5539.2008.03.001
- [4] Yao W. The current situation and development of standardization in oil & gas storage and transportation industry in China[J]. Oil & Gas Storage and Transportation, 2012(6): 416-421. DOI: doi:10.6047/j.issn.1000-8241.2012.06.004
- [5] Li J., Wang Y., Li Y. Contamination Control in Batch Transportation of West Oil Product Pipeline[J]. Oil & Gas Storage and Transportation, 2010(2): 110-112. DOI: CNKI:SUN:YQCY.0.2010-02-009
- [6] Yang X., Gong J. Study on Contamination Cut and Disposal for Products Pipeline Operated with Batch Transportation[J]. Oil & Gas Storage and Transportation, 2004(4):19-22. DOI: CNKI:SUN:YQCY.0.2004-04-004
- [7] Zhang J. Technologies for Pipelining High-Pour-Point and Viscous Crudes and Their Development[J]. Engineering Science, 2002(6):71-76. DOI: CNKI:SUN:GCKX.0.2002-06-013
- [8] Zheng Z., Wang S., Wu Y., et al. Relative Technologies to Improve Transportability of Oil and Gas Pipelines[J]. Oil & Gas Storage and Transportation, 2010,29(2), 100-106. DOI: CNKI:SUN:YQCY.0.2010-02-007
- [9] Wei X., Liu X., Wang W., et al. Overview on Viscosity Reducing Methods of Heavy Oil[J]. Special Petrochemicals, 2002 (5), 45-48. DOI: 10.3969/j.issn.1003-9384.2002.05.015
- [10] Zheng Q. Heavy oil viscosity reduction technology and delivery method[J]. Oil-gas Field Surface Engineering, 2006,25(4), 6-7. DOI: 10.3969/j.issn.1006-6896.2006.04.003
- [11] Zhou C., Wu C., Ren S., et al. Outline Heavy Oil Viscosity Methods[J]. Inner Mongolia Petrochemical Industry, 2007,33(4), 128-129. DOI: 10.3969/j.issn.1006-7981.2007.04.066
- [12] Xu X., Sun G. Current status and research direction of crude oil processing technology in Tahe Oilfield[J]. Oil-Gasfield Surface Engineering, 2011,30(5), 40-42. DOI: 10.3969/j.issn.1006-6896.2011.5.019
- [13] Anhorn J., Badakhshan A. MTBE (methyl t-butylether), a carrier for heavy oil transportation and viscosity mixing rule applicability. Preprints of 43rd Annu. CIM Petrol Soc Tech Meeting, June 1992.
- [14] Zhao H., Wang Y., Zhao T. Chemical Visbreaking Method of Heavy Oil[J]. Chemical Industry Times, 2005,19(8), 64-66. DOI: 10.3969/j.issn.1002-154X.2005.08.020
- [15] Guevara E., Zagustin K., Zublillaga V. Core annular flow: the most economical method for the transportation of viscous hydrocarbons. Proceedings of the 4th UNITAR/ UNDP Conference on Heavy Crude and Tar Sands. Aug, 1998.
- [16] Dong Y., Sun N., Chen D., et al. Discussion on the resistance characteristics of heavy oil-foam flow in riser. Drilling & Production Technology, 2016,39(5), 52-55.
- [17] Isaacs J, Speed J. Method of Piping Fluids. US Patent N759374, 1904.
- [18] Prada J., Jose W., Bannwart A.C. Modeling of Vertical Core-annular Flows and Application to Heavy Oil Production[J]. Journal of Energy Resources Technology, 2001(3), 194-199. DOI: 10.1115/1.1377894
- [19] Silva R., Mohamed R., Bannwart A.C. Wettability Alteration of Internal Surfaces of Pipelines for Use in The Transportation of Heavy Oil via Core-flow[J]. Journal of Petroleum Science and Engineering, 2006,51(1), 17-25. DOI: 10.1016/j.petrol.2005.11.016
- [20] Huang Y., Liu H., Wang Z. Calculation of Microbubble Sheet Drag Reduction of Plate by Model of Boundary Layer[J]. Journal of Ship Mechanics, 2003 7(6), 6-13.
- [21] McCormick M.E., Bhattacharyya R. Drag Reduction of a Submersible Hull by Electrolysis[J]. Naval Engineers Journal, 1973 (85), 11-16. DOI: 10.1111/j.1559-3584.1973.tb04788.x
- [22] Ortiz-Villafuerte J., Hassan Y.A. Investigation of Microbubble Boundary Layer Using Particle Tracking Velocimetry[J]. Journal of Fluids Engineering, 2006,128(3), 507-519. DOI: https://doi.org/10.1115/1.2174062
- [23] Jing J., Dai K., Li Y., et al. New Ideas of Drag Reduction for Heavy Oil Flow Using Aqueous Foam[J]. Journal of Southwest Petroleum University (Science & Technology Edition), 2013,35(3), 174-182. DOI: 10.3863/j.issn.1674-5086.2013.03.025
- [24] API SPEC 5L 44th-2007. Specification for line pipe. Washington D.C.: API publishing services, 2007,10.
- [25] Xia D., Wang X., Li X. et al. Properties and Microstructure of Third Generation X90 Pipeline Steel[J]. Acta Metallurgica Sinica, 2013,49(3), 271-276.

- DOI: 10.3724/sp.j.1037.2012.00480
- [26] Qian Y., Xiao W., Liu L., et al. Development and Trial Production of X90M Pipeline Steel with Large Diameter[J]. *Welded Pipe and Tube*, 2014 37(1), 22-26.  
DOI: 10.3969/j.issn.1001-3938.2014.01.005
- [27] Yang F., Luo J., Li H., Guo Y., Feng J. Constitutive Law and Fracture Criteria of X90 Ultrahigh-Strength Gas-Transmission Steel Pipe Material[J]. *Acta Petroleum Sinica*, 2017 ,38(1), 112-118.  
DOI: 10.7623/syxb201701013
- [28] ASME. ASME B31.8. Gas Transmission and Distribution Piping System[M]. New York: ASME, 2010.
- [29] Wu H., Luo J., Zhang D. Hydrostatic Testing Pressure Determination of the Test Pipe Section with a 0.8 Design Factor in The West-to-East China Gas Pipeline[J]. *Natural Gas Industry*, 2013(8), 1-6.  
DOI: 10.3787/j.issn.1000-0976.2013.08.018
- [30] Yang X. Design and management of oil pipeline[M]. Dongying:Petroleum University Press, 1996.
- [31] Zong Y., Wu L., Yang W., et al. Comparison of Process Design of Oil Pipeline between China and North America. *Oil-Gasfield Surface Engineering*, 2014(3), 48-49.  
DOI: 10.3969/j.issn.1006-6896.2014.3.029.