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Research on CO_2 continuous composite pipeline transportation technology

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ABSTRACT

CO_2 transport is a key part of the national " carbon peak, carbon neutral " action. At present, it is mainly transported by tankers, which has many problems such as high transportation cost, high traffic risk, low reliability of continuous supply of carbon sources affected by weather and traffic. To this end, some enterprises began to use pipeline transportation to achieve stable carbon source supply, and pipeline transportation has the advantages of low cost and low risk. However, pipeline construction is to use 10 meters of pipes to form a pipeline by welding. The construction period of pipeline construction is long, the construction cost is high, and there are many welding points and many pipeline risk points. In view of the above problems, a continuous composite pipe is formed through thinking innovation and design evaluation. The design of the continuous composite pipe is composed of three layers of thermoplastic polymer layers on both sides of the intermediate metal layer. The thermoplastic polymer of the inner lining layer prevents internal environmental corrosion and transmission medium enhancement layer. The intermediate metal layer resists circumferential stress and axial force, and the outer thermoplastic polymer prevents external corrosion and wear. The continuous composite pipe can be processed into a section of 800 m ~ 1500 m according to different pipe diameters. The construction of CO_2 transmission pipeline by this process will greatly reduce the welding point of the pipeline, improve the safety of the pipeline, greatly shorten the construction period, reduce the labor intensity, reduce the construction cost, and provide valuable technical support for the implementation of the national " carbon peak, carbon neutralization " action.

Keywords: CO_2 continuous composite pipe pipeline transportation

1. INTRODUCTION

Carbon dioxide is one of the important greenhouse gases, which has an important impact on global climate change. In order to cope with the problems caused by climate change and achieve a low-carbon economy, the capture, storage and utilization of carbon dioxide have become the current research hotspots. Some oilfields in China have entered the stage of tertiary oil recovery. At this stage, conventional oil recovery methods have been difficult to achieve good oil recovery results. As a new type of oil recovery method, CO2 flooding has been applied abroad, but it is still in the exploratory stage in China. It is of great significance to explore carbon dioxide flooding for the further development of crude oil in China. CCUS-EOR (carbon dioxide capture and storage and enhanced oil recovery) technology is a technology that CCUS is used in oilfield development. It mainly reduces the viscosity of crude oil, improves the mobility ratio of crude oil and water, expands the volume of crude oil, makes light hydrocarbon extraction and vaporization in crude oil, miscible effect, molecular diffusion, interfacial tension reduction, dissolved gas flooding, permeability improvement and other mechanisms of oil displacement to improve oil recovery. At the same time, a large amount of carbon dioxide can be buried underground to reduce greenhouse gas emissions. CCUS-EOR technology can achieve the dual purpose of increasing oil production and reducing carbon capture cost, which is a win-win solution[1-7].Because the source of carbon dioxide in China is far away from the place of injection or use, and pipeline transportation has the advantages of large transportation volume, long transportation distance and good economy, promoting CO2 pipeline transportation is the most economical mode of transportation. CO2 continuous composite pipeline

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transportation technology is an important means of carbon dioxide transportation, storage and utilization. It has the advantages of high transportation efficiency, low cost and high safety.

2. CO_2 TRANSPORT STATUS

Compared with foreign countries, China started late in CO_2 transportation. At present, it is mainly transported by tankers (CO_2 is stored in high-pressure storage tanks, and then transported to the destination by tankers) and through manganese steel pipelines. These two methods have their own advantages and disadvantages. Tanker transport CO_2 has the characteristics of high flexibility and wide application range, but there are also security risks and high transportation costs. The manganese steel pipeline transportation of CO_2 has the advantages of large throughput, low cost and high safety, but it requires long construction time and high construction investment.

2.1 tanker transport

Limited by the high one-time investment cost of pipeline construction, CO_2 pipeline transportation in China is still in the experimental stage. At present, in China, CO_2 transportation is mainly by land cryogenic tank transportation.

a b

Fig. 1 (a) loading and unloading process of tanker ; (b) CO2 transport tanker

2.1.1 Cost analysis of tanker hauling

Although there are some safety hazards and high transportation costs in tanker transportation, it has the characteristics of high flexibility and wide application range, which is very suitable for short-distance and small-batch CO_2 transportation tasks. Tank car capacity according to user needs, ranging from 2 tons to 30 tons. However, in the first million-ton CCUS full-chain demonstration project in Shengli Oilfield and Qilu Petrochemical, the long-distance transportation of CO_2 has become a challenge. It takes more than 7 hours for each tank car to go back and forth, and can run up to nearly 80 times a day, which takes a lot of time and resources. In addition, the transportation cost of liquid carbon dioxide is also relatively high. It takes 0.8 yuan to 1 yuan to transport 1 km per ton of CO_2. According to the standard of 25.5 tons per vehicle, the transportation cost of tank car can reach 160,000 yuan per day. This high-cost transportation mode is not conducive to the large-scale application and promotion of CO_2. Therefore, the use of pipeline transportation can effectively solve this problem. In contrast, pipeline transportation costs are lower. With the increasing demand for CO_2 emission reduction, the construction of CO_2 pipeline will become one of the future development trends, which is expected to further reduce the cost of CO_2 transportation and improve transportation efficiency.

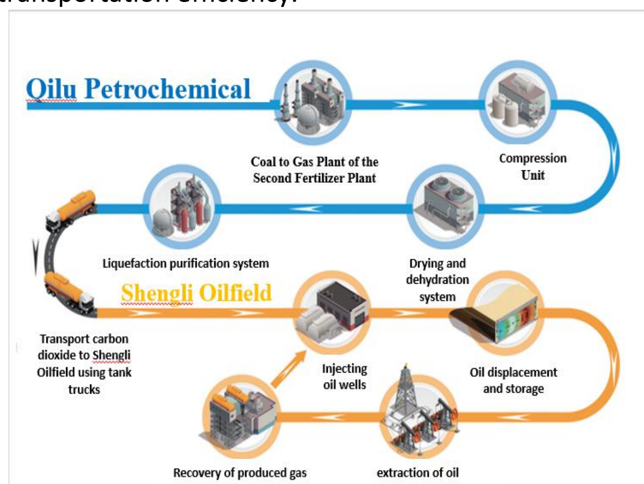

Fig. 2 Flow chart of Qilu Petrochemical-Shengli Oilfield million-ton CCUS project

2.1.2 Risk analysis of tanker hauling

(1) Risk analysis of hauling system

Tanker hauling system is a kind of low temperature and high pressure transport vehicle specially used for transporting CO_2. This transport mode needs to be carried out at-20 ℃ and 2MPa to ensure that CO_2 can be safely transported. However, since liquid CO_2 is easily affected by the environment during storage and transportation, CO_2 will inevitably leak. Therefore, a series of precautions must be strictly followed during transportation to ensure the safety and reliability of the transportation process. The tanker hauling system transports CO_2 at -20 ℃ and 2MPa. Due to the liquid CO_2 in the storage, transportation process are susceptible to environmental impact, carbon dioxide transport vehicles must be low temperature, high pressure professional transport vehicles, and in the liquid, transportation, unloading process have strict precautions[8].

First, operators must receive professional systematic training to ensure that they can operate the tanker correctly and wear appropriate protective equipment, such as cotton gloves and helmets, to prevent low temperature damage to the skin. In addition, because CO_2 is a low-temperature asphyxiating gas, suffocation injury accidents may occur during loading and unloading, so careful operation is necessary. Secondly, during each loading and unloading process, the valve must be opened and closed carefully to prevent problems such as low temperature freezing of the valve. In addition, since liquid CO_2 is a high-pressure gas, frequent handling operations may lead to CO_2 leakage and ejection, increasing the risk of injury.

(2) Tank car hauling instability analysis

In addition to security risks, there are many uncertain factors in the process of tanker transportation. Although tank drivers have undergone strict training, objective factors such as traffic accidents and weather changes may affect the transportation process. In addition, due to the particularity of liquid CO_2, the complexity of post-accident treatment is much higher than that of ordinary traffic accidents. These uncertainties further increase the cost and risk of tanker hauling.

2.1.3 nodule

In summary, although tanker transportation is a common mode of CO_2 transportation, its high cost, high safety hazards and high uncertainty of transportation process limit its development in large-scale application and promotion. It is obviously not suitable for industrial systems such as CCUS that need to continuously transport a large amount of CO_2. There is no worldwide precedent for using road tankers in CCUS systems. Therefore, the trend of CO_2 transportation in the future will be to solve these problems in a safer, more reliable and more efficient way such as pipeline transportation.

2.2 Manganese steel pipeline transportation

The CO_2 source near the location of China 's main oil producing areas is very limited, so it is necessary to collect gas from other areas and transport it to designated land through pipelines. Although the domestic CO_2 pipeline technology research started late, it has begun to implement engineering practice construction. At present, China 's Shengli Oilfield and Jilin Oilfield have built supercritical carbon dioxide pipeline[2, 9].These pipelines are made of manganese steel and subjected to internal and external corrosion treatment to improve their corrosion resistance and service life. However, although manganese steel has the advantages of wear resistance and strength, there are still some shortcomings, including high cost, heavy weight, difficult manufacturing and corrosion problems.

2.2.1 Cost analysis of manganese steel pipeline

(1) Processing cost analysis

Manganese steel is a series of steel grades formed by adding alloying element manganese on the basis of carbon steel. It is not only a steel, but also a general term for a series of steel grades. High manganese steel is a kind of material with unique characteristics. Under the condition of strong impact and extrusion, the surface layer will be hardened rapidly, so that it still maintains good toughness and plasticity in the heart, and the hardened layer has excellent wear resistance. This characteristic is not available in other materials. However, due to the high cost of manganese steel compared to other materials, the construction of supercritical carbon dioxide pipelines may increase costs. In addition, the wear resistance of high manganese steel can only show its superiority under the condition of forming work hardening, and is poor in other cases. In order to achieve the standard of transporting CO_2, this will undoubtedly further increase the difficulty of processing manganese steel and increase production costs. With an annual transmission capacity of 2 million tons as the design goal, the design adopts a 6-inch single pipe, a single pipe length of 2000 m, and a total material price of 2.5803 million yuan.

(2) Transportation and installation cost analysis

Due to the high density of manganese steel, the produced supercritical carbon dioxide pipeline will become heavier accordingly. This may bring additional difficulties and costs to transportation and installation. Especially in long-distance transportation, the weight of the pipeline will increase the transportation cost, and it may also require greater equipment and more manpower to install and maintain the pipeline. Manganese steel is a difficult-to-machine material, so its installation and processing methods are relatively simple. In general, manganese steel pipes up to 10 meters long are processed and installed by welding. Because there are many welding points, there is a big risk. Each welding point is a potential risk point, and the welding quality needs to be strictly controlled. Especially in special parts such as elbows and pipeline nodes, the risk is more significant[10]. Therefore, in the processing of manganese steel, it is necessary to strictly manage and supervise the welding process and welding personnel to ensure the processing quality and work safety.

(3) Construction cost analysis

When connecting manganese steel, due to its many connection points, a lot of welding work is needed, and the welding work is more complicated. Under the influence of temperature rise, high manganese steel is prone to liquefaction cracks, which affects its performance. Liquefaction cracks and weld cracks often appear near the weld, both of which are hot cracks. This greatly increases the welding cost of manganese steel pipe[11]. In addition, the welding of manganese steel requires the use of special welding materials, which are relatively expensive, thus increasing the cost of welding materials[12]. At the same time, the welding of manganese steel requires the use of professional welding equipment, which is expensive and increases the cost of equipment. In the maintenance process, the welding quality of manganese steel is higher, and more time and energy are needed to carry out maintenance, thus increasing the maintenance cycle cost. In addition, there are many welding points of manganese steel, especially in the elbow, pipeline joints and other locations. Additional welding points are needed to ensure the firmness of the connection, but this will also increase the risk of corrosion. Therefore, if there is a corrosion problem, it needs to be repaired and replaced, which increases the corrosion cost. In summary, the welding maintenance cost of manganese steel is relatively high, and the influence of manpower, materials, equipment, cycle and corrosion should be considered.

2.2.2 Corrosion risk analysis of manganese steel pipeline

Because manganese steel itself contains high manganese element, it has certain corrosion resistance. However, in practical use, there are still many deficiencies in the corrosion resistance of manganese steel. The corrosion of manganese steel pipelines mainly includes internal corrosion and external corrosion.

(1) Corrosion risk analysis of manganese steel pipeline transportation

The corrosion inside the pipeline is mainly caused by CO_2 itself. When the water content exceeds its solubility in supercritical CO_2, it precipitates and condenses into liquid phase, which combines with CO_2 to form carbonic acid, posing a major threat to metals. Yin [13] et al.showed that when the temperature was 30 ℃, only 0.03 MPa CO_2 would cause extremely serious corrosion on the surface of carbon steel. The corrosion mechanism is shown in Figure 3.

Formation and hydrolysis of carbonic acid：

$$CO_2+H_2O \leftrightarrow H_2CO_3 \quad (1)$$

$$H_2CO_3 \leftrightarrow H^++HCO_3^- \quad (2)$$

$$HCO_3^- \leftrightarrow H^++CO_3^{2-} \quad (3)$$

Cathodic reaction:

$$2H^++2e^- \rightarrow H_2 \quad (4)$$

$$H_2CO_3 \leftrightarrow H^++HCO_3^- \quad (5)$$

$$2HCO_3^- \leftrightarrow CO_3^{2-}+H_2 \quad (6)$$

Anodic reaction:

$$Fe \rightarrow Fe^{2+}+2e^- \quad (7)$$

Film-forming mechanism:

$$Fe^{2+}+CO_3^{2-} \rightarrow FeCO_3 \quad (8)$$

$$Fe^{2+}+2HCO_3^- \rightarrow Fe(HCO_3)_2 \quad (9)$$

$$Fe(HCO_3)_2 \rightarrow FeCO_3+CO_2+H_2O \quad (10)$$

Figure 3 Internal Corrosion Mechanism of Metal Pipeline

At present, the main methods for steel corrosion are : surface coating and adding a certain amount of corrosion inhibitor to the pipeline.

Coating protection is a widely used CO_2 corrosion protection method in the world. Coating is one of the important means of anticorrosion of manganese steel.Yang[14]et al.conducted an evaluation experiment on the four current mainstream steel corrosion protection systems in China. The experimental results show that the solvent-based epoxy-polyurethane system has poor resistance to chloride ion erosion. The adhesion of polyurea protection system and polyurea protection system is poor, and it is easy to fall off during use. Solvent epoxy-polyurethane system, polyurea protection system, solvent epoxy-fluorocarbon system and waterborne two-component epoxy-polyurethane system have poor salt spray resistance. Therefore, although the coating has certain corrosion resistance, there is no coating system with good enough performance for supercritical CO2 transport. In addition, coating defects such as pores and breakages are fatal defects that affect their corrosion resistance. Because supercritical CO_2 is an excellent extractant[15-20]， The solvent and other substances in the organic map coating can be extracted from the coating, so the coating is prone to problems such as coating peeling and cracking during use. When there are more pores on the surface of the coating, the metal substrate under the pores that is not protected by the coating will form a corrosion micro-cell with the alloy in the coating (the sample substrate as the anode, the coating as the cathode) to accelerate the metal corrosion.Lv[21]et al found that high manganese steel is prone to electrode reaction in 3.5 % NaCl solution, resulting in corrosion. In addition, as a CO2 transport pipeline, the surface quality of manganese steel is not stable. Manganese steel is prone to produce oxide skin during heat treatment, which affects its surface quality and coating adhesion.

For economic considerations, corrosion inhibitors are widely used to reduce the internal corrosion of gas pipelines in major oil fields in China. Among them, film-forming corrosion inhibitors are better[22，23]. At present, the thin film corrosion inhibitors used in oilfield CO_2 corrosion environment mainly include amines, such as primary amines, secondary amines, polyamines, sulfides, phosphides, etc[10]. It is mainly through physical and chemical adsorption. Before the corrosion occurs, it can be physically and chemically adsorbed with the metal substrate to form a covering film on the metal surface. This kind of adsorption film is more dense than the precipitation film and the oxide film. It plays a more excellent physical barrier effect, inhibits the cathodic and anodic reactions, and achieves the purpose of reducing the reaction rate[24].

Zhang Zhi[25]et al found that corrosion inhibitors can effectively inhibit CO_2 corrosion of N80 tubing, but it is still necessary to carry out wellbore integrity management as soon as possible when the tubing safety factor is lower than the safety line.Zhang et al[26] calculated the corrosion rate and corrosion inhibition rate at different temperatures and pressures under the condition of adding corrosion inhibitors. The results showed that when the pressure reached 4MPa, although the corrosion inhibition rate reached 85.89 %, the corrosion rate would be greater than 0.076mm / a, which was prone to corrosion. Since the CO_2 flooding test in the peripheral oilfield of Changyuan, the corrosion monitoring results show that the wellbore corrosion rate of some oil wells has exceeded the industry standard, and corrosion pits and leakage points have also been found in the field operation[27].

At present, although there are many studies on the corrosion inhibition effect of corrosion inhibitors in supercritical CO_2 environment, it shows that amines, imidazolines and other corrosion inhibitors still have good corrosion inhibition effect, but it has not been found that a corrosion inhibitor can reduce the metal corrosion rate to an acceptable range. This is because supercritical CO_2, as a good extractant, can extract corrosion inhibitors from liquid water into the supercritical phase, reducing their effective action in the environment, thereby reducing the slow-release efficiency.

(2) External corrosion risk analysis of manganese steel pipeline transportation

The external corrosion of supercritical CO_2 pipeline is mainly caused by the harsh external environment. The corrosion environment outside the pipeline includes atmospheric corrosion environment, soil corrosion environment and industrial corrosion environment[28]. The laying environment of CO_2 transportation pipeline is complex. External corrosion is mainly reflected in point and pit corrosion problems. In severe cases, stress corrosion problems will also occur. From the perspective of the corrosion causes of CO_2 transmission pipelines, China 's CO_2 transmission pipelines have been in the underground environment for a long time. The chemical composition of the soil is very complex, especially the soil is rich in water, air and inorganic salts, water and inorganic salts can make the soil conductive, provide conditions for chemical reaction [29，30]. Water and pipeline metal materials will also react with each other in air, and the reaction process is relatively long. The chemical composition, water content and pH of the soil will affect the corrosion of the pipeline. The corrosion caused by the soil is the main cause of pipeline corrosion[31]. In addition, the smoothness of the metal surface also directly affects its corrosion resistance.

The metal material of the pipeline itself is unstable, and the pipeline is buried underground for a long time, so it is very vulnerable to the influence of the external environment and corrosion[28]. The properties of the internal materials of the pipeline have a great influence on the corrosion resistance of the pipeline. The corrosion resistance of ordinary alloy materials is stronger than that of multi-alloy materials. However, due to the characteristics of the metal itself, external corrosion is still serious.

At present, the commonly used material in the anti-corrosion work outside the CO2 pipeline is asphalt. Long-term use of asphalt will cause asphalt aging[32]. If the operation is improper during the anti-corrosion period of the pipeline, the coating will be damaged and the application effect of the coating will be reduced. The quality of anti-corrosion joint of pipeline will affect the anti-corrosion effect of pipeline. The elbow and joint position of pipeline are most prone to corrosion. If the anti-corrosion work is not in place, the overall anti-corrosion effect of pipeline will be affected. In addition, pipeline welding can also cause coating failure.

At present, the anti-corrosion measures outside the pipeline are to use anti-corrosion coatings. The most common method is to spray an anti-corrosion coating outside the pipeline to isolate the pipeline wall from the corrosive medium and play an electrochemical protection role. In general, manganese steel anti-corrosion coating can choose inorganic coating, organic coating and composite coating of different types of anti-corrosion materials. The inorganic coating has the advantages of high temperature resistance, oxidation resistance and chemical corrosion resistance. The organic coating has good weather resistance and aesthetics. The composite coating is a combination of organic coating and inorganic coating, which combines the advantages of both. In addition, in the process of coating construction, it is necessary to pay attention to the thickness, quality and uniformity of the coating, deal with the defects and damage of the coating surface in time, and carry out regular inspection and maintenance according to the requirements of use, so as to prolong the service life of manganese steel and improve its corrosion resistance. However, the application of these materials has some defects.

2.2.3 nodule

In summary, manganese steel pipeline transportation is a commonly used CO_2 pipeline transportation method in China. Due to the high density of manganese steel material, the produced supercritical carbon dioxide pipeline is heavier, which brings additional difficulty and cost to transportation and installation. Manganese steel is difficult to process. Generally, up to 10 meters of pipes are processed and installed by welding connection. There are many welding points and there are great risks, so it is necessary to strictly control the welding quality. Especially in special parts such as elbows and pipeline nodes, the risk is greater. As a pipeline for transporting supercritical CO_2, even if manganese steel has much stronger corrosion resistance than ordinary carbon steel, because of the limitation of metal material itself, whether it is internal anti-corrosion and external anti-corrosion, because of the characteristics of CO_2 itself, the use of corrosion inhibitors can not achieve the desired effect, and the corrosion phenomenon still exists. At present, the most effective means of anti-corrosion through special coatings has the problems of high construction difficulty and difficult repair and maintenance in the later stage.

3. CONTINUOUS METAL COMPOSITE PIPE CONVEYING

Aiming at the existing CO_2 transportation problem, a continuous composite pipe is formed through thinking innovation and design evaluation. The continuous composite pipe design is composed of three layers of thermoplastic polymer layer on both sides of the intermediate metal layer. The inner layer is lined with thermoplastic polymer to prevent internal environmental corrosion and transmission medium enhancement layer. The intermediate metal layer resists circumferential stress and axial force, and the outer layer thermoplastic polymer prevents external corrosion and wear. Because the material is a composite material, it is not easy to react with CO_2-H_2O, and its corrosion resistance is much higher than that of metal. The continuous composite pipe can be processed into a section of 800 m ~ 1500 m according to different pipe diameters, and because there are many processing methods, the processing method is more flexible, and the processing difficulty is lower than that of manganese steel pipe, which can effectively solve the corrosion problem at the elbow and near the contact point. The construction of CO_2 pipeline by this process will greatly reduce the pipeline welding point, improve the pipeline safety, and further reduce the cost of CO_2 transportation.

3.1 Design of continuous metal composite pipe

Continuous metal composite pipe is a kind of pipe material composed of metal layers of different materials. It has excellent mechanical properties and corrosion resistance, and is widely used in various fields. In this paper, we will discuss the design principle, structure and processing technology of continuous metal composite pipe, and how to select the appropriate material and design scheme according to different application scenarios.

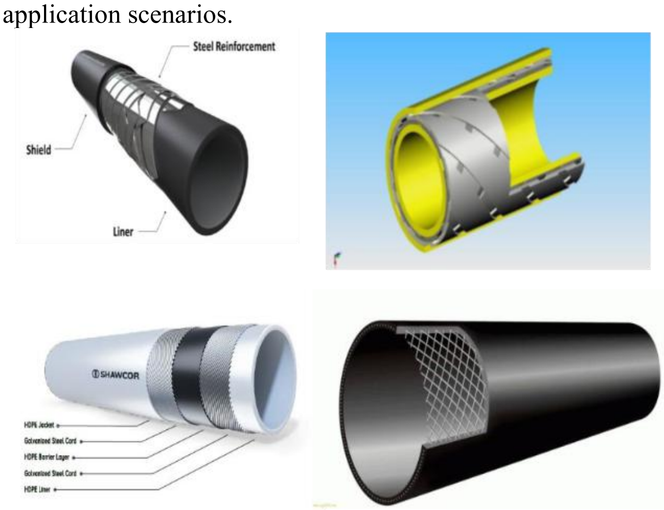

Fig. 4 Metal continuous composite pipe schematic diagram

3.1.1 Internal pressure sealing layer material

High density polyethylene was selected as the sealing material, Shieh[33]et al found that high density polyethylene can be used to transport supercritical CO2.

3.1.2 Selection of armored layer material

Since the internal pressure sealing layer material selects the ultra-high molecular weight polyethylene material, the small molecule medium slowly penetrates into the annular domain through the internal pressure sealing layer material (the area between the internal pressure sealing layer and the outer coating layer), and the material in this area is carbon steel. Therefore, it is necessary to consider the corrosion of the infiltrated medium to the steel.

In order to reduce the gas pressure accumulation in the annular domain and avoid the damage of the outer coating due to the pressure accumulation, an exhaust valve is set at the joint position of each root canal. When the pressure difference between the annular domain and the external environment reaches 0.2 MPa, the exhaust valve will open and discharge the gas in the annular domain.

3.1.3 Anticorrosion treatment of joint

The joint is a key component of the hose. The contact parts of the joint and the dielectric joint are welded with nickel-based 625 material, such as the red part in the figure. The material has good corrosion resistance and ensures the safety of the joint.

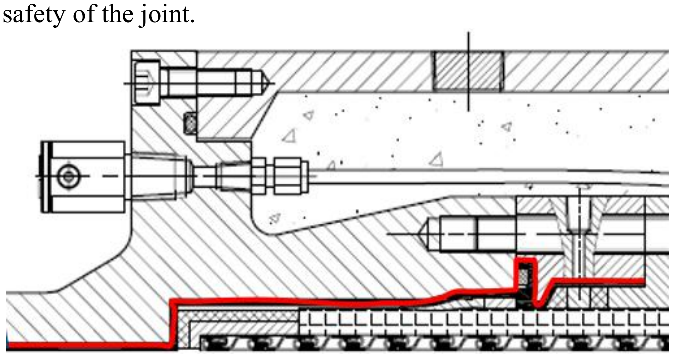

Fig.5 Joint anticorrosion treatment

3.2 Performance of continuous metal composite pipe

Continuous metal composite pipe is a new type of pipe material, which is composed of two or more different metal layers. It has the advantages of high strength, high corrosion resistance, high toughness and good weldability, and is widely used in petroleum, chemical, marine and other fields. In this paper, we will discuss the performance characteristics of continuous metal composite pipes.

3.2.1 Continuous metal composite pipe parameters

The diameter range is 1.8 inches to 14 inches, the length range is 5000 m to 800 m, the pressure range is 0 to 40 MPa, and the temperature range is -30 °C to 120 °C.

3.2.2 CO2 corrosion evaluation

Corrosion experiments were carried out on continuous composite pipes, and the penetration results are shown in Table 1.

Table 1 Corrosion test results of continuous composite pipe

Gas	Temperature (°C)	Permeation Coefficient ($cm^3 \cdot cm/ cm^2 \cdot s \cdot bar$)
CO_2	50	9.86E-09
	60	1.36E-08
	70	1.73E-08
	80	3.49E-08
	90	3.06E-08

It can be seen from Table 1 that the permeability coefficient of CO_2 increases with the increase of temperature. The larger the permeability coefficient is, the easier the material is to penetrate. With the penetration of CO_2, it is prone to corrosion. Zhenguang[34] and other experiments found that the microstructure of the steel is composed of ferrite and chromium carbides, and the corrosion products are mainly FeCO3 crystals. The corrosion mechanism is shown in Figure 6.

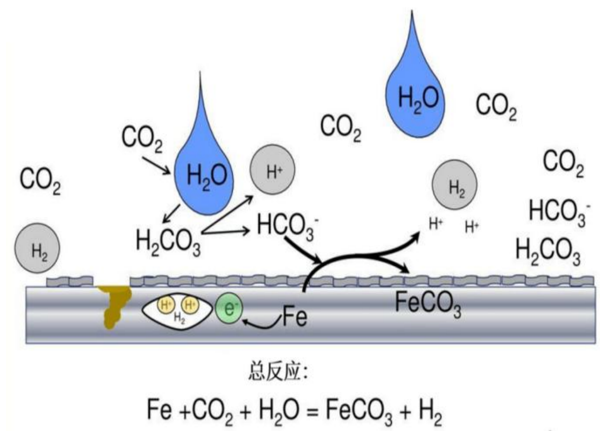

Fig.6 CO_2 corrosion mechanism

Due to the penetration, there is corrosion in the annular domain. For different corrosion conditions, the experimental results are shown in Table 2.

Table 2 Corrosion rate under different corrosion conditions

material	test condition		test conclusion
Pressure armored layer - carbon steel	temperature	55℃	Corrosion rate :0.0907mm /a No pitting
	pressure	1.7MPa	
	CO_2 partial pressure	1.44MPa	
Pressure armored layer - carbon steel	temperature	81℃	Corrosion rate :0.0145mm /a No pitting
	pressure	3MPa	
	CO_2 partial pressure	2MPa	
Pressure armored layer - carbon	temperature	120℃	Corrosion rate :0.0118mm /a No pitting
	pressure	5.2MPa	

steel	CO_2 partial pressure	3MPa	
Tensile armor layer-carbon steel	temperature	81℃	Corrosion rate :0.0133mm /a No pitting
	pressure	3MPa	
	CO_2 partial pressure	2MPa	
Tensile armor layer-carbon steel	temperature	48℃	Corrosion rate :0.0133mm /a No pitting
	pressure	1.7MPa	
	CO_2 partial pressure	0.6MPa	
Tensile armor layer-carbon steel	temperature	120℃	Corrosion rate :0.0091mm /a No pitting
	pressure	5.2MPa	
	CO_2 partial pressure	3MPa	

It can be seen from Table 2 that the corrosion rate increases with the increase of temperature, pressure and CO_2 partial pressure. However, it is worth noting that, to a certain extent, the corrosion rate under higher temperature, pressure and CO_2 partial pressure is smaller than that under lower conditions, which may be due to higher temperature, pressure and CO_2 partial pressure. The faster oxidation reaction leads to less accumulation of corrosion products and thus protects the material. In addition, no pitting corrosion was observed in all tests, indicating that these armor layers have good corrosion resistance. Continuous metal composite pipe has excellent corrosion resistance.

3.3 Characteristics of continuous metal composite pipe

Compared with manganese steel pipes, continuous composite pipes have inherent advantages and better corrosion resistance. It does not require harsh processing conditions, and has lower processing difficulty than manganese steel ; the construction cost is much lower than that of manganese steel pipeline.

3.3.1 corrosion prevention

The internal environment of the pipeline may involve oil, gas, water and two-phase or three-phase mixed transportation, while the external environment may involve soil, air and seawater. In view of these different environments, corresponding anti-corrosion measures need to be adopted to ensure the long-term use of pipelines.

3.3.2 Flexible and rigid

Continuous metal composite pipe has low bending stiffness and high tensile stiffness. This means that the tube has the flexibility of plastic tube and the pressure resistance of metal tube. Due to its flexibility, the pipe can adapt to curved or tortuous pipe layout ; its pressure resistance ensures that the pipeline will not rupture or deform under high pressure. At the same time, it has high corrosion resistance and wear resistance, and can adapt to the needs of different media and working environment.

3.3.3 Light weight, continuous and easy installation

The length of continuous metal composite hose can vary from 400 m to 3000 m. Compared with pure metal hose, metal reinforced composite hose has only 1 / 3 weight, while non-metal reinforced composite hose has only 1 / 7 weight. In addition, the composite hose has fewer joints, is easy to disconnect, and the laying speed is fast, which can be used for trench laying or open laying on complex geological terrain.

The metal reinforced composite hose is reinforced by metal mesh or spiral steel strip, which makes it have higher pressure bearing capacity and wear resistance, and can withstand higher pressure and greater impact force. Non-metallic reinforced composite hoses usually use high-strength fiber-reinforced materials, such as glass fiber and carbon fiber, to make them have higher strength and elastic modulus, and can withstand greater tension and bending.

Due to the small number of joints, the installation and disassembly of composite hoses are relatively easy, which can reduce engineering time and labor costs. In addition, the laying speed of the composite hose is fast, and a lot of laying work can be completed in a short time, which effectively improves the progress of the project. In the complex geological terrain, the trenching or laying method of composite hose can effectively avoid the interference of terrain obstacles and underground pipelines, and ensure the smooth progress of the project.

3.3.4 The smooth inner wall is not easy to scale and the ability of conveying medium is improved.

The surface roughness of the polymer inner wall of the continuous composite metal pipe is only a few tenths of that of the metal pipe, which means that the liquid or gas inside the composite hose can flow more smoothly, reducing the friction resistance of the fluid, thereby improving the efficiency of transportation.

At the same time, the composite hose in the same diameter, the same pressure and the same medium conditions, compared to the metal pipe, its transport capacity will increase by about 30 %. This is because the inner wall surface of the composite hose is smooth, the friction force when the fluid passes through is small, the inner diameter is relatively large, and the flow channel design is more reasonable.

In addition, the composite hose also has a certain elasticity during the transportation process, which can reduce the vibration and impact of the pipeline when it is stressed, thereby protecting the pipeline from fatigue fracture and other problems, and prolonging the service life of the pipeline. At the same time, the installation, maintenance and replacement of composite hoses are relatively simple, and there is no need for tedious operations such as welding or cutting like metal pipes, which reduces labor and time costs.

3.3.5 Low installation cost

First of all, the processing length of continuous composite pipes is generally between 800 meters and 1500 meters, which means that relatively long pipes can be processed in a short time, which greatly shortens the processing cycle and cost. Moreover, since the connection of continuous composite pipes does not require welding, the manual input during installation is greatly reduced, and the safety hazards and environmental pollution during installation are also reduced.

Secondly, the quality of the continuous composite pipeline is lighter, which is lighter than the traditional manganese steel pipeline, so it also has a greater advantage in transportation cost. In addition, due to the low difficulty of laying continuous composite pipelines, the laying process does not require too much tedious operation, so the construction cycle and cost can also be better optimized.

In addition, the continuous composite pipe has many other advantages. For example, the installation of continuous composite pipes is to lay pipes processed into 800 meters to 1500 meters, and almost no welding is needed, which greatly reduces the manual input in the installation process ; the continuous composite pipe is lighter, the transportation cost is much lower than that of manganese steel, and the laying difficulty is lower.

According to the annual conveying capacity and the processing capacity of continuous composite pipe, the design of 2 million tons / year continuous composite pipe adopts 6 inch double pipe, the length of single pipe is 2000 m, and the total cost of materials is 2.82 million yuan (excluding construction cost). The equivalent diameter of 2000 meters of manganese steel pipeline costs 2.5803 million yuan (including material costs and anti-corrosion welding inspection costs, excluding construction costs) ; the comparison results are shown in Table 3.

Table 3 CO2 pipeline cost comparison

Numbers	Material	Length /m	Inside diameter /mm	Unit price /(yuan / m)	Anticorrosion welding flaw detection unit price /(yuan / m)	Material total price / ten thousand yuan	Total price / ten thousand yuan	Annual throughput / million tons	remark
	Manganese steel pipe	2000	304.80	392.16	298.00	198.43	258.03	200.00	canalis singularis
	Continuous composite pipe	2000*2	152.4*2	105	-	282.00	282.00	200.00	double transistor

According to table 3, compared with manganese steel pipe, the total price of continuous composite pipe is slightly higher than that of manganese steel pipe because of double pipe transportation. However, the construction period and labor intensity of continuous composite pipelines are much smaller than those of manganese steel pipelines, and no additional anti-corrosion welding inspection is required. In addition, continuous composite pipe also has the advantages of anti-corrosion, light weight, easy installation and smooth inner wall, so it has more advantages in CO2 pipeline.

3.4 Continuous metal composite pipe connection method

First of all, for different use conditions, non-metallic composite pipes provide a variety of joint forms to choose from, including flange end joints, pipe-to-pipe joints, and welded neck joints. These different forms of joints can be flexibly selected according to specific needs to meet the needs of different installation forms and working environments.

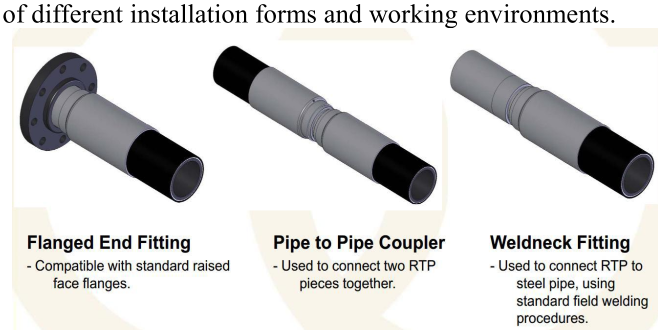

Fig. 7 Metal continuous composite pipe connection mode

Secondly, the processing length of continuous composite pipes is generally between 800 meters and 1500 meters, which means that relatively long pipes can be processed in a short time, reducing the number of connection points. At the same time, the continuous composite pipe adopts different connection forms between different sections, which can greatly reduce the solder joints during the installation of manganese steel pipes and reduce the risk of solder joints being corroded. Such advantages can not only improve the service life of pipelines, but also reduce maintenance and replacement costs.

3.5 nodule

In summary, continuous metal composite pipelines have great application prospects in transporting CO_2. First of all, the non-metallic composite pipeline has high corrosion resistance and pressure resistance, which can adapt to the severe working environment such as high pressure, high temperature and high salt content, and will not be corroded by transporting CO_2. Secondly, non-metallic composite pipes have good sealing and wear resistance, which can ensure the stable transportation of CO_2 and reduce leakage and loss. In addition, the continuous metal composite pipeline also has good flexibility and elasticity, which can effectively reduce the vibration and deformation of the pipeline during transportation and improve the service life of the pipeline.

In addition to the above advantages, non-metallic composite pipelines also have the characteristics of convenient installation and maintenance, light weight, and low cost, which can provide more reliable and economical solutions for CO_2 transportation. Therefore, in the future field of CO_2 transportation, non-metallic composite pipelines will be widely used to provide more reliable and efficient technical support for the production, transportation and application of CO_2.

4. CONCLUSION AND FORESIGHT

(1) Tanker hauling is a commonly used CO_2 transportation method at present, but it has problems such as high cost, high safety hazard and high uncertainty in the transportation process, which limit its development in large-scale application and promotion. Therefore, the future trend of CO_2 transportation will adopt more safe, reliable and efficient ways such as pipeline transportation to solve these problems.

(2) At present, there has been a supercritical CO_2 pipeline with manganese steel and internal and external anticorrosive materials in China, but there are still a series of problems such as high construction cost, easy corrosion, and difficulty in subsequent maintenance.

(3) A new type of continuous composite pipeline transportation CO_2 solution is proposed, which solves the problem that the inner and outer walls of the metal pipeline are easily corroded, reduces the production, installation and maintenance costs, reduces the solder joints of the metal pipeline, and reduces the risk of CO_2 leakage.

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