The application of risk-based inspection on the management of coal chemical device pressure equipment management

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Abstract. China has the world's largest coal chemical industry and is the country with the most coal chemical devices and equipment. Through years of experience in equipment management, risk-based inspection is applied to the management of coal chemical equipment to form a set of C-RBI technology, which has achieved good results. This article takes the core gasification device of the coal chemical industry as an example. First, the corrosion flow is analyzed through the damage mode recognition. The main damage mechanism of the key equipment of the device is judged, and then the risk analysis is carried out to determine the risk ranking of the equipment in the device. In accordance with the principle of the unification of economy and safety, online monitoring is implemented to reduce the operation risk of the device. Finally, the suggestions and suggestions of the use of maintenance strategies and consequences are given. Through the application of risk -based inspection in equipment management, the rational application of limited resources can be achieved, thereby reducing the risk of pressure equipment operation of coal chemical equipment, ensuring the lives and property of the personnel of the enterprise, improving the reputation of the enterprise, and maintaining social stability.

Keywords: coal chemical device, injury mechanism, risk-based inspection, online supervision testing, equipment management.

1 Introduction

As a country with insufficient oil and gas resources, my country has vigorously developed the coal chemical industry in recent years. It currently has the world's largest coal chemical industry and it is also the world's largest source of coal chemical technology in the world's largest coal chemical industry. There are fewer standards for the management of coal chemical equipment management at home and abroad. It has always been a large number of standards and specifications from the equipment management of the petrochemical industry. However, there are large differences between coal chemical industry and petrochemical industry in terms of raw materials, equip-

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ment, corrosion mechanisms, etc, resulting in many gaps in equipment management and the lack of systematic management methods[1].

Coal chemical plant equipment failure accidents have also occurred from time to time in recent years. Analysis of enterprise failure accidents can reveal that the main reason is imperfect management systems and failure to detect hidden dangers early, leading to accidents. Like petrochemical companies, the media in coal chemical companies' devices are also highly corrosive, toxic, flammable and explosive. At the same time there are many high-temperature and high-pressure equipment in the devices, which have led to great unsafe conditions in coal chemical plants, unstable factor. How to promptly discover and deal with these unsafe and unstable factors has become an urgent problem for coal chemical enterprises to solve[2-4].

Risk-based inspection technology has been widely used in refining, chemical and other industries. Risk-based inspection (RBI) technology is a systematic and dynamic technology. On the one hand, it is necessary to fully evaluate the service history, inspection and maintenance history of the equipment, and determine the inspection cycle based on the current equipment damage level and risk status. It is also necessary to reasonably adjust the inspection depth and resource use to ensure that more attention is paid to high-risk equipment. There are corresponding measures for low-risk equipment to allow owners to focus more on high-risk equipment, reducing costs while improving equipment safety and reliability[5].Introduce risk assessment technology into equipment management, consider the production importance, maintainability and other factors of the equipment, and combine with online detection technology to propose equipment management and maintenance plans. We upgraded this technology and combined it with the characteristics of coal chemical equipment to form a set of risk-based inspection and management technology (C-RBI) exclusive to coal chemical industry, we applied it and achieved good results[6].

This article takes the core unit of coal chemical industry and coal gasification unit as an example to introduce C-RBI technology. The coal gasification unit of a petrochemical company was completed and put into operation in July 2008.The process technology route of the gasification unit adopts the coal water slurry pressurization technology of the American GE Company, including coke grinding pulping, coal water slurry gasification, water gas washing and black water flash evaporation, gasification furnace slag removal system, black water filtration system etc, several main process units. The coal-water slurry gasification process uses petroleum coke and coal as gasification raw materials. Under the gasification conditions of pressure 6.5Mpa and temperature 1350~1450°C, crude coal gas is produced. And preliminary slag removal and dehydration are performed and sent to purification device. The processing raw materials of the device are mainly coal and petroleum coke[7].C-RBI technology first analyzes the corrosion flow through damage mechanism identification. Determine the main damage mechanism of each key equipment of the device, and conduct risk analysis to determine the risk ranking of the equipment in the device. Then based on the damage mechanism and risk results, and in accordance with the principle of unifying economy and safety, implement online monitoring to reduce device operation risks. Finally, suggestions for the use of maintenance strategies and consequence mitigation measures are given. After this technology was first applied to this device, it has been running smoothly and safely for 12 years and has achieved very good results[8-9].

2 Damage mechanism analysis

Through a comprehensive analysis of the production process flow, coal quality indicators, medium corrosivity, equipment structure and materials of the coal gasification unit. It was determined that the main potential failure mechanisms in the coal gasification unit are: internal corrosion thinning (including uniform corrosion thinning and local corrosion thinning), environmental cracking, external corrosion, high temperature hydrogen damage etc. The failure modes and failure mechanisms of each unit are detailed in Table 1.

Table 1. Main potential failure mechanisms of gasification equipment

unit	failure mode	damage mechanism
Grinding and pulping unit	Internal corrosion thinning	Solid-liquid phase erosion and corrosion
	environmental cracking	Alkali embrittlement
Coal water slurry gasification unit	Internal corrosion thinning	Solid-liquid phase erosion and corrosion
		High temperature sulfur corrosion
		High temperature H_2S/H_2 corrosion
		Acid water corrosion
	environmental cracking	Stress corrosion cracking caused by chloride ions
		Wet hydrogen sulfide damage
		Stress corrosion cracking caused by polythionate
Slag water treatment unit	Internal corrosion thinning	Solid-liquid phase erosion and corrosion
		Acid water corrosion
	environmental cracking	Stress corrosion cracking caused by chloride ions
		Wet hydrogen sulfide damage
Water gas scrubber and black water flash evaporation unit	Internal corrosion thinning	Solid-liquid phase erosion and corrosion
		Acid water corrosion
	stress corrosion cracking	Stress corrosion cracking caused by chloride ions
		Wet hydrogen sulfide damage
black water filtration unit	Internal corrosion thinning	Solid-liquid phase erosion and corrosion
		Acid water corrosion
	environmental cracking	Wet hydrogen sulfide damage
Utility Unit	Internal corrosion thinning	General erosion and corrosion

Erosion corrosion of solid-liquid phase is the most common corrosion mechanism in coal gasification equipment, whether it is the coal-water slurry in the feed system or the coal slag generated after the gasification reaction. A solid-liquid mixed phase will be formed during the flow process, cause erosion and corrosion to the equipment and pipelines of the installation. The main influencing factors can be divided into four aspects: fluid mechanics factors, material factors, solid phase particle factors in the two-phase fluid, and liquid phase factors. The four factors are intertwined and affect the erosion and corrosion performance of the material.

Scouring decay, also known as abrasion corrosion, is a metal damage phenomenon caused by high-speed relative motion between the metal surface and the corrosive fluid. It is the result of the interaction between erosion and corrosion of the material. It is a highly harmful local corrosion. Erosion and corrosion are mainly concentrated in the coal-water slurry feeding part. Slag water system, black water and gray water systems where there are solid-liquid two-phase pipelines and equipment. Erosion corrosion is often caused by local thinning, and generally exists in places where the flow velocity and flow direction change suddenly, such as elbows, tees, and large and small heads. What is manifested is the layer-by-layer peeling off of the equipment's metal due to dielectric erosion.

3 Risk Analysis

Equipment risks come from two aspects: On the one hand, there is the possibility of failure of the evaluation unit. On the other hand, they are the consequences of failure of the evaluation unit. The risk calculation formula is as follows.

$$R(t) = P_f(t) \cdot C(t) \tag{1}$$

Among them, $R(t)$ is the risk; $P_f(t)$ is the possibility of failure; $C(t)$ is the consequence of failure.

The possibility of failure mainly considers the possible damage mechanism, damage sensitivity, rate and other parameters of the pipeline, and determines the possibility level based on the frequency of hazardous events. See Table 2 for the detailed classification of failure possibility grades.

Table 2. Possibility level classification table

Possibility level	Failure probability F
1	0.000 00<F≤0.000 01
2	0.000 01<F≤0.000 10
3	0.000 10<F≤0.001 00
4	0.001 00<F≤0.010 00
5	0.010 00<F≤1.000 00

In terms of failure consequences, the characteristics of the medium in the equipment and pipelines, as well as parameters such as release volume and release rate, are mainly considered. The casualty area caused by pipeline failure and damage and the fatal area caused by toxic media leakage are used as measurement indicators to determine the consequences. See Table 3 for the detailed classification of security risk consequences.

Table 3. Classification of security risk consequences

consequence level	Final consequence area (CA) range/m^2
A	CA≤9
B	9＜CA≤93
C	93＜CA≤279
D	279＜CA≤929
E	CA＞929

In order to intuitively display the risk level of the entire device, a risk matrix is drawn with the failure consequence level (A~E) as the horizontal axis and the failure possibility level (1~5) as the vertical axis. When equipment units are plotted into a risk matrix, higher risk equipment or pipeline units tend to be distributed in the upper right corner of the matrix. Through the colors of different areas of the risk matrix, the risk level of the equipment (i.e. high risk, medium-high risk, medium risk and low risk) is obtained. The current risk matrix of the coal gasification unit is shown in Figure.1.

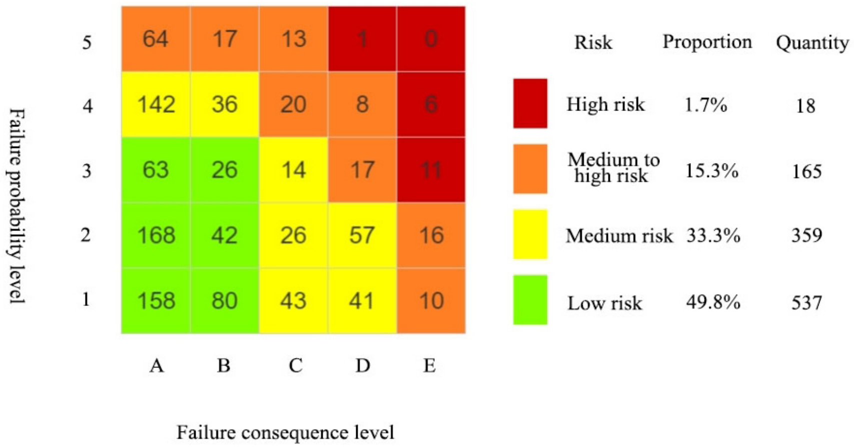

Fig. 1. Current risk matrix diagram

In the coal gasification unit, the gasifier, scrubber and high-pressure flash tank are the key equipment of the coal gasification unit. Therefore, it is necessary to conduct a detailed analysis and description of the risk levels of these equipment to provide reasonable risk reduction suggestions guide.

The safety risk of the rising cylinder of the gasifier is at high risk, the safety risk of the combustion chamber and descending cylinder of the gasifier is in the medium-high risk segment, the safety risk of the quench chamber and the lower small cylinder of the gasifier is at low risk. The safety risk of the scrubber and The safety risk levels of each part of the high-pressure flash tank are medium and low risks.

The temperature inside the gasification furnace can reach 1400°C, and the requirements for internal components are relatively high, the wall thickness of the ascending cylinder and the descending cylinder are both 6mm, and the materials are 316L and Incoloy825 respectively. Most of the media inside the ascending cylinder are hydrogen and carbon monoxide Mixture. Most of the medium inside the descending cylinder is slag water. High-temperature H_2S/H_2 corrosion will occur inside both components, and the material used in the drop barrel. Incoloy 825 is a general engineering alloy that is resistant to acid and alkali metal corrosion in both oxidizing and reducing environments. The high nickel content gives the alloy effective resistance to stress corrosion cracking. It has good corrosion resistance in various media, such as sulfuric acid, phosphoric acid, nitric acid and organic acids, alkali metals such as sodium hydroxide, potassium hydroxide and hydrochloric acid solution. Compared with the descending cylinder, the ascending cylinder is more thinned due to high-temperature H_2S/H_2 corrosion, so the possibility of thinning failure of the ascending cylinder is greater than that of the descending cylinder.

The inner walls of the quench chamber and combustion chamber of the gasifier are lined. The inner wall of the combustion chamber has an insulating and wear-resistant lining. The inner wall of the quench chamber is lined with 316L stainless steel composite plate, so the possibility of thinning of their inner walls is low. The medium inside the chamber is mainly slag water, so the safety consequences are low. The medium inside the combustion chamber is mainly flammable and explosive hydrogen and carbon monoxide, so the safety consequences are E.

The top medium of the scrubber and the high-pressure flash tank is gaseous. The top medium of the scrubber tower is synthesis gas, which is flammable and explosive. The top medium of the high-pressure flash tank contains gaseous hydrogen sulfide, toxic and harmful. Therefore, the safety consequences of the scrubber and the top of the high-pressure flash tank are higher, D and C respectively. The medium in the middle or bottom of the two types of equipment is mainly water, so the safety consequences are low, rated A. Both the scrubber tower and the high-pressure flash tank are lined with stainless steel composite plates, so the possibility of thinning and failure of the inner wall is very low, both are 1. Generally speaking, the safety risk level of scrubbers and high-pressure flash tanks is not high.

4 Online monitoring and testing

The risk analysis determines the overall risk level of the coal gasification unit and the risk ranking of the equipment. According to the risk ranking, especially considering the damage mechanism and failure possibility, and combined with the enterprise's economic budget, the medium corrosion monitoring, wall thickness monitoring, corrosion hanging Film and material adaptability evaluation and other measures.

4.1 Media corrosion monitoring

Before the coal-water slurry is gasified, there is no effective monitoring point to obtain the content of sulfur, chlorine and other harmful elements in the coal. Therefore, during the process after gasification, medium monitoring should be done to ensure that there is a possibility of thinning a monitoring point is set in each corrosion loop of pipelines larger than 4.In this way, we can better understand the content of harmful substances in the pipeline medium, reasonably arrange the frequency of online inspection of pipelines, and ensure the safe use of these pipelines. If the content of harmful substances in the medium increases sharply, online thickness measurement should be arranged immediately to grasp the remaining thickness of the pipeline or equipment to avoid sudden leakage and shutdown.Main monitoring points: high-pressure quench water pipeline, C1401 top outlet syngas pipeline, high-pressure flash tank inlet and outlet pipelines, and vacuum flash tank inlet and outlet pipelines. The types of harmful media monitored include: Cl-, H2S, NH3, CN-, CO32-, HCO3-, etc., as well as the PH value in liquid media.

4.2 Arrangement of on-site corrosion thickness measurement points

To achieve good corrosion control, the most important thing is to reasonably arrange on-site corrosion thickness measurement points throughout the device and monitor the corrosion status of the entire device. The corrosion monitoring points in the current installation are arranged at:(1) P1102 inlet and outlet coal-water slurry line, P1201 outlet coal-water slurry line(2) F1201 to V1203 black water line, C1401 bottom to V1403 black water line, V1403 bottom to V1405 black water line, V1405 bottom to V1406 black water line, V1406 to V1408 black water line, P1404 entrance and exit black water line. These monitoring points are monitored at locations where leaks have occurred. Now it is necessary to correct this point distribution range based on the RBI calculation results. First of all, according to the RBI calculation results, pipes with a thinning probability greater than 3 are widely distributed throughout the entire device, including 27 pipes in the coke pulping unit. 52 pipes in the coal-water slurry gasification unit, and 71 pipes in the water-gas washing unit. There are 30 slag water treatment units and 3 black water filtration units. These are the pipes that may have thinning leaks that need to be focused on.Therefore, based on the materials, operating conditions, media and other factors of these pipelines, select the elbows, tees, large and small heads of some pipelines where the flow rate and flow direction change, as well as the high-temperature parts of the container pipeline, the parts prone to liquid accumulation, and about 1 meter before and after the injection point. locations and conduct corrosion monitoring points.

4.3 Material selection adaptability evaluation and corrosion coupons

Corrosion coupons can also be hung on the upper and lower parts of the scrubber, high-pressure flash tank, and vacuum flash tank to explore the corrosion mechanism. The hanging piece can be made of different materials to provide some practical guidance for the material selection of the coal gasification device. Based on the expert experience of the China Special Inspection Institute, corresponding material selection adaptability evaluation tables are made for coal gasification equipment current risk assessment units with medium to high risk and high risk, as well as assessment units with various failure possibilities greater than 3[10].

5 Long-term equipment management and data return

After completing the risk assessment and online monitoring, based on the implementation effects of the above measures, the key tasks of follow-up long-term maintenance and consequence mitigation were determined, and the requirement of returning follow-up monitoring, inspection, maintenance, and repair data and re-conducting C-RBI every four years was proposed[11].

5.1 Use a maintenance strategy

During the operation of the coal gasification unit, frequent changes in the source of raw coal should be avoided as much as possible. Once the coal source changes, changes in sulfur content and acid value of crude syngas, black water, slag water, and gray water should be closely monitored. According to the changes in the value of the monitoring medium, on-site corrosion monitoring and thickness measurement work is carried out.

The operating process temperature should be maintained to avoid medium temperature and pressure fluctuations. In addition, parts with higher corrosion rates in the risk assessment results can be considered to be replaced with higher-grade materials[12].

5.2 Consequence Mitigation Measures

For the operation and maintenance of coal gasification, it is recommended to add the following preventive measures to reduce the consequences of its failure:

(1)First aid measures: In case of skin contact, contaminated clothing should be taken off immediately, rinsed with plenty of running water for at least 15 minutes, and seek medical treatment. In case of eye contact, immediately lift the eyelids and rinse thoroughly with plenty of running water or saline for at least 15 minutes, and seek medical advice. Once inhaled, you should quickly leave the scene and go to fresh air to keep the respiratory tract open. If breathing is difficult, give oxygen. If breathing stops, perform artificial respiration immediately. When breathing and heartbeat stop, artificial respiration and chest compressions are performed immediately.

(2)Firefighting measures: Cut off the air source when extinguishing the fire. If the gas source cannot be cut off, it is not allowed to extinguish the flame at the leakage point. Cool the container with water spray and if possible move the container from the fire area to an open area. Fire extinguishing media: mist water, solvent-resistant foam, dry powder, carbon dioxide.

(3)For parts with high operating temperature, high operating pressure, and the medium is mainly flammable and explosive substances, it is recommended to install a remote monitoring system and emergency cut-off device, while reducing the activity time and frequency of on-site personnel during operation to avoid medium leakage May cause fire, explosion and casualties.

(4)Emergency response to leakage: Quickly evacuate personnel in the leakage contaminated area to a windward location, immediately isolate the area by more than 150m, strictly restrict access and cut off the source of fire. It is recommended that emergency responders wear self-contained positive pressure respirators and anti-static overalls. Cut off the source of the leak as much as possible, and cover sewers and other places near the leak point with industrial covering or adsorbent/absorbent to prevent gas from entering. Proper ventilation to accelerate diffusion, spray water to dilute and dissolve. Build dikes or dig pits to contain large amounts of wastewater. Leaking containers must be properly disposed of and inspected by relevant departments before use.

(5)Handling and storage: closed operation, local exhaust. Operators must undergo special training and strictly abide by operating procedures. It is recommended that operators should at least wear self-priming filter gas masks (full face masks), wear anti-static overalls, wear rubber gloves, and be equipped with corresponding types and quantities of fire-fighting equipment and leakage emergency treatment equipment. Items should be stored in a cool, ventilated warehouse. The temperature should not exceed 30°C. Direct contact with or mixing with the following substances is prohibited: strong acids, strong bases, strong oxidants, heat, ferric chloride, aluminum chloride, iron and alkali metals.

6 Discussion

According to the actual service conditions of each device, especially for early service devices, through targeted C-RBI implementation, various risks of the whole life process of the equipment can be predicted early, combined with various risk control measures, and effectively improve the management level of the equipment. Reduce enterprise equipment operation risks.

1.According to the specific corrosion status of coal chemical equipment, a dynamic corrosion database of main equipment, pipeline and main corrosion data information of coal chemical equipment can be created based on C-RBI to facilitate the management, tracking and centralized analysis of daily corrosion data, daily monitoring and testing data and regular inspection data of the device, so as to realize the effective utilization of daily management data.

2.Combine C-RBI technology with reliability-centered maintenance (RCM), instrument interlocking control system (SIL), etc., to carry out the integrity management of coal chemical equipment and better ensure the intrinsic safety of equipment.

7 Conclusions

C-RBI technology is used for equipment management in core coal chemical equipment and coal gasification equipment. First, the corrosion flow is analyzed through damage mechanism identification. Determine the main damage mechanism of each key equipment of the unit, and conduct a risk analysis to determine the overall risk level of the coal gasification unit and the risk ranking of the equipment. According to the risk ranking, especially considering the damage mechanism and failure possibility, combined with the enterprise's economic budget , and determined measures such as medium corrosion monitoring, wall thickness monitoring, corrosion coupons, and material adaptability evaluation. After the completion of risk assessment and online monitoring, according to the implementation effect of the above measures, the key work of follow-up long-term use maintenance and consequences mitigation is determined, and the requirements of regression of follow-up monitoring, inspection, maintenance and repair data are put forward and C-RBI is re-conducted every four years. After this technology was first applied in this device, it has been running smoothly and safely for 12 years and has achieved good results. Effectively protect the lives and property of the company's personnel, enhance the company's reputation, and maintain social stability. However, this technology still needs corresponding research and improvement in terms of improvement of key equipment monitoring technology methods, equipment integrity, and informatization.

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