Analysis and Research on the Safe Operating Environment of Smelting Equipment

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Abstract: As one of the high-risk industries, the smelting industry involves many operational and operational risks. Smelting equipment carries the main safety risks, and its safe operation is crucial. The operating environment of smelting equipment is relatively complex and harsh, and the probability of accidents and failures caused by equipment reasons is high, resulting in significant economic losses and personnel casualties. Therefore, the safe operation of smelting equipment is of great significance for improving operational efficiency, ensuring the health of workers, protecting the environment, and enhancing the competitiveness of enterprises. This article analyzes the safe operating environment of smelting equipment, explores the main environmental characteristics and potential risks such as high temperature, high pressure, toxic and harmful gases, and dust pollution. Based on the operational risks of smelting equipment, safety measures for the current operating environment are evaluated, and corresponding application strategies and improvement measures are proposed. Through practical application analysis, the application effect of these strategies in actual production is demonstrated. As a fundamental condition for equipment operation, a safe operating environment is effectively managed and controlled through a management system that includes risk analysis and assessment, investigation and treatment, emergency prevention, and continuous improvement. This reduces the operational risks of smelting equipment and enhances its safe operating efficiency.

Keywords: Smelting Equipment Risks; Environmental; Safety; Hazards

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1 Introduction

The safe operation of smelting equipment plays a core role in production and operation, and its operating environment is extremely harsh. The equipment operating environment is an important factor affecting equipment performance and safety, and there is complexity and uncertainty. Effective safety management not only involves equipment design and maintenance, but also includes various factors such as operation, maintenance, environmental monitoring, emergency prevention, and emergency response. Therefore, it is of great practical significance to conduct in-depth analysis of the composition and impact mechanism of the equipment's safe operating environment, explore effective optimization solutions, and apply them in actual production. [8]

2 Research Background and Purpose

In response to the diversity, interactivity, and potential threats to the safe operation of smelting equipment, higher requirements are put forward for the safe operation environment of smelting equipment. The research aims to analyze and optimize the safe operating environment of smelting equipment, providing theoretical support and practical guidance for improving the safe operation capability of smelting equipment.

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3 Research Method

3.1 Research on the Smelting Industry

Smelting enterprises produce metal alloys or roasted products through a series of processes, including material grinding, drying, roasting, smelting, re crushing, and exhaust gas recovery. Metal products are widely used in fields such as steelmaking, aviation, and electronics, and are of great significance to industrial development and people's livelihoods. The smelting industry can be divided into black metal smelting, non-ferrous metal smelting, precious metal smelting, etc., including the smelting and processing of metals such as gold, silver, copper, iron, manganese, aluminum, zinc, etc. Through on-site inspection of the operating environment of the equipment, the main smelting equipment includes blast furnaces, converters, electric furnaces, vacuum furnaces, heating furnaces, quenching furnaces, tempering furnaces, isothermal quenching furnaces, internal heating rotary kilns, roasting furnaces, smelting furnaces, continuous casting machines, etc. Auxiliary equipment includes electrolysis equipment, high-pressure kettles, filter machines, centrifugal separators, fans, scraper conveyors, bucket elevators, belt conveyors, pumps, lifting machinery, dust collectors, air compressors, wet acid production, dry acid production, heat treatment equipment, etc. Site environmental indicators: annual average temperature, annual average relative humidity, annual average rainfall, annual average wind speed, maximum snow depth, annual average wind speed. Equipment operating environment: temperature range, compressed air pressure, use of flammable and explosive gases, production process with toxic and harmful gas content, high temperature and high pressure, low temperature and low pressure substances, etc. The operation rate of enterprise smelting equipment, the occurrence rate of accidents and failures, and the statistics of equipment maintenance costs, output, energy consumption, leakage points, etc. [9]

Taking molybdenum metal smelting and processing enterprises as an example, the smelting equipment includes roasting furnaces, rotary kilns, molybdenum iron smelting furnaces, heating furnaces, high-temperature fans, electrostatic precipitators, bucket elevators, scraper conveyors, electric heating equipment, acid making equipment, etc. The operating environment of the equipment is: temperature ≤ 2000 ℃, compressed air pressure ≤ 4MPa, natural gas and electric furnace heating are used for production, and sulfur dioxide, steam, and high-temperature gas are associated with the production process. Equipment operation rate: 93% for smelting equipment, 89% for chemical equipment, and statistics on equipment maintenance costs, output, energy consumption, leakage points, and other data.

3.2 Risk Assessment

Using a combination of qualitative and quantitative methods, analyze the characteristics and risks of the operating environment of smelting equipment.

3.2.1 Risk Analysis

(i) High Temperature Environment

The rotary kiln in the smelting process can reach up to 600 ℃, the multi chamber furnace can reach up to 700 ℃, and the smelting furnace barrel can reach up to 2000 ℃. The equipment has high requirements for high temperature resistance. High temperature environment may lead to material aging, structural deformation, cracking, control failure, etc. To cope with high temperature environments, it is necessary to use high-temperature resistant materials or equip with effective air or water cooling systems.

Equipment material aging: Long term operation of equipment in high temperature environments can lead to a decrease in the mechanical properties of equipment materials, increasing the risk of equipment accidents/failures.

Insufficient heat dissipation: An incomplete heat dissipation system may cause overheating of equipment or auxiliary facilities, increasing the risk of fire/explosion.

(ii) High Pressure Environment

The rotary kiln in the smelting process can reach up to 600 ℃, the roasting furnace can reach up to 700 ℃, and the smelting furnace barrel can reach up to 2000 ℃. The equipment has high requirements for high temperature resistance. High temperature environment may lead to material aging, structural deformation, cracking, control failure, etc. To cope with high temperature environments, it is necessary to use high-temperature resistant materials or equip with effective air or water cooling systems. [14]

(iii) Toxic and Harmful Substances

The smelting production process is accompanied by various toxic and harmful substances, such as sulfur di-

oxide, carbon monoxide, methane, acidic and alkaline substances, heavy metals, etc., which pose a threat to human health and the environment.

Health impact: The leakage of harmful substances can have a significant impact on the physical and mental health of workers.

Environmental pollution: The emission of harmful substances can lead to a decrease in air quality and damage the surrounding ecological environment.

(iv) Dust

The material dust generated during the smelting process poses a threat to the normal operation of equipment and the health of workers. Dust pollution may cause equipment damage and personal health problems. [3]

Equipment damage: Dust may accelerate the wear of mechanical components, cause electrical circuit short circuits, and lead to control system failure.

Health issues: Long term exposure to dusty environments may lead to respiratory diseases such as silicosis.

(v) Noise/Vibration

Smelting equipment will generate noise or vibration during operation, which will have a certain impact on the equipment, personnel, and environment.

Equipment damage: Vibration can cause loosening of equipment bolts, poor contact, and cracking of the casing. It may cause certain devices to malfunction or be in an abnormal operating state.

Personnel hazards: Excessive noise can cause occupational diseases, such as noise induced hearing loss.

Environmental hazards: Causing harm to the surrounding ecology within a certain range, which may affect environmental monitoring data.

(vi) Static Electricity

In the production process of the smelting industry, static electricity can be generated through friction, impact, falling, oscillating, filtering, and other methods. The accumulation of static electricity may cause equipment failure, affecting the normal operation and service life of the equipment.

Equipment damage: causing fires and explosions, damaging electronic components, affecting instrument accuracy, and leading to misoperation.

Environmental hazards: In places involving flammable and explosive substances, it can cause fires, explosions, and even secondary disasters.

3.2.2 Safety Measures Taken

(i) Regularly Inspect and Maintain Equipment According to Maintenance Standards

Measures: Regularly conduct comprehensive inspections and maintenance of smelting equipment, including temperature, pressure, gas and dust leakage point detection. The use of high-precision detection equipment can improve emergency response speed. [10]

Application example: A temperature monitoring system and automatic alarm control device are installed on the production site, which can issue timely warnings when equipment abnormalities are detected and automatically start the cooling system, effectively preventing equipment overheating.

(ii) Education and Training

Measures: Develop corresponding operating procedures and emergency plans, regularly train and organize drills for operators to enhance their operational skills and ability to respond to emergencies.

Application example: Conduct professional education and training as well as emergency drills to effectively reduce operational errors and failure rates.

(iii) Environmental Monitoring and Control

Measures: Advanced gas detectors, temperature sensors, pressure detectors, etc. should be used for monitoring to monitor the concentration of harmful gases and dust in the production process in real time, and adjust the process control system in a timely manner. [12]

Application example: Configure efficient dust collection systems and harmful gas recovery and treatment devices to reduce harmful gas emissions, protect personnel's health and the surrounding environment. [11]

(iv) Automated Control System

Measures: Adopt automated control systems instead of traditional monitoring, improve the safety, reliability, and stability of equipment operation systems through real-time data monitoring and fault prediction.

Application example: Using an artificial intelligence based fault prediction system, it can provide early warning before equipment failure occurs, reducing downtime and maintenance costs. [2]

4 Improvement Strategy

4.1 Conserve Energy, Reduce Emissions

Under the premise of ensuring normal production and operation, adopt technical and management measures to minimize energy consumption and environmental pollutant emissions to the greatest extent possible. By optimizing the energy consumption structure, strengthening energy-saving management, promoting new clean energy and other measures, energy consumption can be reduced. Developing advanced smelting technology, using internal heating rotary kilns instead of reverberatory furnaces to save energy and increase production capacity, and using smelting equipment such as blast furnaces and electric arc furnaces to improve the efficiency and purity of steel smelting. Strengthen the concept of energy conservation and emission reduction, fundamentally reduce the generation of harmful substances, and provide guarantees for the safe operation of smelting equipment.

4.2 Using High-quality Materials Suitable for the Operating Environment of the Equipment

In response to the special environment of smelting equipment, new high-temperature and high-pressure resistant materials are adopted to improve the safety performance and service life of the equipment. The filter bag of the high-temperature bag filter adopts pure ultra-fine fiber filter bag, the smelting furnace barrel can use aviation aluminum material for high temperature resistance, the plate heat exchanger adopts Ha type alloy to improve the equipment's acid resistance, and high-pressure alloy material is selected for high pressure resistance. [1]

4.3 Configure Advanced Recycling and Disposal Devices

Adopting cyclone dust removal, bag dust removal, electrostatic precipitator, and water film dust collector to recover dust materials, using domestic sewage treatment equipment, industrial sewage treatment equipment, etc. to treat wastewater, and using organic amine equipment to recover sulfur dioxide gas. Improve the level of pollutant control technology, optimize recycling and treatment systems, and reduce the impact on the environment. [5, 6]

4.4 'Leak Free' Factory Management

The 'leak free' factory has comprehensively improved its on-site management level, ensuring the safe, stable, and economical operation of equipment, maximizing the efficiency of existing equipment, promoting energy conservation and emission reduction, enhancing economic benefits, and supporting the high-quality development of enterprises. Implement scientific management and maintenance of sealing points, prevent production processes and equipment from leaking, and strictly prohibit unorganized discharge of solid, liquid, and gas to achieve zero leakage on the production site. Adopting a non sealed combination inspection door, the upper and lower doors have large curved surfaces in contact, without the need for sealing gaskets. The sealing effect is good, easy to clean, and easy to maintain. It is suitable for complex environments such as high temperature and cold, and can effectively solve problems such as dust leakage caused by loose sealing and inconvenient operation caused by complex or reasonable control mechanism design. [17]

4.5 Adopting Automated Monitoring and Early Warning

Classify and grade smelting equipment, determine key monitoring points for key equipment, consider the characteristics of equipment operating environment, such as corrosiveness, temperature differences, pressure changes, dust, noise, vibration, radioactivity, etc., equip with pH meters, temperature recorders, pressure transmitters, dust detectors, noise automatic monitoring instruments, vibration status monitoring instruments, radioactivity detectors and other equipment for monitoring, integrate multiple monitoring modules, comprehensively monitor the operating environment of smelting equipment, analyze and process monitoring data, establish warning models, and output real-time warnings and emergency responses. [15]

4.6 Using Intelligent Technology to Analyze and Predict

Further integrate and apply advanced technologies such as artificial intelligence, the Internet of Things, and big data analysis, optimize and improve the equipment operating environment based on data-driven management systems, strengthen equipment operation data analysis and

fault prediction, achieve more efficient, secure, and fast management and work modes, and improve the intelligence level of equipment safe operation. [7, 13]

4.7 Accident and Fault Management

Summarize and analyze the types of accidents that have occurred within our enterprise and the smelting industry, analyze the causes of accidents, summarize lessons learned, form a management concept that focuses on prevention, rapid response, and reasonable handling, improve the management requirements for the safe operation environment of smelting equipment, strengthen the management of accident failure reports, regular troubleshooting and maintenance, publicity and education, analysis and summary, clarify personnel responsibilities, and strengthen the ability to actively participate in emergency response to accidents and failures. [16]

4.8 Establish a Sound Safety Production Standardization System

Establish a sound safety production standardization within the enterprise, adopt a dual prevention system of risk grading control and hidden danger investigation and governance, regularly conduct safety training and risk assessment, form a new safety management model that is full of staff, comprehensive, and whole process, strengthen performance management and continuous improvement, form standards in technology, management, process, equipment operation, etc., and build a standardized safety production system for the enterprise. Guide the safety attitude and behavior of the operators, establish the enterprise's safety values, and effectively improve the level of enterprise safety production. [4, 19]

4.8.1 Equipment Classification Maintenance

Develop three-level inspection standards for equipment (workshop level, team level, position level), equipment maintenance technical standards, maintenance operation standards, and equipment maintenance standards. Regularly organize professional technical personnel to inspect the operation status of smelting equipment, record the equipment operation status in real time, timely eliminate equipment operation faults, maintain equipment according to operation standards, and effectively eliminate hidden dangers and risks in smelting equipment operation through hierarchical standard management.

4.8.2 Safety Protection

Install protective facilities at key parts of the equipment, such as interlocking devices, photoelectric sensing devices, anti reverse devices, protective covers, guardrails, etc., to prevent operators from coming into contact with or approaching hazardous areas. Through the monitoring system, real-time monitoring of the operation status of smelting equipment can be achieved, and any abnormal situations in equipment operation can be detected in a timely manner. Equip fire extinguishers, fire embankments, firewalls, and other fire prevention facilities to ensure proper protection against equipment fires. [18]

4.8.3 Personal Protection

Provide personal labor safety protection equipment for workers, such as acid and alkali protective clothing, protective goggles, anti-static clothing, etc. Regularly conduct health checks on employees, especially those engaged in toxic and harmful operations, to ensure their physical health.

4.8.4 Emergency Management

Enterprises should develop emergency response plans based on their own situation, including response measures for sudden events such as poisoning, suffocation, electric shock, fire, collapse, and explosion. Equip necessary emergency supplies, such as emergency power supply, first aid kit, fire extinguisher, lifeline, oxygen cylinder, etc. Establish a sound emergency mechanism, set up a safety technical rescue team, and ensure that contingency plans can be quickly activated in case of emergencies.

5. Research Results

By implementing optimization strategies, the safe operation performance of the equipment has been significantly improved, specifically manifested in: 1. Equipment operation rate ≥ 96%; 2. Reduce maintenance costs by 30%; 3. Total energy consumption reduced by 7.1%; 4. The cumulative output of the main products has increased by 19.93%, effectively improving the working environment for workers, reducing occupational disease risks, shortening accident risk handling time, and enhancing the emergency response capability of the enterprise.

6 Summary

This article systematically analyzes the characteristics of the safe operating environment and risk features of smelting equipment, and proposes effective optimization strategies based on safety measures in practical applications. The feasibility of these strategies is demonstrated through practical application results. Strengthening the application of advanced technology in the management of the operating environment of smelting equipment, achieving more accurate and intelligent safety monitoring and early warning, can help improve the safety of smelting equipment operation and the level of environmental protection.

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