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Cement Kiln Co-processing: An Efficient way to Treat Industrial Hazardous Waste

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ABSTRACT
With the acceleration of industrialization, hazardous waste generation has surged dramatically, while traditional disposal methods face challenges such as capacity saturation and secondary pollution. Cement kiln co-processing technology, leveraging its advantages of thorough high-temperature decomposition and comprehensive resource utilization, has opened new pathways for industrial hazardous waste management. However, current applications of this technology still encounter issues including inconsistent technical standards, inadequate pretreatment capabilities, and insufficient environmental risk control. This paper systematically analyzes the significance and practical challenges of cement kiln co-processing in industrial hazardous waste treatment. Targeted strategies are proposed to improve technical specifications, enhance pretreatment levels, and strengthen regulatory frameworks. The aim is to promote standardized development of cement kiln co-processing technology and provide reference solutions for addressing industrial hazardous waste disposal challenges.

KEYWORDS
Cement kiln co-processing; Industrial hazardous waste; Pretreatment technology; Environmental risk management

1 Introduction

Industrial hazardous waste, characterized by high toxicity, significant environmental hazards, and complex disposal challenges, remains a critical challenge in environmental governance. China generates over 100 million tons of such waste annually. Traditional disposal methods like landfilling and incineration face limitations including land consumption and secondary pollution risks, making them inadequate for meeting growing demands. The cement kiln co-processing technology leverages the high-temperature and alkaline conditions of cement production to completely decompose toxic substances in hazardous waste. Simultaneously, it converts the waste's calorific value and mineral components into energy and raw materials for cement manufacturing, achieving the "turning waste into treasure" concept. While this technology has been widely adopted in developed European and American countries, China has been actively advancing its implementation in recent years. However, improvements are still needed in technical standards and risk management. In-depth exploration of optimized strategies for cement kiln co-processing of industrial hazardous waste holds significant practical value for enhancing China's waste disposal capabilities and promoting green transformation in the cement industry.

2 The Significance of Cement Kiln Co-processing of Industrial Hazardous Waste

2.1 Effective Means to Relieve the Pressure of Hazardous Waste Disposal

The pressure on industrial hazardous waste disposal has been growing, becoming a critical bottleneck hindering regional environmental quality improvement and green industrial development. With increasingly stringent environmental regulations and heightened corporate environmental awareness, hazardous waste declarations have been rising annually. However, traditional disposal facilities face challenges such as lengthy construction cycles and complex approval processes, leading to severe capacity shortages. Many regions now grapple with massive hazardous waste stockpiles, leaving some enterprises in a situation where they have waste but nowhere to dispose of it. This not only increases environmental costs for businesses but also creates hidden ecological risks. The cement kiln co-processing technology leverages existing cement production lines without requiring new facilities, enabling rapid deployment of disposal capacity. With temperatures exceeding 1450° C in cement kilns—far surpassing the 1100° C required for hazardous waste incineration—this process completely degrades organic pollutants' molecular structures, achieving harmless treatment [1]. The 3-5 second residence time in cement kilns ensures thorough combustion and decomposition of hazardous waste, outperforming conventional incinerators. More importantly, China currently operates over 1,700 new dry-process cement production lines, which theoretically hold immense potential for co-disposal. Fully utilizing this capacity could significantly alleviate the shortage of hazardous waste disposal facilities, resolve industrial challenges, and safeguard regional environmental security.

2.2 Innovative Practices to Promote the Green Transformation of the Cement Industry

The cement industry, a traditional high-energy-consuming and high-emission sector, must drive green transformation through technological innovation amid tightening resource constraints and growing environmental pressures. Co-processing hazardous waste has opened new development pathways for cement enterprises, transforming their single production model into a "production + environmental services" integrated approach. During co-processing, combustible materials from hazardous waste replace part of coal consumption, significantly reducing fossil fuel usage. Each ton of hazardous waste processed saves 0.1-0.3 tons of standard coal equivalent, lowering costs while cutting carbon emissions. Metal oxides and silica-alumina components in hazardous waste can serve as auxiliary raw materials for cement production, minimizing natural mineral extraction and achieving cascaded resource utilization. More importantly, co-processing expands profit margins for cement companies, shifting from reliance on cement sales to diversified business models that enhance risk resilience. Guided by the "dual carbon" goals and green development principles, co-processing technology for cement kilns has become a crucial driver for industry transformation and high-quality development, injecting new vitality into traditional industries.

2.3 An Important way to Realize Resource Recycling

The circular economy is characterized by efficient resource utilization and waste recycling. The co-processing of hazardous waste in cement kilns exemplifies this model. Hazardous waste is not worthless "scraps" but contains valuable heat and material resources that require proper methods. This technology treats hazardous waste as "urban mines," maximizing resource recovery through precise pretreatment and blending. High-calorific hazardous waste like waste mineral oil and organic solvents can serve as alternative fuels for coal, with each ton of waste mineral oil providing 0.8 to 1 ton of standard coal equivalent. Silica, alumina, and iron-rich components in sludge and furnace slag can be used as raw materials or additives in cement production, conserving natural resources like limestone and clay while reducing final landfill solid waste [2]. Crucially, mineral crystals generated during clinker production become permanently fixed in cement products, completely preventing heavy metal migration into the environment and achieving true harmlessness. This comprehensive resource utilization model not only addresses environmental pollution from hazardous waste but also provides alternative resources for cement production, creating a triple-win scenario of environmental, economic, and social benefits. It represents a significant attempt to implement circular economy principles and build a resource-efficient society.

3 Problems Faced by Cement Kiln Co-processing of Industrial Hazardous Waste

3.1 The Technical Standard System is not yet Perfect

The co-processing technology for hazardous waste in cement kilns has seen late development in China, with technical standards and regulations lagging behind practical needs, resulting in a lack of unified industry guidance. Although national-level documents such as the Cement Kiln Co-processing Solid Waste Pollution Control Standard have been issued, there remain many operational gaps. The most prominent issue is the absence of scientific basis for hazardous waste blending ratios. Enterprises generally rely on empirical methods for material input, which can either cause excessive dosage affecting cement product quality or insufficient dosage wasting disposal capacity. Additionally, there are no detailed regulations on hazardous waste pretreatment processes, equipment configurations, or operating procedures, leading to inconsistent pretreatment standards across enterprises and compromising the safety and stability of co-processing [3]. While emission limits have been set for characteristic pollutants like dioxins and heavy metals, there are no targeted monitoring requirements for special pollutants generated during co-processing, making comprehensive environmental risk control unattainable. The lack of evaluation standards linking cement product quality with hazardous waste co-processing has raised public concerns about cement products from co-processing lines, resulting in low social acceptance of this technology. The absence or lag in technical standards hinders the development and standardization of cement kiln co-processing technology, complicates environmental supervision, and necessitates a comprehensive institutional framework to promote healthy industry development.

3.2 Insufficient Capacity for Hazardous Waste Pretreatment

Pre-treatment serves as a critical component in the co-processing of hazardous waste within cement kilns, playing a decisive role in ensuring both safety and treatment effectiveness. However, many cement enterprises currently face insufficient pre-treatment capacity, which has become a bottleneck constraining the full utilization of co-processing technologies. Some companies, in an effort to reduce costs, have installed basic crushing and mixing facilities while neglecting essential advanced treatment equipment such as sorting, dewatering, and homogenization systems. This results in unstable physicochemical properties of waste entering the kiln, compromising operational stability and product quality. The low technical proficiency in pre-treatment, particularly the lack of effective methods for handling complex

and specialized hazardous waste, poses significant challenges. Waste with high moisture content or heavy metal contamination, if introduced directly into the kiln without treatment, can lead to reduced temperatures, decreased combustion efficiency, formation of scale that blocks production, and environmental pollution from heavy metal emissions. Additionally, the low level of automation and intelligence in pre-treatment processes—relying heavily on manual operations and empirical judgment—fails to achieve precise material blending and accurate quality control. Insufficient pre-treatment capacity also manifests in a shortage of specialized technical personnel and management teams, with many operators lacking adequate understanding of hazardous waste characteristics. This results in non-compliant practices during storage, transportation, and feeding, creating safety hazards. If these weak links in pre-treatment capabilities remain unresolved, it will hinder the large-scale promotion and safe, stable operation of hazardous waste co-processing in cement kilns.

3.3 The Environmental Risk Prevention and Control Mechanism needs to be Strengthened

The co-processing of hazardous waste involves numerous toxic substances. Inadequate risk prevention measures could easily lead to environmental pollution incidents, endangering public health and ecological security. The primary issue with current environmental risk control mechanisms lies in an incomplete full-process management system. Risk identification remains insufficient across all stages including hazardous waste reception, storage, pretreatment, and discharge, while emergency response plans lack specificity. During waste reception, some enterprises fail to rigorously verify waste sources and strictly comply with hazardous waste identification and classification standards, allowing unidentified or unsuitable waste for co-processing to enter disposal systems, thereby increasing environmental risks. In storage phases, temporary hazardous waste storage facilities often fail to meet requirements, with inadequate anti-seepage, anti-leakage, and anti-volatility measures causing groundwater and soil contamination. During co-processing, online monitoring systems for pollutants like kiln tail gas and ash are either incomplete or malfunctioning, preventing real-time emission tracking. This results in delayed detection and response when emissions exceed standards. Monitoring frequency for characteristic pollutants such as dioxins remains insufficient to reflect complete emission patterns, coupled with a lack of emergency response measures. When sudden incidents like leaks, fires, or explosions occur, inadequate emergency handling capabilities may lead to accident escalation.

4 Strategies for Promoting the Coordinated Treatment of Industrial Hazardous Waste in Cement Kilns

4.1 Improve Technical Specifications and Establish Standardized Processing Procedures

Establishing a scientific and comprehensive technical standard system is the foundational project for achieving standardized development of co-processing hazardous waste in cement kilns. We must strengthen top-level design by formulating technical guidelines for co-processing based on existing standards, taking into account the physicochemical characteristics of different types of hazardous waste. These guidelines should specify technical parameters such as entry conditions and dosing methods for various waste types. For organic solvent waste, parameters like calorific value range, maximum moisture content, and dosing position must be defined. For heavy metal-containing waste, requirements for heavy metal types, content limits, and pretreatment procedures should be clearly specified. Standardized pretreatment protocols must be established, detailing process flows and operational procedures to ensure standardized practices in pretreatment [4]. These standards should encompass physical treatments (crushing, sorting, mixing), chemical treatments (neutralization, solidification), and biological treatments, while providing appropriate processing methods and process parameters tailored to waste characteristics. Pollutant emission monitoring standards should be improved by adding monitoring indicators for characteristic pollutants in co-processing, increasing monitoring frequency, and implementing strict monitoring for persistent pollutants like dioxins and heavy metals. Additionally, evaluation standards linking cement product quality with co-processing should be developed. Scientific testing should verify that cement products from co-processing lines meet quality standards, thereby addressing public concerns.

4.2 Improve the Level of Pretreatment and Ensure the Safety of Coordinated Disposal

Enhancing pretreatment capabilities is crucial for ensuring the safe and efficient operation of cement kiln co-processing of hazardous waste. Cement enterprises should prioritize pretreatment system construction as a key component of co-processing projects, investing in comprehensive equipment. Based on the types and characteristics of hazardous waste, complete pretreatment production lines should be established, including receiving and temporary storage systems, physical treatment systems (crushing, screening, mixing, homogenization), chemical treatment systems (neutralization, solidification, stabilization), and thermal treatment systems (drying, dehydration) to ensure waste meets kiln entry requirements after thorough processing. Technological innovation in pretreatment should be strengthened: developing specialized equipment for high-humidity, high-salinity, and high-viscosity hazardous waste; creating efficient dewatering devices to address high moisture content in sludge waste; researching low-temperature pyrolysis technology

for high-molecular organic waste; improving resource utilization rates; and applying plasma technology to decompose refractory organic pollutants, thereby reducing environmental risks [5]. Automation and intelligence should be enhanced through intelligent batching systems that automatically calculate optimal ratios based on real-time waste composition analysis, ensuring precise material input. Automatic control systems should monitor and regulate parameters like temperature, pressure, and flow rate during pretreatment stages to maintain stable operations. By leveraging big data and AI technologies, optimized pretreatment process models can be developed to continuously improve treatment effectiveness.

4.3 Strengthen the Supervision System and Establish a Whole-process Risk Control Mechanism

Establishing a comprehensive environmental risk management mechanism is crucial for ensuring the safe operation of cement kilns in hazardous waste co-processing. To strengthen the full-process supervision system, mechanisms should be established for monitoring hazardous waste generation, collection, transportation, co-disposal, and emission monitoring. Environmental authorities should collaborate with relevant departments to create an information management platform for hazardous waste co-disposal, achieving electronic transfer manifests, visualized disposal processes, and real-time pollutant emissions to form a closed-loop management system. Enterprises must install video surveillance and online monitoring equipment at critical stages including receiving, storage, pretreatment, and feeding, enabling regulatory authorities to access data at any time. Immediate alerts should be issued and addressed upon detecting issues. Enhanced emission monitoring requires cement enterprises to equip complete online monitoring facilities for particulate matter, sulfur dioxide, and carbon monoxide, while conducting periodic manual monitoring for characteristic pollutants like dioxins and heavy metals. All monitoring data must be uploaded to environmental authorities in real-time and disclosed to the public. Regulatory authorities should intensify enforcement inspections, strictly penalizing illegal acts such as exceeding emission standards or falsifying data to deter violations. Additionally, environmental risk emergency systems must be improved. Enterprises should develop detailed emergency plans for unexpected incidents during hazardous waste co-disposal, equip emergency supplies and equipment, and conduct regular drills to enhance emergency response capabilities.

5 Conclusion

The co-processing of industrial hazardous waste in cement kilns is an innovative approach to solving the problem of hazardous waste disposal, promoting the green transformation of the cement industry, and facilitating resource recycling. Facing practical challenges such as imperfect technical standards and insufficient environmental risk prevention, it is necessary for the government, enterprises, research institutions, and all sectors of society to build consensus and work together. By improving the technical specification system to provide standardized guidance for co-processing, enhancing the level of pretreatment to strengthen the technical defense line for safe disposal, and reinforcing the supervision of the entire process to establish a rigorous risk prevention network, we can promote the maturity of cement kiln co-processing technology and achieve the goals of harmless disposal and resource utilization of hazardous waste. Under the guidance of the new development philosophy, cement kiln co-processing technology will undoubtedly play a greater role in serving the construction of ecological civilization, assisting the realization of the "dual carbon" goals, and ensuring environmental safety, contributing wisdom and strength to building a beautiful China with bluer skies, greener mountains, and cleaner waters.

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