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Research on the Application of Blockchain Technology in Environmental Pollution Control of Chemical Enterprises

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Abstract: Addressing the challenges of environmental pollution control in chemical enterprises, this study provides a detailed analysis of the application of blockchain technology in this field based on the current status of blockchain technology and environmental pollution control practices in chemical enterprises. The analysis reveals that blockchain technology, with its decentralized, tamper-proof, and traceable characteristics, can effectively enhance the credibility of environmental monitoring data in chemical enterprises, enable precise tracking and responsibility identification of pollution sources, strengthen the supervision of environmental management funds, and promote effective compliance with environmental policies and regulations. Through this analysis, the article aims to provide new technical pathways and solutions for environmental pollution control in chemical enterprises, thereby supporting the green and sustainable development of the chemical industry.

Keywords: Blockchain technology; Chemical enterprises; Environmental pollution control; Application

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1. Introduction

The chemical industry, as a pivotal sector of the national economy, plays a crucial role in driving economic development and meeting diversified societal needs. However, the production processes in this industry are often accompanied by the emission of large amounts of pollutants, posing a heavy burden on the ecological environment. From sulfur dioxide and nitrogen oxides in waste gas to heavy metals and organic compounds in wastewater and hazardous waste in solid waste, the pollution problems of chemical enterprises have become significant factors restricting the sustainable development of the industry and affecting the quality of life of residents. Traditional means of environmental pollution control have gradually exposed limitations when faced with the complex and diverse pollution issues of chemical enterprises, such as data opacity, difficult supervision, and vague responsibility identification. Blockchain technology, as an emerging and disruptive information technology, has achieved remarkable application results in recent years in various fields such as finance, supply chain management, and healthcare. Its unique technical characteristics provide new ideas and possibilities for solving the difficult problems of environmental pollution control in chemical enterprises. The introduction of blockchain technology into the field of environmental pollution control in chemical enterprises is expected to build a more efficient, transparent, and credible governance system, enhance governance efficiency, and promote the transformation of the chemical industry toward a green, low-carbon, and sustainable direction [1]. Therefore, in-depth research on the application of blockchain technology in environmental pollution control in chemical enterprises has important practical significance and urgency.

2. Application status of blockchain and its technology

Since its inception, blockchain technology has continuously expanded its application scope and influence. In China, blockchain technology is showing vigorous development. According to the "Blockchain White Paper (2024)" released by the China Academy of Information and Communications Technology, as of the first half of 2024, the number of blockchain-related enterprises in China has exceeded 8,000, representing a 23% increase compared to the same period last year. In terms of industrial applications, blockchain has the most widespread and mature applications in the financial sector. For example, banks have simplified and improved the efficiency of payment processes by utilizing blockchain technology to build cross-border payment systems. With blockchain-based cross-border payment technology, transaction times can be reduced from the traditional 2–3 days to just a few hours, while transaction costs can be reduced by approximately 30%–40% [2]. In the field of supply chain management, numerous large enterprises have achieved full traceability of supply chain information through blockchain technology. By leveraging blockchain platforms to upload information such as raw material procurement, production processing, and product distribution in real-time, enterprises at various nodes of the supply chain can share authentic and transparent information, significantly improving inventory turnover rates and enhancing supply chain collaboration efficiency. Additionally, blockchain technology is continuously being applied in areas such as government services, healthcare, and copyright protection, injecting new momentum into the digital transformation and innovative development of various industries.

3. Current status of environmental pollution control in chemical enterprises

According to relevant data in 2024, chemical enterprises remain a significant source of environmental pollution that cannot be ignored. In terms of waste gas emissions, data from the Ministry of Ecology and Environment shows that the chemical industry accounts for a considerable proportion of the total industrial emissions of nitrogen oxides in China, and the proportion of sulfur dioxide emissions is also significant. These waste gas emissions not only pollute the atmospheric environment, causing environmental issues such as acid rain and photochemical smog, but also pose a serious threat to the respiratory and cardiovascular health of surrounding residents. As a result, crop yields in surrounding areas have decreased, with some regions experiencing a reduction of 15% to 20% [3].

From the perspective of wastewater, according to data from the China Environmental Statistical Yearbook 2024, the chemical industry accounts for 18% of the total industrial wastewater emissions in China. Chemical wastewater contains heavy metals such as mercury, cadmium, and lead, as well as organic compounds such as polycyclic aromatic hydrocarbons and phenols, which seriously pollute water bodies. For example, when the mercury content in wastewater from coastal chemical enterprises exceeds standards, it can lead to a sharp decrease in the number of fish in surrounding waters, causing rare fish species to be on the verge of extinction. Shellfish and other seafood become contaminated with heavy metals and are unsafe for consumption, which can have a significant impact on the local fishing industry and food safety for residents.

In terms of solid waste, relevant environmental protection reports indicate that the chemical industry generates 16% of the total industrial solid waste in China. When chemical enterprises indiscriminately pile up waste residues containing large amounts of toxic and hazardous substances, over time, the harmful substances in the waste residues can infiltrate into the ground, causing soil pollution to spread, fertility to decline, and crops to grow abnormally. Additionally, some harmful substances can be washed into surface water by rain, affecting the safety of water use for surrounding residents. Traditional governance methods, when facing these pollution problems, such as adsorption, combustion, and catalytic conversion technologies for waste gas treatment, physical, chemical, and biological treatment methods for wastewater treatment, or landfill, incineration, and resource utilization methods for solid waste disposal, all expose issues such as information opacity, difficulty in tracing pollution sources, high regulatory costs, and low treatment efficiency. These methods are inadequate to effectively address the complex and severe environmental pollution situation in chemical enterprises [4].

4. Application of blockchain technology in environmental pollution control in chemical enterprises

4.1. Transparency of environmental monitoring data

4.1.1. Data collection and uploading

In the process of building an environmental monitoring system, chemical enterprises can install various types of sensing devices at core production equipment, pollution control equipment, and sensitive areas around the plant boundaries. For example, gas sensors can be used to detect the concentration of waste gas emissions, and water quality sensors can analyze the composition of wastewater. These monitoring devices continuously acquire environmental parameters at a preset sampling frequency and transmit the collected information to blockchain network nodes via the Internet of Things architecture. The node end uses encryption algorithms to desensitize the raw data and then writes the verified data packets into an immutable distributed database based on a preset consensus protocol. This technical architecture significantly improves data acquisition efficiency and accuracy through automated collection and instant transmission mechanisms while effectively avoiding measurement deviations and the risk of information falsification present in traditional manual sampling. It is worth noting that the unique timestamp marking and chained storage characteristics of blockchain provide traceability and audit guarantees for environmental monitoring data [5–6].

4.1.2. Data sharing and supervision

Relying on the distributed ledger system of blockchain technology, a secure and transparent multi-entity sharing mechanism for environmental monitoring data is established among government regulatory authorities, third-party environmental organizations, responsible enterprises, and the public [7–8]. Through this architecture, environmental regulatory authorities can retrieve pollution emission parameters from responsible enterprises in real-time, enabling dynamic supervision of industrial environmental behaviors. Scientific research-based environmental institutions can access complete monitoring datasets to support the construction of environmental impact assessment models.

The public, through a permission-based hierarchical mechanism, can access corporate environmental information disclosure modules, significantly enhancing the transparency of visual supervision of industrial pollution sources. In typical cases, ecological and environmental departments can instantly obtain wastewater discharge datasets from specified chemical enterprises through the blockchain supervision platform, including key indicators such as instantaneous flow rate, chemical oxygen demand (COD), pH value, and heavy metal ion concentration. When detected values deviate from preset thresholds, the system automatically triggers alerts and initiates joint law enforcement procedures. Simultaneously, the public can access real-time environmental monitoring reports of enterprises by entering their unified social credit codes through mobile terminal applications or public data service platforms, quantitatively evaluating the potential impact of production activities on surrounding ecosystems. This multi-party collaborative supervision model not only forms social constraints but also encourages enterprises to actively achieve pollutant reduction targets through technological transformation. It is worth noting that the chained data storage mechanism and irreversible timestamp recording characteristics of blockchain fundamentally eliminate the possibility of data tampering, thereby strengthening the credibility of the environmental governance system [9].

4.2. Pollution source tracking and responsibility identification

4.2.1. Establishing a traceability system

Based on the traceability features of blockchain technology, a pollution emission tracking system covering the entire lifecycle of chemical enterprises can be constructed. By writing the entire process data, including raw material procurement traceability information, production and processing parameter logs, warehousing and transportation trajectories, and end-of-pipe emission monitoring values into the blockchain network, irreversible storage with multi-node collaborative verification is achieved. When environmental abnormalities occur, relying on the chained data tracking capability of blockchain, multi-dimensional information such as production equipment operating status timelines, raw and auxiliary material feeding ratio records, and energy consumption dynamic curves can be analyzed in reverse to locate the pollution responsible entities precisely. It is worth noting that the cross-validation mechanism of distributed ledgers can simultaneously restore equipment operation and maintenance records and environmental compliance audit reports during pollution events. Through smart contracts, the pollution responsibility identification procedure is automatically triggered, ensuring the judicial effectiveness of pollution traceability.

4.2.2. Precise responsibility identification

The tamper-proof characteristic of blockchain ensures the authenticity and integrity of pollution emission data, providing a reliable basis for responsibility identification. Once a pollution source is identified, the responsible entity cannot deny its pollution behavior. Regulatory authorities can accurately characterize the illegal behaviors of enterprises based on the data on the blockchain and impose penalties according to law. Simultaneously, third parties damaged by pollution events can claim compensation based on evidence from the blockchain, protecting the legitimate rights and interests of victims.

4.3. Supervision of environmental governance funds

4.3.1. Tracking fund flows

Environmental governance funds for chemical enterprises, including government environmental subsidies, the company’s own environmental investment, and social capital participation in environmental projects, can be fully tracked on a blockchain platform. From fund allocation, usage to settlement, every step of the information will be recorded on the blockchain. For example, when the government provides environmental subsidies to a chemical branch of Sinopec, details such as the allocation amount, time, and purpose will be documented on the blockchain. When the enterprise uses these funds to purchase pollution control equipment or pay for environmental projects, related transaction information will also be uploaded to the blockchain in real-time. Through the blockchain's distributed ledger, stakeholders such as regulators and investors can clearly see the flow and usage of funds, ensuring their allocation to environmental governance projects.

4.3.2. Preventing fund misappropriation

The smart contract function of blockchain technology can effectively prevent the misappropriation of environmental governance funds. Smart contracts are automatically executed contracts with terms encoded on the blockchain. When fund usage meets preset conditions, the smart contract executes automatically, releasing the funds. If the fund usage doesn't meet the conditions, the funds cannot be misappropriated. For instance, if a Sinopec chemical branch receives environmental project funds for building a new wastewater treatment facility, smart contracts on the blockchain platform can set conditions for fund usage. Only when certain conditions are met, such as project progress reaching a certain stage and relevant equipment purchase contracts being signed and accepted, will the funds be automatically paid to suppliers or contractors. This technically eliminates the risk of fund misappropriation, ensuring the smooth implementation of environmental governance projects.

4.4. Compliance with environmental policies and regulations

4.4.1. Smart contract applications

Requirements related to environmental policies and regulations are embedded into the blockchain system in the form of smart contracts. Chemical enterprises are automatically monitored and constrained by these smart contracts during their production and operation processes. For example, environmental regulations stipulate that the exhaust emission concentration of chemical enterprises must be controlled within a certain standard range. By setting smart contracts in the blockchain system, when the enterprise's exhaust emission monitoring data exceeds the prescribed standards, the smart contract automatically triggers an alert mechanism and sends warning information to the regulatory authorities. Additionally, the smart contract can automatically initiate corresponding punitive measures based on violations, such as restricting the production scale of the enterprise or deducting environmental credit scores [10].

4.4.2. Violation alerts and penalties

The blockchain system can monitor the environmental behavior of chemical enterprises in real-time, immediately sending out alerts if any violations of environmental policies and regulations are detected. Regulatory authorities can promptly take measures to investigate and address these violations upon receiving the alert information. For instance, if a Dow Chemical (China) factory's wastewater discharge chemical oxygen demand repeatedly exceeds the national emission standards, the blockchain system detects this abnormality and immediately sends warning information to the Shanghai Ecological Environment Bureau and the enterprise. Following an on-site inspection to confirm the violation, the bureau can impose penalties such as fines and production suspension for rectification based on environmental regulations. Through the application of blockchain technology, timely detection, precise early warning, and effective punishment of environmental violations by chemical enterprises are achieved, promoting strict compliance with environmental policies and regulations.

5. Conclusion

In summary, blockchain technology has demonstrated significant potential in environmental pollution control for chemical enterprises. By enhancing transparency in environmental monitoring data, it improves data credibility and regulatory efficiency. Through pollution source tracing and responsibility identification, the technology enables quick and accurate determination of pollution sources and accountability. In terms of environmental governance fund supervision, it effectively prevents fund misappropriation, ensuring reasonable fund usage. Additionally, in complying with environmental policies and regulations, smart contracts facilitate automatic monitoring and early warning systems for violations. However, the application of blockchain technology in environmental pollution control for chemical enterprises still faces challenges, such as the need to further enhance technical performance to handle massive environmental data and the requirement for further improvement in laws and regulations regarding blockchain applications. In the future, with the continuous development of blockchain technology and its deep integration with the chemical industry, it is expected to provide more comprehensive and efficient solutions for environmental pollution control in chemical enterprises, supporting the green and sustainable development of the chemical industry and making a greater contribution to protecting the ecological environment.

Disclosure statement

The authors declare no conflict of interest.

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