

Exploration of the scientific development of AI-assisted pyrolysis of waste plastics (Part B)

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Abstract: The pyrolysis of waste plastics, as a kind of environmentally friendly and efficient waste treatment method, has received widespread attention. This paper expounds the development strategy of the basic theoretical system for AI waste plastics pyrolysis; explores the main functional analysis and key technology implementation strategies of the AI waste plastics pyrolysis model; explores the design of the AI waste plastics pyrolysis system; expounds and analyzes the application cases of AI waste plastics pyrolysis; discusses the future development trends and challenges of AI waste plastics pyrolysis technology, pointing out that how to achieve the optimal environmentally friendly waste plastics pyrolysis has become a key issue that needs to be urgently addressed. This paper provides a reference for intelligent solutions for waste plastics pyrolysis.

Key words: AI; waste plastics; pyrolysis; scientific development

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(Continued from the previous issue)

3 Design exploration of AI waste plastic pyrolysis system

The design of an AI-based intelligent system for waste plastic pyrolysis is a crucial step towards achieving the sustainable development goal of waste plastic pyrolysis. Introducing and applying AI theories and technologies to the practical design of this intelligent system not only tests their applicability to the specific needs of waste plastic pyrolysis but also provides an opportunity to further explore the innovative and exploratory goals for sustainable development of the AI-based intelligent system for waste plastic pyrolysis through practical design.

3.1 Exploration of the architecture and module design of AI waste plastic pyrolysis system

System architecture and module design are pivotal steps in software development and systems engineering, encompassing the decomposition of complex systems into

manageable and maintainable components. These designs must closely align with the application of intelligent technologies, achieving intelligent, efficient, and refined management of the waste plastic pyrolysis process through rational structural layout and functional allocation.

3.1.1 Exploration of system architecture design

The architectural design of an AI-based waste plastic pyrolysis system is an interdisciplinary and multi-stage process that requires the comprehensive application of advanced data processing technologies, AI algorithms, and systems engineering principles. Through rigorous demand analysis, reasonable technology selection, scientific architectural design,

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and effective implementation strategies, an efficient and environmentally friendly waste plastic pyrolysis system can be constructed, providing strong technical support for solving the plastic pollution problem.

Refer to existing successful cases both domestically and internationally, such as practices that utilize AI to optimize the pyrolysis process, thereby increasing yield and reducing pollutant emissions. Learn from their successful experiences and technical details.

The following is a study exploring the architecture design of the AI waste plastic pyrolysis system from the perspectives of system requirements analysis, technology selection, architecture design, and implementation strategy:

3.1.1.1 System requirement analysis

Conduct an in-depth analysis of the requirements for the entire system to be developed, including but not limited to: the raw data that the system needs to receive, the results that the system should provide, performance indicators such as processing speed, accuracy, and stability, as well as cost and resource constraints, including budget, power consumption, and equipment space.

3.1.1.2 Technical selection

Data collection: The front-end data collection layer is responsible for collecting and preprocessing raw data. Utilizing big data technologies and cloud computing platforms for data processing, such as Hadoop and Spark, to handle and store vast amounts of real-time and historical data, including data cleaning and feature extraction.

Model construction: Selecting appropriate AI technologies, such as deep learning, reinforcement learning, or machine learning algorithms, for predicting and optimizing the pyrolysis process.

Control and execution: Integrate intelligent controllers and actuators, such as PID controllers, to adjust the parameters of the pyrolysis process based on the output of the AI model.

AI model layer: Deploy AI models for prediction and optimization, such as using deep neural networks to predict the yield and quality of pyrolysis products.

Control execution layer: Based on the output of the AI model, adjust the parameters of the pyrolysis process, such as temperature and pressure, through an intelligent controller.

Backend monitoring and decision-making layer: Monitor

system operation status, conduct anomaly detection and preventive maintenance, and provide decision support.

3.1.1.3 Implementation strategy

Implement in stages: Divide the project into stages such as requirement analysis, system design, prototype development, testing and verification, and online deployment, and advance step by step. Through a feedback loop, continuously collect system operation data, optimize AI models and system parameters, and enhance overall performance. Ensure that the system design complies with environmental standards, adheres to data protection laws and regulations, and safeguards the safety of operators.

Interdisciplinary Collaboration: Assemble a team of experts from fields such as chemistry, mechanics, electronics, and computer science to ensure the comprehensiveness and innovativeness of the system.

Continuous optimization: Through a feedback loop, continuously collect system operation data, optimize AI models and system parameters, and enhance overall performance.

Compliance and safety: Ensure that the system design complies with environmental standards, adheres to data protection laws and regulations, and safeguards the safety of operators.

3.1.2 Exploration of the design of functional modules (types)

Each module is responsible for a specific function, reducing complexity. Modules should be open to the outside world, allowing for expansion and modification; internally, they should be closed, not affected by external changes. Components within a module are closely related, while connections between modules should be minimized to reduce mutual dependencies. Utilizing mature frameworks and libraries, such as Spring Boot and React.js, can enhance development efficiency. Databases are selected based on data types and requirements, including relational databases like MySQL and NoSQL databases like MongoDB.

The functional module system should include the following core modules:

3.1.2.1 Data acquisition module

Responsible for collecting various parameter data in real-time during the pyrolysis process, including temperature, pressure, reaction rate, etc., to provide a foundation for

subsequent data analysis.

3.1.2.2 Data preprocessing module

Perform operations such as cleaning, removing outliers, filling missing values, and standardization/normalization on the collected data to ensure data quality and enhance the accuracy and reliability of subsequent analysis.

3.1.2.3 Model Training and Optimization Module

Select an appropriate machine learning or deep learning model, such as a regression model for predicting product yield, or utilize reinforcement learning to optimize pyrolysis process parameters. Utilize machine learning or deep learning algorithms to establish a predictive model for the pyrolysis process, and continuously iterate and optimize to enhance the model's predictive accuracy and adaptability.

3.1.2.4 Control strategy formulation module

Based on the trained model, generate the optimal pyrolysis process control strategy to achieve precise regulation of the pyrolysis process, thereby improving energy conversion efficiency and product quality.

3.1.2.5 Monitoring and fault diagnosis module

Monitor the status of the pyrolysis process in real-time, quickly identify abnormalities, and provide a fault diagnosis and early warning mechanism to ensure stable system operation.

3.1.2.6 User interaction module

Provide an intuitive and user-friendly operation interface, enabling users to easily monitor system status, adjust parameter settings, view analysis reports, etc., thereby enhancing the practicality and user experience of the system.

3.2 Exploration of the design and selection of AI intelligent algorithms

Selection criteria: The main considerations are its adaptability and accuracy in handling complex data, optimizing pyrolysis process parameters, predicting pyrolysis product distribution, and enhancing system efficiency.

Selection strategy: Adjust the hyperparameters of the model through methods such as grid search, random search, or Bayesian optimization to achieve optimal performance. Firstly, through comparative analysis, select deep learning algorithms with high accuracy prediction capabilities, such as Convolutional Neural Networks (CNN) or Recurrent Neural

Networks (RNN), to monitor and predict key parameters such as temperature and pressure in the pyrolysis process of waste plastics in real time, thereby achieving precise control over the pyrolysis process. Secondly, introduce reinforcement learning algorithms to construct a dynamic decision-making system, which automatically optimizes the optimal process conditions by simulating the impact of different operation strategies on the pyrolysis effect of waste plastics, thereby improving pyrolysis efficiency and product quality. In addition, combine global search methods such as genetic algorithms and particle swarm optimization to solve multivariable optimization problems and effectively model the complex nonlinear relationships in the pyrolysis system.

Validation methods and measures: Cross-validation, A/B testing, and other methods are employed to ensure the stability and reliability of the selected algorithm in the actual pyrolysis system. Through extensive training and testing with experimental data, algorithm parameters are continuously adjusted to enhance the model's generalization ability, ultimately achieving efficient application of intelligent algorithms in the field of waste plastic pyrolysis.

3.3 Exploration of integrated design for ai-assisted pyrolysis of waste plastics

Based on the integration and application of intelligent technology, a comprehensive platform capable of efficiently processing waste plastic pyrolysis databases, optimizing pyrolysis process flows, and designing and implementing intelligent control is constructed. The trained model is integrated into the control system as a decision engine. The platform should have good scalability and flexibility to adapt to the needs of waste plastic pyrolysis facilities of different sizes.

Here are some key integrated design strategies:

3.3.1 Data acquisition and preprocessing

Integrated sensor network: Deploy various sensors (such as temperature, pressure, and gas composition sensors) to collect real-time data during the pyrolysis process.

Data cleaning and integration: Utilize AI algorithms to clean and integrate the collected data, ensuring its accuracy and completeness.

3.3.2 Construction and optimization of intelligent models

Machine learning model: Construct a model using

supervised or unsupervised learning algorithms to predict the type, quantity, and quality of pyrolysis products, and optimize pyrolysis process parameters.

Deep learning model: By utilizing techniques such as deep neural networks, it achieves modeling of complex nonlinear relationships and enhances prediction accuracy.

3.3.3 Process control and intelligence

AI-driven PID controller: Integrates intelligent PID control algorithms to dynamically adjust key parameters of the pyrolysis process (such as temperature, pressure, residence time, etc.) based on the output of the AI model.

Intelligent execution system: Through the integrated control module, it achieves automated operation of the pyrolysis equipment, enhancing production efficiency and stability.

3.3.4 Resource recycling and energy utilization

AI-optimized product separation: Utilizing AI algorithms to optimize the product separation process, thereby enhancing the purity and value of the recovered materials.

Energy management system: Integrating AI energy consumption prediction and optimization technology to achieve efficient energy utilization during the pyrolysis process and reduce energy consumption.

3.3.5 Environmental monitoring and energy conservation and emission reduction

Pollutant emission monitoring: Integrate AI models to conduct real-time monitoring of pollutant emissions, ensuring compliance with environmental standards.

Energy conservation and emission reduction strategy: Through AI analysis, propose specific strategies for energy conservation and emission reduction, such as optimizing process parameters and improving equipment energy efficiency.

3.3.6 System integration and management platform

Internet of Things (IoT) Platform: Build a unified IoT platform that integrates all devices and data, enabling remote monitoring and management.

Decision support system: Develop a decision support system that provides scientific decision-making basis based on AI analysis results, optimizing pyrolysis processes and resource allocation.

3.3.7 Continuous learning and optimization

Online learning: Leveraging AI's online learning capabilities, continuously optimize models and control strategies based on real-time data, thereby enhancing system performance.

Feedback loop: Establish a closed-loop system, adjust model parameters based on actual operational feedback, and achieve adaptive optimization of the system.

3.3.8 Safety and compliance

Safety protection system: Integrates AI safety protection mechanism to ensure the safe operation of the system and prevent misoperations and accidents.

Compliance inspection: Utilize AI technology to conduct compliance inspection to ensure that the pyrolysis process complies with relevant regulations and standards.

4 Application case and analysis of AI-based pyrolysis of waste plastics

AI-assisted pyrolysis of waste plastics not only enhances the intelligence level of waste plastics pyrolysis technology but also provides technical support for achieving sustainable plastic recycling. These application cases demonstrate the potential of AI-assisted pyrolysis of waste plastics in improving the efficiency, environmental friendliness, economic benefits, and reducing environmental impacts of the waste plastics pyrolysis process.

4.1 Case and analysis of optimizing process parameters for AI waste plastic pyrolysis

Data-driven pyrolysis process optimization is one of the important applications of intelligent technology in the field of waste plastic pyrolysis. By training machine learning models on historical data, the efficiency, oil yield, and properties of by-products during the pyrolysis process under different operating conditions (such as temperature, pressure, residence time, etc.) can be predicted. A research team has analyzed the impact of factors such as temperature, pressure, and residence time during the pyrolysis process on oil yield and by-product characteristics using machine learning models (such as neural networks or support vector machines). Through training the model, they are able to predict the optimal output of the pyrolysis process under different parameter settings, thereby optimizing the pyrolysis process and improving resource recovery efficiency.

Research institutions and enterprises in Germany may have conducted in-depth research on optimizing pyrolysis process parameters using AI technology. By analyzing a large amount of data through AI models, they predict the efficiency and product characteristics of the pyrolysis process under different operating conditions, achieving process parameter optimization, improving resource recovery rates, and reducing environmental impacts. Research institutions and enterprises in France are exploring how to utilize AI algorithms to optimize the pyrolysis process, especially for specific types of plastics (such as polypropylene and polyethylene), to increase oil yield and reduce environmental pollution.

The case study in this section demonstrates that the pyrolysis model can assist engineers in real-time adjustment and intelligent optimization of process parameters, thereby maximizing production efficiency and optimizing product value.

4.2 AI-enabled intelligent, efficient, and high-quality pyrolysis case studies and analysis

By adopting advanced sensor technology and real-time data processing algorithms, the intelligent control system can automatically adjust operating parameters such as heating rate and ventilation volume based on preset process parameters and real-time feedback information, ensuring efficient and stable pyrolysis process and maximizing the quality and yield of products. Furthermore, by integrating machine learning models, the system can continuously learn and adapt to the characteristics of different types of waste plastics, optimize pyrolysis process conditions, and further enhance resource recovery and energy conversion efficiency. This intelligent control system not only significantly improves production efficiency and product quality but also reduces human operational errors, providing reliable technical support for the widespread application of waste plastic pyrolysis technology.

Germany's robust industrial foundation and technological prowess position it at the forefront of intelligent waste plastic pyrolysis. A research team from Purdue University has developed a technology that utilizes AI and machine learning to convert waste plastics into fuel. This study, published in the *Journal of American Chemical Society Sustainable Chemistry & Engineering*, demonstrates the potential of AI in enhancing pyrolysis efficiency and optimizing product quality.

Companies in the United States, such as Ensyn Technologies, are developing AI-driven pyrolysis technology. By integrating sensor data and AI algorithms, they achieve automated control and optimization of the pyrolysis process, thereby improving energy recovery efficiency.

This case study demonstrates that AI-assisted pyrolysis of waste plastics can enhance the efficiency and quality of waste plastic processing, reduce manual intervention, and improve the controllability of the overall pyrolysis process quality.

4.3 Case study and analysis of AI-assisted pyrolysis of waste plastics to promote the development of green circular economy

AI-driven waste plastic pyrolysis technology plays a pivotal role in advancing the development of a green circular economy. By enhancing the efficiency of waste plastic processing, mitigating environmental pollution, and generating economic value, it facilitates efficient resource utilization and sustainable development. A specific company has developed an AI-driven intelligent pyrolysis system that integrates deep learning algorithms and real-time data monitoring to optimize key parameters during the pyrolysis process, such as temperature, pressure, and residence time, thereby enhancing the efficiency of converting waste plastics into valuable products. The system is also equipped with a fault prediction model that can identify potential equipment issues in advance, reducing downtime and boosting overall operational efficiency. This case study demonstrates that the introduction of AI technology has significantly enhanced the intelligence level of the pyrolysis process, not only improving production efficiency and minimizing human operational errors but also reducing operational costs and equipment failure rates through predictive maintenance.

This case study demonstrates that AI intelligent systems can help maximize resource utilization and reduce waste generation.

4.4 Case study and analysis of by-product classification and prediction

Utilizing machine learning for the classification and prediction of by-products (such as fuel oil, carbon black, metals, etc.) enhances the automation level of the recycling process. By predicting the characteristics of by-products,

subsequent processing flows and logistics can be planned more effectively. By integrating learning methods (such as random forests or gradient boosting trees) to analyze various by-products (such as fuel oil, carbon black, metals, etc.) during the pyrolysis process, their yield and quality can be predicted. Research institutions in Japan are developing AI models to predict the characteristics of different by-products generated during the pyrolysis process, including the purity of oil products and the quality of carbon black. This helps to enhance the value of by-products and guide subsequent processing flows.

This case study demonstrates the significant role of AI in predicting and classifying by-products generated during the pyrolysis process. By utilizing deep learning models to predict the type and quality of these by-products, more efficient and environmentally friendly recycling and utilization can be achieved, such as reusing carbon black as fuel or material.

4.5 Cases and analysis of quality control and real-time monitoring

Machine learning models can monitor and predict changes in product quality during the pyrolysis process, such as the purity of oil products and the particle size distribution of carbon black, thereby enabling online quality control and avoiding the production of unqualified products. Computer vision and deep learning models, such as convolutional neural networks (CNN), are used to monitor changes in product quality in real-time during the pyrolysis process. Through image analysis, the system can quickly identify and predict the characteristics of by-products, such as the purity of fuel oil and the particle size distribution of carbon black, thus achieving online quality control. Some industrial projects in the United States utilize AI technology to monitor the pyrolysis process in real-time, analyzing sensor data to predict and adjust process parameters.

This case study demonstrates the implementation of AI quality control and real-time monitoring to achieve optimal resource recovery efficiency and energy utilization.

4.6 Case and analysis of equipment fault prediction

By monitoring equipment operation data and utilizing machine learning models to predict potential equipment failures, maintenance can be carried out in advance, reducing

downtime and maintenance costs. Equipment operation data is collected through sensors, and machine learning techniques such as time series analysis or anomaly detection algorithms are employed to predict potential equipment failures, enabling preventive maintenance of the equipment. This not only reduces the duration of unplanned downtime but also lowers maintenance costs.

This section explains how AI can predict potential equipment failures, schedule maintenance in advance, reduce downtime, and enhance the operational efficiency of factories through data collected by Internet of Things (IoT) sensors.

4.7 Case and analysis of resource recovery rate prediction

Based on historical data, regression models are used to predict the resource recovery rates of different types of waste plastics under specific processes, helping decision-makers optimize recycling procedures and resource allocation, and guiding production planning. Researchers at the University of Tokyo are developing a technology that utilizes AI for waste plastic classification and pyrolysis process optimization. By analyzing vast amounts of data, the AI system can predict optimal pyrolysis conditions, thereby improving resource recovery rates and reducing energy consumption. Some research institutions and companies in the United States are exploring the application of AI in the pyrolysis process, analyzing real-time data to optimize key parameters such as temperature, pressure, and residence time, in order to increase oil yield and reduce the generation of harmful by-products. Some projects in France are studying the application of AI in waste management, including waste plastic classification, pretreatment, and pyrolysis process optimization, to achieve efficient resource recovery and waste treatment.

This section explains how AI can be used to conduct more precise classification and pretreatment of different types of waste plastics, remove impurities and enhance the purity of plastics, thereby improving the recovery rate of oil and other valuable by-product resources during the pyrolysis process and increasing the added value of the products.

4.8 Case studies and analysis of environmental impact assessments

Utilize machine learning models to assess the environmental impacts of various pyrolysis processes,

such as greenhouse gas emissions and pollutant releases, in order to promote the selection and improvement of more environmentally friendly processes. By constructing an environmental impact model, process parameters can be optimized to reduce negative environmental impacts and promote sustainable development. By establishing an environmental impact model, the environmental footprint of different pyrolysis processes can be predicted, assisting enterprises in selecting green processes with minimal environmental impact. The Fraunhofer ISE Institute in Germany is researching AI-driven pyrolysis technology, aiming to enhance the efficiency and selectivity of waste plastic pyrolysis while reducing the generation of harmful substances by optimizing pyrolysis conditions and process parameters. Researchers at the University of Tokyo are developing AI models to predict the oil yield and gas production during the pyrolysis process, as well as identify optimal pyrolysis conditions.

This section explains how AI optimizes the pyrolysis process, reduces the production of by-products and emissions of harmful substances, achieves cleaner and more sustainable waste plastic treatment, and enhances the economic efficiency of resource recovery and environmental sustainability.

4.9 Cases and analysis of international cooperation

Germany's AI application in the field of waste plastic pyrolysis is also reflected in its cooperation with other countries, such as exporting pyrolysis technology equipment and sharing relevant experience. This not only promotes the global dissemination of technology but also helps raise awareness of plastic pollution issues and the adoption of solutions in the international community. Large enterprises and startups in the United States collaborate to implement AI-driven waste plastic pyrolysis demonstration projects. These projects aim to demonstrate how AI can improve recycling efficiency, reduce costs, and promote the development of a circular economy. Large enterprises and startups in Japan collaborate to implement AI-driven waste plastic pyrolysis demonstration projects. For example, some companies may collaborate with research institutions to optimize pyrolysis processes using AI, improve resource recovery rates, and reduce costs.

Through an in-depth analysis of multiple successful cases in this section, we have summarized the key experiences of AI application in the field of waste plastic pyrolysis. Firstly, the adoption of an integrated intelligent system can significantly enhance the efficiency and stability of the pyrolysis process, ensuring the optimal operating state of the pyrolysis technology through real-time data monitoring and intelligent algorithm optimization. Secondly, case studies have shown that a decision support system combined with artificial intelligence plays a crucial role in predicting the quality of pyrolysis products, optimizing the recycling process, and improving resource utilization. Furthermore, case analysis also reveals the potential of AI in solving environmental problems and promoting circular economy, especially in reducing waste generation, improving energy self-sufficiency, and promoting sustainable development. Successful cases demonstrate that interdisciplinary cooperation and technological innovation are key to driving the transformation of the waste plastic pyrolysis industry towards intelligence and greenification.

5 Future development trends and challenges of AI-based waste plastic pyrolysis technology

The future development trends and challenges of AI-based waste plastic pyrolysis technology are primarily manifested in the following aspects: Firstly, technical challenges include uncertainty in data quality, accuracy and real-time issues in model predictions, and the complexity of system integration, which require continuous technological innovation and optimization to overcome. Secondly, economic feasibility poses another key challenge. Balancing equipment investment costs, operating expenses, and output value to ensure the economic benefits of intelligent pyrolysis systems requires in-depth economic analysis and market research. Additionally, the adaptability to policies and regulations is also a challenge. Different regions have varying environmental standards and technical specifications for waste plastic pyrolysis, necessitating intelligent systems with flexible adjustment capabilities to meet diverse needs. However, these challenges also present opportunities. Firstly, the application of intelligent technology can achieve efficient automation of the pyrolysis process, improve production efficiency and

product quality, and reduce the likelihood of human error. Secondly, intelligent data analysis and decision support systems can accurately predict market changes, optimize raw material ratios and product output, and enhance the market competitiveness of enterprises. Furthermore, with the global emphasis on sustainable development and environmental protection, intelligent pyrolysis technology, characterized by resource recycling, is expected to receive more policy support and financial investment, promoting its rapid development and widespread application. Lastly, the integration of intelligent technology can also drive cooperation between upstream and downstream industries, forming a more collaborative and efficient circular economy system, collectively promoting the maturity and popularization of waste plastic pyrolysis technology.

Facing the future development trends and challenges of AI-based waste plastic pyrolysis technology, research directions include but are not limited to developing more efficient and flexible AI control systems, optimizing pyrolysis process parameters to enhance resource recovery efficiency, exploring interdisciplinary collaboration to address data security and privacy protection issues, and constructing

comprehensive life cycle assessment models to gain a deeper understanding of the long-term environmental impact of the technology.

6 Conclusion

The research on AI waste plastic pyrolysis presented in this paper indicates that waste plastic pyrolysis technology is continuously being optimized and innovated. How to achieve optimal green pyrolysis has become a key issue that urgently needs to be addressed.

The pyrolysis of AI waste plastics is expected to achieve a higher level of automation, stronger intelligent decision-making capabilities, and broader industrial integration. With the continuous advancement of pyrolysis technology and the gradual reduction of costs, this technology will become more widespread and become one of the important means to solve the global plastic pollution problem. At the same time, with the promotion of sustainable development goals, it is expected that more innovative applications and business models will emerge, further promoting the development of waste plastic resource utilization.

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