Recycling and Treatment Technologies of Hazardous Waste in Developing and Developed Countries

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Abstract. Reducing the illegal discharge and storage of hazardous waste is a serious global challenge. Effective hazardous waste management is essential to protect ecosystems, biodiversity and human health from irreversible damage. Through the comparative analysis of existing literature and the cases of four representative countries, China, India, the UK and the USA, this article discusses the development and application of hazardous waste treatment technology. The study found that developing countries are facing challenges such as a surge in waste generation, insufficient formal treatment facilities, weak law enforcement, and the dominance of the informal recycling industry. Although developed countries have advanced technology, they are trapped by problems such as ageing infrastructure, stagnation of investment, dependence on cross-border disposal and lack of supervision of emerging pollutants. Common treatment methods - including physical/chemical pre-treatment, pyrolysis, incineration and biological treatment - each face inherent technical challenges, such as complex and changeable waste composition, high cost, exhaust gas treatment problems and secondary pollution risks. In summary, effective hazardous waste management needs to adopt a comprehensive strategy, combine the national conditions of each country, and work together in terms of appropriate technology selection, strengthening law enforcement, infrastructure investment, informal industry standardization and international cooperation.

Keywords: Waste treatment technology, hazardous waste management, secondary pollution, international cooperation.

1. Introduction

In recent years, the development of heavy industry in each country has led to the many dangerous waste. For dangerous waste, every country needs to find a way to deal with it. Because of the great harm it causes to the environment. However, each country has different ways of handling dangerous waste at different time, and it is gradually upgrading its own technology to deal with dangerous waste. For different hazardous waste, each country will have different technologies and means to treat and recycle. Companies in each country that recycle and dispose of dangerous waste should obtain the corresponding license to carry out commercial activities of recycling and disposal. Such as in China, dangerous waste management is challenging because they are extremely toxic to the environment and humans [1]. In India, the country's rapidly developing industries have led to the generation of a large amount of hazardous waste [2]. In UK, political reactions to hazardous waste transfer and disposal are partly explained by the nature of the issue [3]. In America, Dengerous Groud provides a comprehensive analysis of the criminal dumping culture by detailing the generation of dangerous waste, the legal treatment methods, the government's response measures and efforts to control illegal dumping [4]. For every country, when the companies carry, store and dispose dangerous waste without a license for transportation, storage and disposal of dangerous waste, these companies want to reduce the cost. But the behaviors will damage the environment, make more animals die. The legal transportation, storage and disposal of dangerous waste is responsible for everyone and environment. With the development of country's heavy industry, more and more dangerous waste needs to be disposed. However, not all companies treat dangerous waste according to the legal treatment method. As a result, the ecological environment of some areas of every country has been destroyed.

2. Sources, classifications, treatment techniques and difficulties of hazardous waste

2.1. Source

Hazardous waste mainly comes from industrial activities, and the amount generated by medical care and daily life is relatively small. Industrial sources include drill chips, refinery sludge, waste lubricants and waste catalysts; medical sources include infectious dressings and pathological tissues; and sources of life include waste batteries and fluorescent tubes.

2.2. Classification

In order to select the appropriate treatment technology, hazardous waste is usually classified according to the characteristics that directly affect the treatment process. High-calorific value waste (such as organic solvents and waste oil) is suitable for energy recovery and incineration, while low-calorific value waste (such as sludge and drill chips) needs to be added with auxiliary fuel. Waste with high water content needs to be dehydrated before heat treatment. Waste with high heavy metal content (such as electroplating sludge and circuit boards) needs to be stabilised before incineration or metal recovery. Organic waste can be treated by thermal debonding, pyrolysis or incineration, while inorganic waste (such as acid and alkali) needs to be chemically neutralised.

2.3. Environmental hazards

Heavy metals and benzene substances are carcinogenic, teratogenic and mutagenic. Petroleum hydrocarbons can remain in the environment for months to decades, diffuse through soil, water and air, and produce bioenrichment effects in the food chain. The spread of pollutants in soil, water and air will lead to ecosystem destruction and damage to human health [5-7]. Among them, soil pollution is the most persistent, water pollution spreads the fastest, and air pollution is the most difficult to control.

2.4. Handling methods and difficulties

The main treatment technologies include physical/chemical pre-treatment, thermal debonding, pyrolysis, incineration and biological treatment. Physical/chemical treatment faces challenges such as uneven waste composition and difficult reaction control. Thermal detachment technology is limited by high energy consumption and the risk of heavy metal volatilisation [8]. Pyrolysis technology is limited by problems such as high cost, large fluctuations in raw materials and complex gas purification [9]. Although the incineration technology can achieve a destructive efficiency of more than 99%, it will produce dioxins, furan, ash slag containing heavy metals and a large amount of CO2 emissions. The slow speed of biological processing may cause secondary pollution and is only applicable to biodegradable compounds. At present, there is no universal optimal treatment method; the choice of specific process depends on the composition of waste, the characteristics of pollutants and the economic feasibility.

3. Dangerous waste recycling and treatment technology and difficulties in developing countries

3.1. China's dangerous waste recycling and treatment technology and difficulties

The production of dangerous waste is increasing year by year in China, but the treatment capacity of dangerous waste far exceeds the production volume. The core way of recycling and treatment of dangerous waste in China is resource utilisation technology. Incineration and heat disposal technology will also be used in China. A large amount of drilling waste will be generated in the process of oil and gas exploration and development. China has successfully operated the use of salt ore to treat drilling waste. This has been built and used in many countries [8]. China still faces many

challenges in recycling and handling hazardous waste. For example, structural overcapacity, technical bottlenecks are still prominent, digitalisation and supervision are short, and the cross-regional coordination mechanism is not perfect. The approval ability far exceeds the actual demand, and the malicious low-price competition in the industry has led to business difficulties for some enterprises. The overall level of resource utilisation is low, and the treatment technology of special categories of waste such as fly ash and waste salt is immature. China needs to improve the standard system of resource-oriented products, promote the construction of a national digital supervision platform, and encourage enterprises to develop core technologies in conjunction with universities in the recycling and treatment of dangerous waste.

3.2. India's dangerous waste recycling and treatment technology and difficulties

India's hazardous waste exceeds 7.2 million tons per year. It mainly comes from industrial waste in tanning, textile, metal processing, chemical industry and other industries, as well as the rapidly growing urban electronic waste and medical waste. However, India's disposal facilities for hazardous waste are seriously inadequate and the technology is backward. A large amount of hazardous waste still depends on landfill treatment, and more than 90% of solid waste is landfilled in an unscientific way, resulting in the continuous intensification of groundwater pollution and air pollution. The core difficulties in India are weak implementation of regulations, gaps in supervision, backward infrastructure, insufficient processing capacity, the dominance of the informal recycling sector, serious environmental and health risks, weak public awareness, and lack of professional talents. It is especially important to implement the best strategy for the effective management of industrial hazardous waste in India to maximize safety and minimise the impact on the environment [9]. It is necessary for India to strengthen the regulatory enforcement and punishment mechanism, integrate the informal sector into the regular system, provide skills training, and invest in advanced resource recovery technology in the future.

3.3. Comparative analysis of the management of hazardous waste in China and India

As the two largest developing countries, China and India have both experienced rapid industrialisation and faced the problem of increasing hazardous waste generation, but there are significant differences in infrastructure capacity, informal sector dynamics and regulatory law enforcement.

Infrastructure and disposal capacity: China has established a huge disposal capacity, which has now exceeded the annual waste generation; its core strategy is resource utilisation, supplemented by incineration and heat disposal. The salt mine disposal of drilling waste has been successfully put into operation [8]. However, China is also facing the problem of structural overcapacity, including regional mismatch between waste sources and disposal facilities, technical bottlenecks in special waste treatment such as fly ash and waste salt, and vicious low-price competition that squeezes the living space of regular operators. In contrast, India produces more than 7.2 million tons of hazardous waste every year, but the disposal facilities are seriously inadequate and the technology is backward. More than 90% of solid waste is landfilled in an unscientific way, resulting in a continuous increase in groundwater and air pollution. India's examination and approval capacity is far lower than the actual demand, while China's approval capacity exceeds the demand, but the spatial layout is unreasonable.

Informal recycling sector: The informal sector poses a major challenge in both countries, but its manifestations are different. In India, the informal recycling sector dominates hazardous waste disposal, which operates outside of regulation and operates in an unsafe manner, causing serious environmental and health risks. In China, although there are relatively few large-scale informal recycling, the formal sector is disturbed by the vicious low-price bidding behaviour of unlicensed operators, which not only harms the interests of regular enterprises, but also inhibits investment in cleaner technologies. Both countries face difficulties in integrating informal or semi-regular operators into the regulatory system.

Supervision and law enforcement: Both countries have established a perfect system of hazardous waste regulations, but there are still gaps in the implementation level. China's digital supervision platform is still under construction, and the cross-regional coordination mechanism is not perfect. India, on the other hand, faces problems such as weak implementation of regulations, lack of supervision, weak public awareness and shortage of professional talents. Under these two backgrounds, there is still a huge gap between policy design and actual implementation. Although it is expressly prohibited by law, illegal dumping and unauthorised disposal are still repeatedly prohibited. Effective management requires the two countries to strengthen the supervision, law enforcement and disciplinary mechanisms; in addition, China also needs to improve the standard system of resource-based products and build a national digital supervision platform [1,4,5].

4. Hazardous waste recycling and treatment technology and difficulties in developed countries

4.1. The technology and difficulties of hazardous waste recycling and treatment in the UK

There is a structural shortage of hazardous waste disposal capacity in the UK. Britain is facing the severe challenge of insufficient capacity for disposal of dangerous goods and waste, and there are only two large high-temperature incinerators in the country. It is running at full capacity and does not have the capacity recovery function. A large amount of dangerous goods waste can only be disposed of across borders and transferred to the European continent for disposal. High-temperature incineration in the UK targets chemical waste and medical waste, but most facilities have huge investment in exhaust gas treatment, lack of recycling, and poor economy. Emerging technologies include mechanical and chemical destruction and ultrasonic decontamination. There are also difficulties in hazardous waste recycling in the UK. The core difficulties are stagnant infrastructure investment, difficulties in specific waste disposal, and pressure on supervision and law enforcement. In the future, the UK needs to integrate hazardous waste disposal into the national key infrastructure, and the government will intervene to solve the investment problem.

4.2. The technology and difficulties of hazardous waste recycling and treatment in USA

The annual commercial treatment of hazardous waste in the United States is stable at about 7 million tons. But the infrastructure is seriously ageing. Incineration and landfill are still the mainstream treatment methods. There are two ways of nuclear waste treatment, one is vitrification and the other is grouting. Glassification is generally considered to be a more stable and safer sealing method, but the grouting cost is lower and faster. Vitrification is to mix waste and molten silicate to make an inert glass column, and the construction cost is extremely high. Grouting uses cement-like materials to cure waste into concrete, but most people think it is not safe enough. Hazardous waste might posture a significant threat to human health or the environmental matrices (water, air, soil) when inadequately treated, transported, sorted, or managed/disposed of [10]. The core difficulty of hazardous waste recycling and treatment in the United States lies in the competition of nuclear waste cleaning technology. Hazardous waste treatment facilities face climate risks, complex regulations hinder resource recovery, and emerging hazardous waste supervision lags behind. In the future, the recycling and treatment of hazardous waste in the United States needs to control costs and make safer treatment in the technological competition of nuclear waste treatment and provide technical guidance for hazardous waste recycling and treatment facilities threatened by climate risks.

4.3. Comparative analysis of hazardous waste management in UK and the USA

As two major developed countries, although the United Kingdom and the United States have advanced hazardous waste treatment technologies, they face completely different challenges in terms of infrastructure renewal, cross-border waste transfer, and regulatory policies for emerging pollutants.

Technological progress and ageing infrastructure: The annual disposal of commercialised hazardous waste in the United States remains at a stable level of about 7 million tons, and incineration and landfill are still the main disposal methods. In terms of nuclear waste treatment, there are two competitive technologies: one is glass curing, that is, mixing waste with molten silicate to form inert glass blocks, which is extremely stable but extremely expensive; the other is grouting, that is, using cement The material is cured quickly and costly, but it is considered to be relatively low in safety [7]. However, the infrastructure in the United States is seriously ageing, and treatment facilities are increasingly facing climate risks such as floods and hurricanes. In contrast, there are only two large high-temperature incinerators in the UK, both of which are operating at full capacity, but do not have energy recovery functions. Although emerging technologies such as mechanical chemical destruction and ultrasonic decontamination are under development, infrastructure investment is stagnant. In addition, due to the high cost of exhaust gas treatment and the lack of integration of recycling, most incineration facilities face the problem of poor economic efficiency [3].

Challenges of cross-border transfer: Britain is facing a structural shortage of domestic disposal capacity, forcing it to export a large amount of hazardous waste to the European continent for treatment. This reliance on cross-border disposal has caused political and legal complexity, especially after Brexit, when it has become more difficult to maintain regulatory coordination with the EU waste transportation rules. Public opposition and international legal constraints complicate disposal planning, which to some extent explains the political response to the transfer of hazardous waste [3]. With its vast land area and perfect treatment infrastructure, the United States has a low dependence on cross-border exports. However, when dealing with imported waste from other countries, it faces the pressure of international rules and needs to deal with complex interstate transportation regulations that vary greatly between states.

The lag in the supervision of emerging pollutants: both countries have gaps in the supervision of emerging waste types. In the United States, the supervision of emerging hazardous wastes clearly lags behind technological development, such as perfluorine and polyfluoroalkyl substances (PFAS), lithium battery waste and microplastics, etc., and there is no clear regulatory path. The complexity of current regulations also hinders innovation in the field of resource recovery, and overlapping requirements at the federal and state levels set up obstacles to the adoption of new treatment methods [7]. Britain faces similar challenges in dealing with specific categories of waste, including PFAS and other persistent organic pollutants, and regulatory adjustments after Brexit have added more uncertainty. Both countries need to strengthen the revision of regulations on emerging hazardous wastes and integrate hazardous waste treatment facilities into national key infrastructure planning to stimulate investment vitality and ensure future treatment capacity [3,7].

5. Conclusion

This review discusses the technical status and challenges faced by developing countries, developed countries and a number of specific countries in hazardous waste recycling and treatment, and elaborates on the specific situation, existing technologies and difficulties of each country. Although countries vary in terms of status, technology and challenges, hazardous waste must be scientifically recycled and treated to prevent pollution from land, air and water, and to avoid the destruction of the ecological environment and serious harm to human health.

Based on comparative analysis, this review puts forward the following suggestions: developing countries should strengthen supervision and law enforcement, standardise the informal recycling industry through training and certification, and increase investment in infrastructure treatment facilities; developed countries should accelerate infrastructure renewal, resolve technical disputes such as nuclear waste treatment, and focus on perfluoro Update the regulatory framework for emerging pollutants such as polyfluoroalkyl substances (PFAS) and lithium battery waste; all countries should strengthen international cooperation and promote the coordination and unification of technology transfer, standardisation of treatment procedures and cross-border transfer regulations.

There are some limitations in this review. The analysis is mainly based on second-hand literature, and there may be publication deviations; the selected countries cannot cover the diversity of practices in countries around the world; the rapid evolution of technology, and some conclusions may soon be outdated; in addition, the inconsistency of reporting standards also limits the depth of quantitative comparison.

Future research should make up for the above shortcomings in the following ways: using standardized indicators to carry out comparative empirical research, conducting vertical case studies to track the effectiveness of policy implementation, and pay more attention to the integration of informal industries and the treatment technology of emerging pollutants. This requires countries and enterprises to work together to improve technology and infrastructure.

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