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Efficient Resource Utilization Technology and Application of Urban Sewage Sludge

Sumei Zhang, Jinxiang Li, Xiaoping Wen*, Fahui Wang, Junliang Liu

School of Mechanical and Power Engineering, Henan Polytechnic University, Jiaozuo 454003, China
*Corresponding Author: Xiaoping Wen

Abstract: This article introduces the industry background of urban sewage sludge resource utilization in our country, analyzes the current research status of comprehensive sludge resource utilization, and elaborates on key technologies such as sludge and biomass co-pyrolysis gasification, carbon-silicon separation, and waste heat utilization. Application cases indicate that this project has created a "full industrial chain of sludge drying, pyrolysis gasification energy recovery, and comprehensive carbon utilization," which has significant economic and social benefits and serves as a good demonstration.

Keywords: Urban sewage sludge; Resource Utilization; Application.

1. Introduction

In recent years, with the acceleration of the urbanization process in our country, the scale of cities has dramatically increased and the urban population has surged, which has caused the ecological construction of urban environments to lag behind urban development[1]. This has generated a large amount of domestic and industrial wastewater, resulting in a significant volume of secondary sludge. Urban sludge provides a breeding ground for other harmful organisms; the salts within the sludge can directly affect the electrical conductivity of the soil, disrupt the nutrient balance for plants, and inhibit their nutrient absorption. The high content of microorganisms and pathogens in the sludge, if untreated and applied or discarded directly, could contaminate the food chain. When sludge is piled up outdoors, it emits foul odors and odors, and with sunlight and wind, pollutant particles can cause air pollution. Moreover, urban sludge often contains heavy metals, which, when leached and dissolved in water, can accompany wastewater into rivers, contaminating surface water and entering groundwater. When applied to soil, heavy metals can accumulate in the surface layer, posing a threat to human health[2].

However, sludge is rich in organic matter and inorganic salts, and after treatment through specific technological processes, it can be converted into fertilizers, soil conditioners, and fuels, widely used in agricultural and industrial processes. Therefore, there has been extensive research and application on sludge treatment both domestically and internationally. Among the sludge treatment methods in developed countries in Europe and America, anaerobic digestion, aerobic fermentation, dewatering, drying, incineration, landfilling, and pyrolysis are the primary methods[3]. Anaerobic digestion is essentially a multi-stage treatment process that places sludge in an oxygen-free environment to allow microorganisms to decompose organic matter, though the costs for sludge treatment are relatively high and the actual treatment effects are not ideal. The technology for aerobic sludge fermentation primarily utilizes the abundant microorganisms in the sludge for biotreatment, but this technique is also costly with lower treatment efficiency.

2. Research Status at Home and Abroad

The traditional sludge incineration method primarily refers to burning by making full use of auxiliary fuel and the thermal energy of the sludge itself to achieve the harmless disposal of sludge. Currently, sludge incineration technology is widely used in the processes of sludge disposal both domestically and internationally. In the treatment process, sludge can be incinerated directly, and it can also be incinerated using coal-fired boilers in power plants or garbage incineration furnaces. With the continuous advancement of sludge incineration equipment and technology, dried sludge and dewatered sludge are often co-fired in certain proportions during sludge incineration treatment. Land filling sludge is one of the most convenient treatment methods. Sludge is treated as waste and mixed with other waste after simple disinfection, and then buried, with soil used for compaction. According to surveys, in 2018, landfilled sludge accounted for 70% of the total sludge in China. However, due to the scarcity of land resources, in economically developed areas, the economic viability and feasibility of sludge landfilling are very poor. In recent years, sludge pyrolysis technology has also been promoted, including low-temperature and high-temperature pyrolysis methods. The low-temperature pyrolysis method involves heating the dried sludge to a certain temperature (generally <500°C) under oxygen-free conditions, resulting in dry distillation and thermal decomposition, which transforms the sludge into four products: oil, reaction water, non-condensable gases (NCG), and coke. However, in the sludge treatment by pyrolysis, the solid volume of the sludge is reduced much more than by incineration, and during the pyrolysis process, the aromatic substance in the produced oil has low toxicity, whereas burning it produces harmful substances and releases gases with unpleasant odors.

The high-temperature pyrolysis method involves heating under conditions that exclude air, causing the breakdown of component molecules into small molecular gases, pyrolysis solutions, and carbon residues. The reaction temperature is usually controlled between 600-1000°C. Compared to traditional low-temperature pyrolysis technology below 500°C, high-temperature pyrolysis is more significant for achieving efficient sludge reduction, effective fixation of

heavy metals, and reduction of flue gas pollution. However, high-temperature pyrolysis requires advanced equipment, poses certain risks, and can easily produce carcinogenic substances at high temperatures, which is quite hazardous.

Li Hui et al. studied the palletization of sludge as a raw material, examining the effects of pelletizing process parameters on energy consumption and granulating performance[4]. Meanwhile, Jiang Longbo and others compared the hardness and combustion characteristics of biomass pellets and biomass-sludge mixed pellets; Nosek R studied the properties of straw-paper sludge mixed pellets; Fang Shiwenz further mixed paper sludge with coal/biomass to investigate its combustion characteristics, and Shang Dier mixed waste rice straw and coconut shells with sludge, compressing the biomass into non-loose particles to prepare biochar. At the same time, Zeng Jun et al. utilized activated municipal sludge to produce biomass carbon, while Yuan Guoan et al. conducted feasibility studies on the preparation of activated carbon through pyrolysis and activation of urban woody waste, suggesting that the pyrolysis of typical urban woody waste to prepare activated carbon is feasible. Deng Shuanghui et al. analyzed the impact of operational parameters on the co-pyrolysis of sludge and biomass and the reactivity of the residual carbon during combustion; Zhang Zhixiao conducted experimental studies on the pyrolysis characteristics of oil-containing sludge under N_2/CO_2 atmospheres, analyzing the weight loss of sludge during thermal conversion under different atmospheres, the law of product precipitation, and the kinetic characteristics of reactions at different stages. Ma Lun et al. experimentally studied the gasification characteristics of the residual carbon after co-pyrolysis of sludge and biomass. Currently, many wastewater treatment plants in China do not consider a complete disposal route when constructing sludge treatment facilities, resulting in treated products having nowhere to go or being unable to be effectively utilized[5]. Looking at the sludge treatment and disposal situations in developed countries like Japan and Europe, resource utilization of sludge is a key focus and development trend for the future. In future planning and construction, treatment processes should be chosen based on a thorough consideration of disposal routes, ultimately achieving reduction, harmlessness, stabilization, and resource utilization of sludge. The best technological route to achieve this desirable vision is the sludge pyrolysis gasification technology, which is also the most advanced hot technology for sludge treatment currently.

3. The Research Methods

This project innovatively proposes a highly efficient coupling resource utilization method for sludge and biomass, conducting systematic research on key technologies and complete equipment for the efficient coupling resource utilization of sludge and biomass from three orderly levels: basic theory and technological process research, key technology research, and pilot tests and industrial applications. Based on the above, research is carried out on the pilot tests of key technologies for the efficient coupling of sludge and biomass and the industrial application of complete equipment to further verify the technical feasibility, equipment stability, and overall economy. From basic theory and technological process research, key technology research, and pilot tests and industrial applications, systematic research on key technologies and complete equipment for the efficient coupling resource utilization of sludge and biomass is gradually conducted. First, the mechanism of pyrolysis and gasification of sludge and biomass is studied, along with the design of processes for resource utilization of sludge and biomass; the key technology research includes the study of mixed fuel preparation technology, coupling pyrolysis and gasification experimental research, carbon-silicon separation, and active carbon preparation technology. Through this process of mixed fuel preparation, energy recovery and utilization, pyrolysis, gasification and combustion, high-temperature treatment of heavy metals, odors participating in high-temperature combustion after drying, carbon-silicon separation, and active carbon preparation, the goals of sludge 'reduction, energy utilization, harmlessness, and resource utilization' are achieved. Based on the above, research is conducted on the pilot tests of key technologies and the industrial application of complete equipment to further verify technical feasibility and conduct a comprehensive analysis of the economic and social benefits of demonstration projects.

4. Application Status

The project team conducted in-depth research on the mechanism of sludge and biomass pyrolysis gasification, established a pyrolysis gasification reaction model, and developed a pyrolysis gasification device that operates stably. Compared to the upward suction type, the calorific value of the pyrolysis gas increased by about 7%, and the content of tar and water vapor was relatively low. It was proposed that the thermal energy from the pyrolysis gas be simultaneously used for sludge drying pretreatment and the activation of carbon-rich ash, which can effectively reduce the operating costs of sludge reduction treatment and activated carbon preparation. Carbon-silicon separation technology was used to achieve efficient separation of carbon-rich components and silicon-rich components in ash; after separation, the organic matter and carbon content of carbon-rich ash could increase by 45%, while the organic matter and carbon content of silicon-rich ash could decrease by 20%, indicating significant carbon-silicon separation effectiveness. The carbon-rich ash was physically activated in an activation furnace to produce activated carbon, while the silicon-rich ash was processed into lightweight aggregates for construction use, achieving the goal of efficient coupling of sludge and biomass for the resource utilization of activated carbon. The project has developed key technologies and complete equipment for the efficient coupling of sludge and biomass to prepare activated carbon for resource utilization, and has promoted its application. This has important scientific application value and practical significance for alleviating the tight situation of energy, environment, and resources in our country, and for supporting the early realization of the national strategies of carbon peak and carbon neutrality.

(1) By utilizing the deep dewatering mechanism of sludge and biomass coupling materials, the cost of sludge pretreatment can be significantly reduced. Specifically, using sludge and biomass coupled fuel can lower the moisture content by 17.6%, which results in a reduction of 44 RMB in external energy costs required for drying each ton of sludge. Based on an annual processing of 200,000 tons of sludge, this leads to a savings of 8.72 million RMB in sludge drying pretreatment costs.

(2) The use of heat recovery from flue gas as a thermal source for the activation furnace in the production of biochar has decreased the operational costs traditionally associated with biochar production, improved the quality of biochar

produced from sludge processing, and increased the market price of biochar to 4,000 RMB/ton. This has enhanced the added value of sludge processing products, thereby improving the economic benefits of the sludge treatment industry.

(3) Based on the construction of a 600 tons/day (200,000 tons/year) sludge processing production line, the fixed asset investment for complete equipment totals 164 million RMB, with annual operating revenue of 150 million RMB, annual taxes of 13.6 million RMB, annual profits of 42.65 million RMB, and an investment recovery period of 3.8 years, demonstrating significant economic benefits.

5. Conclusion

The high-value and efficient resource utilization technology for sludge truly transforms waste into treasure, solving the problem of secondary pollution and achieving harmless treatment of sludge, thereby realizing the long-desired energy-saving and environmentally-friendly social benefits. The high-value and efficient resource utilization technology for sludge has created a full industrial chain of "sludge drying, pyrolysis gasification energy recovery, and comprehensive utilization of carbon production," allowing for scalability and replicability, with good demonstration effects.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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