Analysis on Development of Plasma Gasification for Waste Treatment

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Abstract: China's waste disposal business is now dealing with several significant issues. There are still constraints in the building, large-scale, and kitchen waste treatment processes. A solution combining high resource utilization, low cost, and promotion value of kitchen trash treatment has not yet been discovered. In the central and western regions, there are deficiencies in the handling of household garbage; in particular, the issue of waste disposal in county areas requires immediate attention. Plasma gasification technology can quickly decompose garbage at high temperatures and convert it into combustible gas and vitreous and other substances with high processing efficiency. The technology is carried out in the case of hypoxia, can reduce the generation of nitrogen oxides, and can remove toxic and harmful substances, and the pollution to the environment is small. The combustible gas produced in the gasification process can be used to generate electricity or converted into other fuels to achieve energy recovery. Plasma gasification can greatly reduce the volume of waste, thus reducing the need for landfill disposal. In this paper, principle of plasma gasification waste treatment, advantages, efficiency and application in life are analyzed.

1 INTRODUCTION

Compared with foreign countries, the research of plasma gasification technology in China started late, but developed rapidly. Many domestic universities, scientific research institutions and environmental industry companies have successively set up key laboratories for plasma gasification technology and research institutes related to plasma gasification to actively explore and develop plasma gasification technology. Some research institutions have developed pilot-scale plasma gasification devices. In a word, plasma gasification technology is developing rapidly in China and is gradually moving towards industrial application.

Plasma waste treatment technology is relatively new. At present, it is still in the stage of research and preliminary application, and there is still a certain distance from large-scale commercial application. Energy consumption problem: Plasma disposal of garbage requires a lot of electricity, which may lead to high operating costs. Equipment investment: Plasma waste disposal equipment is usually expensive, and for some small or medium-sized garbage disposal projects, the return on investment may not be ideal. Processing efficiency: Although plasma treatment can achieve the harmless treatment of garbage, its treatment efficiency may not be as efficient as traditional incineration methods, especially when handling a large amount of garbage.

The core equipment of plasma gasification technology is the plasma reactor. Its main working principle is: use high-voltage breakdown of working gas to form a discharge path, and further ionize the breakdown working gas through a high-power DC power supply, and inject it into the plasma gasification furnace to form a high-temperature and high-speed plasma jet with a core temperature of 10,000 degrees and a surface temperature of thousands of degrees as shown in figure 1 (Diao et al, 2024). Eventually, the treated material will be melted or even gasified through the plasma jet.

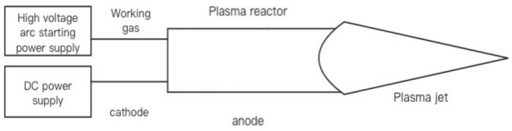

Figure 1. Principle of DC arc plasma reactor technology (Picture credit：Original)

As can be seen from figure 2, the whole process is divided into five parts: waste pretreatment, plasma

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gasification MSW, syngas cooling, syngas purification, and syngas power generation.

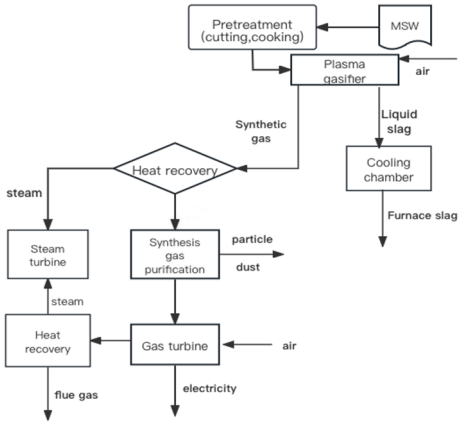

Figure 2. Process schematic of MSW to electricity via plasma-assisted pyrolysis and gasification (Picture credit：Original)

The MSW is pre-treated before entering the plasma gasifier, and the MSW is cut to a diameter of less than 15 cm (Mai et al, 2016). 4% of coke and MSW mixed into the gasifier, coke can absorb and maintain the heat released by the plasma torch, improve the calorific value of the combustion, and in the gasification process, MSW into syngas and liquid slag will lead to MSW continuous decline, at this time, coke can also play a "support" role.

In the gasifier, the plasma torch is placed at the bottom of the gasifier as a heat source, ionizing the medium (air or oxygen) into plasma, and directly acting on the MSW to convert the organic matter in the garbage into syngas, and discharged from the top of the gasifier. The ash and metal in the gasifier are converted into slag and run out of the bottom of the gasifier and extracted using a magnetic separator. The molten slag after the metal is sent to the cooling chamber for cooling, and finally forms glass particles.

The cooled syngas is sent to the purification system for purification, which mainly removes particles, dust, chlorine, sulfur, lead, cadmium, zinc, mercury and other substances in the syngas. Finally, the gas-steam combined cycle power generation method is used for power generation, that is, the purified syngas is sent to the gas turbine for combustion and power generation, while the waste heat of the syngas cooling process and the waste heat of the high temperature flue gas discharged by the gas turbine is recovered to produce steam for the steam boiler to generate power and improve the power generation.

2 MAIN TYPES OF GARBAGE TO BE DISPOSED OF BY PLASMA

At present, foreign plasma gasification melting treatment technology has been commercialized, from the initial application of direct treatment of low-level radioactive waste and medical waste, gradually developed to the treatment of solid waste field. There are many kinds of e-waste, including used printed circuit boards, used tantalum capacitors, used lithium-ion batteries, used liquid crystal displays and used light-emitting diodes. Compared with incineration, the pyrolysis temperature is higher and less air pollutants such as dioxins (Sheng & Li, 2023) and PBdes are generated.

Therefore, plasma thermolysis technology is commonly used to treat hazardous waste contaminants. Medical waste refers to direct or indirect infectious, toxic and other hazardous waste generated by medical and health institutions in medical treatment, prevention, health care and other related activities. Because medical waste contains pathogens, heavy metals and organic compounds, it will pollute surface water, groundwater and soil when accumulated and decomposed in the open environment. Common medical waste treatment methods mainly include incineration treatment, high temperature and high-pressure steam sterilization, plasma treatment technology, microwave disinfection, chemical disinfection, safety landfill method and so on. However, there are some problems in medical waste incineration treatment. The fly ash formed by medical waste incineration contains toxic metals and organic pollutants, which poses a serious threat to the environment.

In the main treatment technology of medical waste, gasification technology can convert various solid substances into gaseous fuel, with high energy conversion efficiency, clean and environmental protection characteristics, is generally considered to be an important means to achieve clean and efficient energy production (Yang et al, 2018).

3 PERFORMANCE OF PLASMA GASIFICATION

Although the plasma gasification process of municipal solid waste is more complicated, it is economically feasible. Waste disposal facilities can charge a certain amount of waste disposal fees for the waste being treated, and have income from the sale of electricity. The current output is mainly electricity,

but liquid fuels, hydrogen, synthetic natural gas, etc., may be sold in the future. Sorting and recycling valuable commodities such as metals and high-value plastics from municipal household waste is also a source of income; Another source of revenue includes the sale of slag and sulfur, which could potentially be recycled as building materials, rockwool and building bricks. And by avoiding landfills and reducing the transportation of waste, plasma technology can also save some additional costs. In addition, the use of plasma gasification technology to treat municipal solid waste can also enjoy government subsidies for renewable energy and carbon emission credits.

However, in terms of economic considerations, there are still some problems in using plasma pyrolysis/gasification technology for direct solid waste treatment. Firstly, the plasma reaction system uses high-grade electrical energy as energy, and high-power consumption is required to maintain the equilibrium hot plasma state. Secondly, the ultra-high temperature of equilibrium hot plasma will cause heat loss and low energy utilization rate. Finally, the reuse value of gas products and the utilization rate of solid product carbon are low.

Since plasma is only used as a high-intensity heat source in the melting furnace, and does not participate in gasification reaction and gasification process control as a gasification agent, the comprehensive thermal efficiency of plasma melting is low, and the operation rate of the batch batch in the plasma melting furnace is low. At the same time, the fluctuation of process conditions and parameters in gasification process will cause the carbon content of gasification residue to increase, and even macromolecular organic matter to appear. The process fluctuation of gasification process will cause drastic changes in the process mode and operating conditions of the melting furnace, resulting in the melting process deviating from the intention and requirements of the melting process. Under the comprehensive treatment mode of hazardous waste, the separation furnace needs to be further improved in terms of thermal efficiency, material universality and process reliability.

4 ENVIRONMENTAL IMPACT

Harmful substances in wastewater can lead to eutrophication of the water body, so that aquatic organisms such as algae over reproduce, consume oxygen in the water, and thus make other aquatic organisms die due to lack of oxygen. This not only destroys the diversity of aquatic life, but also seriously affects the balance and stability of aquatic ecosystems.

Agricultural use of sewage will lead to crop production, quality reduction, and even harm people and livestock, large areas of farmland are polluted, reducing soil quality. The consequences of Marine pollution are also very serious, such as oil pollution, causing the death of seabirds and Marine life. After water pollution, through drinking water or the food chain, pollutants enter the human body, causing acute or chronic poisoning. Arsenic, chromium, ammonium, benzo and pyrene, etc., can also cause cancer. Water contaminated with parasites, viruses or other pathogens can cause a variety of infectious and parasitic diseases. Water polluted by heavy metals is harmful to people's health (Anubhav et al, 2012).

Pollutants such as sulfur oxides, nitrogen oxides and volatile organic compounds contained in exhaust gases will form acid rain, haze and other bad weather after chemical reactions in the atmosphere, seriously worsening air quality. Intensification of the greenhouse effect: Greenhouse gases such as carbon dioxide and methane in some exhaust gases cause the Earth's surface temperature to rise, which leads to global climate change and an increase in extreme weather events. The deterioration of air quality affects plant growth and leads to disruption of the food chain in the ecosystem, which in turn threatens biodiversity (Ren , 2011).

5 THE CURRENT PROBLEMS

5.1 Cost

Reduced (increased) equipment refers to the equipment that is mainly different between the waste incineration power plant and the plasma gasification plant, and it is assumed that the cost of the gasification plant and the rest of the equipment in the incineration plant is the same except for the increased and reduced equipment.

Compared with the equipment composition of ordinary incineration plants, plasma gasification plants mainly increase the gasifier, plasma torch, water cooling equipment, generators and other equipment, and reduce the electricity cost of plasma torches of incinerators, steam cycles (boilers, generators, condensers) and exhaust pipes and other equipment. Although the plasma gasification process is complicated, it is economically feasible. Receiving garbage can charge a certain garbage disposal fee, and the electricity produced can be sold to the power grid; Metals and valuable plastics can also be recovered

from recycled waste, and the slag after gasification can be used to produce building materials, which can almost all the ash; The plasma method is very efficient in generating electricity. Plasma gasification technology can also save the cost of transporting garbage, and plasma gasification technology can enjoy government subsidies and tax exemptions. For example, the construction of a plasma gasification plant requires about $150 million (Ahmed et al, 2024). With the continuous development of plasma gasification technology, the power consumption of the plasma torch has been reduced (Galaly, 2022).

5.2 Processing Conditions and Equipment Duration

The thermal efficiency of the plasma torch is higher than 90%, and the service life is as long as 5000 hours, which is much higher than the level of domestic and foreign counterparts (Rutberg et al, 2013). The owner can shorten the production cycle, reduce production costs, with unified quality and inspection standards, streamlined operation mode to produce high-quality products to meet the needs of the market. The calorific value of domestic waste is low, and it is necessary to mix coal for combustion in fluidized bed, so the flue gas discharge is large and the operation cost is high. The plasma torch incinerator can directly treat domestic waste, solid, semi-solid and liquid waste. The plasma torch incinerator passes into excess air, and the domestic waste is fully incinerated to generate CO2, H2O and other elemental substances, among which mercury, zinc, lead, tin, copper and other heavy metals are discharged with the flue gas in the form of oxides, and the activated carbon injection device is used to spray activated carbon enrichment and post-treatment (Hu & Jiang, 2022).

6 FUTURE DEVELOPMENT TRENDS

At present, the domestic plasma technology to treat hazardous waste also needs to further improve and optimize its process reliability, energy consumption, and comprehensive operating cost. For example, relying on the existing hazardous waste rotary kiln incineration and disposal in collaboration with plasma gasification and melting technology, hazardous waste is classified and classified, coupled with wind, light and other renewable energy sources, and waste heat recovery is used for turbine power generation. High value utilization of syngas after purification reduces energy consumption and operating costs.

7 CONCLUSION

Plasma waste treatment technology is generally considered to be a relatively environmentally friendly treatment method because of its ability to convert harmful substances in waste into harmless or less harmful substances. For example, plasma technology can decompose harmful substances in medical waste at high temperatures and transform them into harmless small molecules or solidify inorganic pollutants such as heavy metals in the glass. In addition, pollutants such as exhaust gases and dioxins generated during plasma treatment can be treated through specialized flue gas purification systems to meet relevant emission standards. However, there are potential risks associated with any waste disposal technology, especially if it is not handled properly or equipment fails. In general, plasma waste treatment technologies have been designed and implemented with the reduction of hazardous substances in mind but need to be continuously monitored and improved to ensure long-term environmental safety.

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