Parameter design of rotary kiln incinerator and application analysis in engineering cases

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Abstract. In this paper, according to the type and scale of hazardous waste incineration, process selection, design of rotary kiln incinerator, and the engineering principle and performance characteristics of rotary kiln incinerator system are analysed, and the proposed method is verified by practical engineering examples. The results showed that the temperature of rotary kiln is controlled at about 850 °C, the residence time of hazardous waste in rotary kiln is about 60min, the rotating speed is 0.88r/min, and the inclination angle is 1.75. The temperature of the second combustion chamber is more than 1100 °C, and the residence time of flue gas in the second combustion chamber is more than 2S. After continuous incineration, the reduction rate of slag ignition is less than 5%, the removal rate of fly ash is more than 99.99%, and the flue gas is discharged up to the standard.

1. Introduction
Hazardous wastes are corrosive, toxic, flammable, reactive, and infectious. At present, there are 479 types in 46 categories in the National Hazardous Waste List. Of china. In recent years, the statistical value of hazardous waste production in China is close to 80 million tons, and the average annual growth rate is about 5.6% [1]. During the hazardous waste disposal process, among which comprehensive utilization of resources, harmless disposal and storage account for 49%, 44% and 7% respectively [2]. Hazardous waste disposal methods include resource utilization and harmless disposal. Resource utilization has been relatively stable after years of development and supply and demand have reached a balance. Harmless disposal due to slow capacity release, long qualification approval time, mismatch of qualifications and demand, inter-provincial transportation restrictions, and other factors have resulted in huge capacity gaps. The current hazardous waste treatment methods mainly include incineration and landfill. Rotary kiln incineration plays an important role as a traditional harmless disposal technology [3]. Rotary kiln incinerators are highly adaptable and can burn combustible materials of different states and shapes. Rotary kiln incineration operation is simple, easier to control, long service life, good
continuous work. Rotary kiln incinerators are the main incineration equipment used, accounting for nearly 85% of the market share in the field of industrial solid waste treatment [4].

2. Types and scale of hazardous waste

According to the types of hazardous wastes in this area, combined with the Technical Guidelines for Hazardous Waste Disposal Engineering (HJ2042-2014) and the National Hazardous Waste List (2016), the incineration hazardous waste of this project: HW02, HW03, HW04, HW05, HW06, HW07, HW08, HW09, HW11, HW12, HW13, HW14, HW16, HW38, HW39, HW45, HW50.

According to the amount of hazardous waste generated, the incineration system designed for this project has a disposal capacity of 1680 kg / h. The entire incineration system operates continuously for 24 hours. The low-level heat value of the waste is 17723 kJ / kg, and the load variation range is 70-120%. The elemental composition of the hazardous waste mixture, as shown in Table 1.

![Table 1 Characteristics of incinerated waste after compatibility](image)

3. Process design route

Due to the influencing factors of incinerator design and the characteristics of hazardous waste, the following points are important consideration in the design of incinerator system.

1) Design of feeding system. Non-continuous feeding method, it is easy to form under-oxygen combustion in some places, and the smoke contains a large amount of carbon black. The continuous mechanical feeding system were adopted to improve the working environment of the workers while avoiding direct contact between the materials and the workers and reducing the risk of human body injury. To prevent the material from being stuck, the feeding system designed to be circular.

2) Furnace design. Although the average calorific value of hazardous wastes is higher, combustion does not exist what problem, the furnace combustion temperature to fluctuate greatly extremely easily, causes the instability combustion, unit time enters the furnace the waste composition changes greatly. Furnace volume thermal load is generally between 300-450MJ/m³.h.

3) Flue gas treatment design. The exhaust gas treatment adopts a combination of cooling, denitrification, activated carbon adsorption, one electricity and one bag (bag dust collector + wet electrostatic precipitator), and wet and dry deacidification technology to effectively treat nitrogen oxides, dust and acid gases in the exhaust gas. The acid gas content is larger (more than 1%), and the equipment is more corrosive at low temperature and high moisture content.

4) Maintenance of equipment. The flue gas is highly corrosive and the life of the equipment is limited. In particular, the nozzles and other parts need to cleaned and maintained frequently. Therefore, as far as possible, consider as much maintenance space and inspection openings as possible in the layout and equipment design. The system design flowchart, as shown in Figure 1.

3.1. Incinerator design

In this project, the rotary kiln incineration equipment selected as the reduction disposal equipment according to the characteristics of the waste. The average calorific value of the incineration waste in this project is about 17723kJ/kg. The second combustion chamber installed behind the rotary kiln, the temperature is controlled at about 1100 °C, and the residence time is more than 3s, and it can completely and effectively destroy all kinds of organic matters in waste. It improves the burnout rate of ash and residual solid carbon, and greatly improve the combustion efficiency of rotary kiln. The second combustion chamber is vertical design, with two burners symmetrically and evenly distributed. The
airflow rotates upward along the furnace of the second combustion chamber to form a turbulent state, which promotes the agitation of flue gas and ensures the full combustion of flue gas. It ensures that the burn out rate of organic gas produced by solid waste pyrolysis is over 99.99%, which destroys dioxin and other harmful substances from the source. The oxygen content in the flue gas controlled at 6-10% (dry flue gas) into the waste heat boiler.

3.2. Exhaust gas treatment process
During incineration, the presence of chlorine will greatly increase the content of heavy metals. The higher the chlorine content in hazardous waste, the more metal migrates into the flue gas [5-6]. In incineration, the presence of sulfur can inhibit the volatility of metals. At low temperature, the formation of stable compound metal sulfate will start to volatilize only when the temperature is above 800°C. However, if the reaction environment is inclined to a strong oxidation state, the volatilization of sulfate will also be inhibited [7-8].

First, a SNCR denitration system is set up, and a urea spray gun interface is left at the flue gas inlet position of the waste heat boiler to remove nitrogen oxides in the flue gas. The temperature of the flue gas after the waste heat utilization of the waste heat boiler is reduced to 550°C, and then it enters the quench tower. In one second, the flue gas suddenly drops from 550°C to 190°C, which can avoid the re-synthesis of dioxins between 200 ~ 500°C. Secondly, the hydrated lime powder sprayed into the flue after the outlet of the quench tower, and the acid-base neutralization reaction carried out in the flue and the bag surface, which can effectively remove the acid substances in the flue gas. The activated carbon adsorbs heavy metals and dioxins in the flue gas and removes suspended particles (such as dust, products of dry deacidification, heavy metals and dioxins adsorbed by activated carbon, etc.). The flue gas that has passed through the bag filter enters the wet washing tower for multiple deacidification.
4. Design of rotary kiln
The incineration process can reach completely harmless combustion under the conditions of sufficiently high temperature, sufficient gas residence time, good turbulent contact and the presence of excess oxygen (6% -10%). The process can be completed in two steps. First, the waste is dried, gasified and burned in the rotary kiln, which is a low temperature process, and secondly, after separating the ash and slag, the flue gas burned at high temperature in a fixed furnace. One-time complete combustion requires a large volume of rotary kiln, high temperature resistance, high cost, and high- energy consumption, so the project adopts the two-step process method of "rotary kiln + secondary combustion chamber.

4.1. Thermal calculation of rotary kiln
The calculation of material balance and heat balance is based on the chemical reaction equation of carbon, hydrogen, sulfur and other combustible elements in the hazardous waste and oxygen in the air. It is assumed that the air required for incineration is dry air, the required air and the generated flue gas are ideal gases, and the air volume is calculated based on 1 kg of hazardous waste.

1) Calculation of theoretical air volume:
\[ V_{o_2} = 0.0889(C_y + 0.3755S_y) + 0.265H_y - 0.0333O_y \] (1)

Where, \( V_{o_2} \) is the amount of theoretical air required for incineration (m³/Kg); \( C_y, S_y, H_y, O_y \) are the mass fraction (%) of carbon, sulfur, hydrogen and oxygen respectively.

2) Calculation of theoretical flue gas volume

\[ V_f = (1.866C_y + 0.7S_y + 0.8N_y + 0.806V_{o_2} + 11.1H_y + 1.24M_y) \times 10^{-2} \] (2)

Where, \( V_f \) is the theoretical amount of smoke produced by incineration (m³/Kg); \( C_y, S_y, N_y, H_y, O_y \) are the mass fraction (%) of carbon, sulfur, nitrogen, hydrogen and oxygen respectively. \( M_y \) is the moisture content (%).

The total excess air coefficient of the rotary kiln incinerator is usually maintained at 1.1 to 1.5 to promote the contact of solid combustibles with oxygen [9].

4.2. Dimension calculation of rotary kiln

1) Inner diameter of rotary kiln

When the total flue gas is changed to 950 °C, the total dry flue gas is calculated as follows

\[ V'_{n} = V_n \frac{1+\beta T_o \cdot \alpha}{3600} \] (3)

\( \beta T_o \) is the volume expansion coefficient of flue gas, so the inner diameter of the rotary kiln is:

\[ D_{rk} = \sqrt{\frac{4V'_n}{\pi \bar{v} (1-\beta)}} \] (4)

\( \bar{v} \) is the average velocity of flue gas outlet, \( \beta \) is the material filling material, (0.1-0.25).

2) Length calculation of rotary kiln

\[ V_k = \frac{\pi}{4} D_{rk}^2 L_k = L_k = \frac{4V_k}{\pi D_{rk}^2} \] (5)

3) Residence time

The residence time of hazardous waste in rotary kiln can be estimated by the following formula:

\[ \theta = 0.19 \frac{L_k}{D_{rk} \bar{v} S} \] (6)

Where, \( L_k \) is the length of rotary kiln, \( D_{rk} \) is the inner diameter of rotary kiln; \( v \) is the speed of the rotary kiln, \( S \) is the tilt Angle of rotary kiln incinerator (1-2°). All kinds of hazardous wastes must be pretreated and mixed before they are sent to rotary kiln for incineration, and the appropriate pretreatment and good blending ratio are necessary for the safe and effective incineration of hazardous waste in the rotary kiln, and help control the generation of pollutants [10]. The total amount of smoke is 5.641 m³/s. The average velocity of flue gas outlet is 1.8 m/s, the material filling material \( \beta = 0.19 \), the volume of the rotary kiln \( V_k = 90 \) m³, the tilt Angle of rotary kiln incinerator \( S = 1.75 \degree \), the speed of the rotary kiln \( v = 1.2 \text{ r/min} \). So, the inner diameter of rotary kiln \( D_{rk} = 2800 \) (mm), and the length calculation of rotary kiln \( L_k = 148000 \) (mm).

5. Project case analysis

The designed disposal capacity of the incineration system is 1680 kg/h, and the low-level heat value of the waste is 17723 kJ/kg. The rotary kiln adopts the downstream type, the temperature is controlled at
about 850 °C, the hazardous waste is completely burned into high-temperature flue gas and ash after 50 minutes of high-temperature incineration, and the thermal reduction rate of slag is less than 5%, as shown in Figure 2.

According to excess air coefficient = 1.4, and the calculated amount of incineration gas is 17356 m³/h. According to online real-time monitoring system data, the smoke and dust is 7.6 mg/Nm³, the emission value of sulfur dioxide is 27.8 mg/Nm³, the emission value of nitrogen dioxide is 79.4 mg/Nm³. After the recovery of waste heat and the purification of flue gas reach the standard, the induced fan will lead the chimney to the atmosphere.

![Fig 2. Actual case of hazardous waste disposal center. (a) Scene of hazardous waste disposal center, (b) DCS control system display diagram](image)

6. Conclusion
The designed disposal capacity of the incineration system is 1680 kg/h, and the low-level heat value of the waste is 17723 kJ/kg. The temperature is controlled at about 850 °C. The temperature of rotary kiln is controlled at about 850 °C, the residence time of hazardous waste in rotary kiln is about 60 min, the rotating speed is 0.88 r/min, and the inclination angle is 1.75. The temperature of the second combustion chamber is more than 1100 °C, and the residence time of flue gas in the second combustion chamber is more than 2 s. After continuous incineration, the reduction rate of slag ignition is less than 5%, the removal rate of fly ash is more than 99.99%, and the flue gas is discharged up to the standard.

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