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Design of intelligent compound pyrolysis unit for hazardous waste of biomass backburning based on computer simulation

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Abstract: *This system generates combustible gas and ignites it by generating combustible gas through the internal heating pyrolysis combustion of biomass fuel in the reverse combustion furnace and outside the pyrolysis furnace, which promotes the pyrolysis of biomass fuel while heating the pyrolysis furnace, pyrolysis of hazardous waste in the pyrolysis furnace, and realizes the recycling of heat energy.*

Keywords: *Biomass; Reverse combustion; Pyrolysis furnace; Computer simulation*

1. Introduction

In 2017, the national hazardous waste generation was 69.3689 million tons, and the average growth rate of hazardous waste generation from 2011 to 2017 was 12.45%. Less than 1% of the types of hazardous waste are treated and can treat more than 25 kinds of hazardous waste, and nearly 90% of enterprises treat less than 5 types.

At present, the treatment methods mainly include landfill, incineration, pyrolysis, etc., among which the landfill method occupies a large land area, and may leak and pollute water resources; Incineration method can treat many types of hazardous solid waste, can well decompose toxic and harmful products in the waste, incineration waste volume is about 5% of the original volume, but will produce a large amount of acid gas and incomplete combustion of the slag, if not properly handled may cause secondary pollution, the problem is tricky.

Pyrolysis technology uses heat to produce fuel gas, fuel oil, and black carbon, etc. without adding oxygen. This method produces low exhaust gas emissions, and because the pyrolysis process is an oxygen-free or hypoxic reaction, it consumes very little oxygen and lacks fly ash to provide a reaction environment, so it does not produce dioxin pollution problems. Some literature shows that more than 90% of heavy metals in solid waste (referring to mass fraction) can be stably solidified into the slag, and the harmlessness is relatively thorough, but its heat consumption and loss are large, and the problem of heat supply and heat reuse needs to be solved.

This project uses biomass fuel reverse combustion to provide energy for the pyrolysis furnace, comprehensively congratulates hazardous waste, realizes the optimization of existing equipment, conforms to the harmless treatment of hazardous waste advocated by the state, and builds an environment-friendly society.

2. Design schemes

The main installation of this work includes reverse combustion furnace, hazardous waste compound pyrolysis furnace, combustion furnace and hot blast furnace, hazardous waste pyrolysis furnace is located inside the reverse combustion furnace, this work produces combustible gas and ignites it through the internal heating pyrolysis combustion of biomass fuel in the reverse combustion furnace and outside the pyrolysis furnace, and the heat formed is used for pyrolysis and indirect heating pyrolysis furnace of direct heating of biomass fuel[1].

The pyrolysis furnace is loaded with hazardous waste, and the pyrolysis process of hazardous waste is started by the heat pyrolysis furnace provided in the reverse combustion furnace, and the combustible gas produced by it can be transported to the reverse combustion furnace and hot blast furnace for pyrolysis and drying recycling. Realize the complete recycling of system heat energy, and exhaust emissions meet

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national standards, as shown in Figure 1.

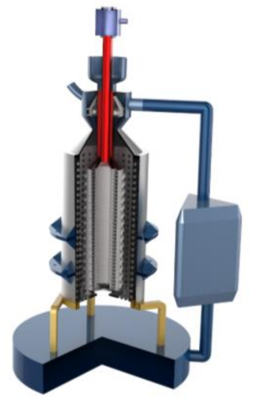

Figure 1: Device structure

2.1 Reverse combustion furnace

Now the biomass internal heating pyrolysis furnace based on the principle of reverse combustion is designed, and the main structure of the work is mainly divided into furnace roof, furnace belly, furnace strip, outer furnace door, auxiliary vent and inner furnace door, as shown in Figure 2. The reverse combustion furnace carries out the internal heating pyrolysis of biomass fuel, the specific step is to pour the amount of biomass fuel required for a complete pyrolysis into the furnace at one time, ignite on top of it, and start burning the biomass at the top[2].

Figure 2: Structure diagram of biomass reverse combustion furnace

Before natural pyrolysis, the heat will initially dry the material, at this time the low-pressure area under the furnace bar uses a blower to blow fresh air, and then under the appropriate oxygen supply conditions, pyrolysis begins, crude gas burning, providing part of the heat required for pyrolysis and drying, the pyrolysis heat source of the process generates heat by spontaneous combustion of part of the biomass raw material. The CO2 produced after gas combustion reacts chemically with C in biomass to generate CO, and then burns to make the combustion more complete and reduce the emission of exhaust gas. Auxiliary vents are provided on the side walls of the reverse combustion furnace to ensure suitable oxygen conditions in the combustion furnace.

The biomass is placed from the top of the work, and the figure 3 below shows the movement process of the combustion zone of the anti-burning furnace under the ignition condition of the center of the top surface of the biomass bed.

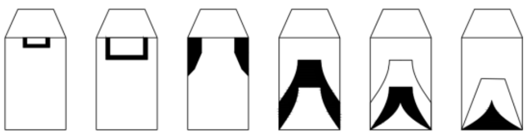

Figure 3: Reverse combustion process

The Biomass pellet combustion is mainly carried out in the furnace, the structure of the furnace will greatly affect the combustion efficiency of the pellets, if the oxygen content in the furnace is insufficient or the size of the furnace is too large, the particles will produce incomplete combustion, resulting in the heat supply is not up to standard. In order to ensure that the particles are fully burned in the furnace and increase the air supply, the structure of the furnace is first improved, and the furnace is designed as a sandwich structure with an inner wall and an outer wall, forming an air supply channel, the outer wall is isolated from the outside world, the inner wall is opened with ventilation holes, and the air enters the furnace through the ventilation holes under a certain pressure, as shown in Figure 4.

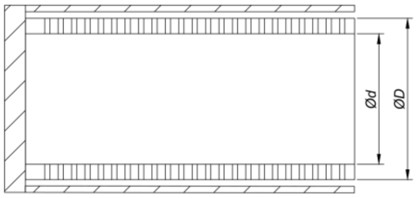

Figure 4: Diagram of the shape and structure of the furnace

Furnace fluid iterative simulation furnace fluid iterative simulation furnace shape structure as shown in the figure 5 below, in order to make the fuel fully burned in the furnace, it is necessary to optimize the ventilation volume, furnace diameter and furnace length, design fluid simulation software to simulate the combustion process of biomass particles in the furnace, the simulation results show the temperature distribution in the furnace.

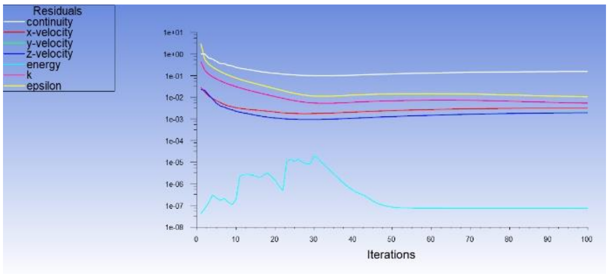

Figure 5: Iterative simulation of furnace fluids

From the simulation results, after preliminary iteration, the gas flow rate in the furnace tends to be uniform and stable, which ensures the oxygen content required by biomass during combustion, improves the complete combustion rate, and reduces the amount of incomplete combustion gas. This structure can be shown to be viable.

According to the characteristics of gas inlet and outlet and reverse combustion, the pressure cloud diagram, vector diagram, velocity cloud diagram and streamline diagram in ANSYS fluid simulation can directly reflect the overall flow direction and pressure of the gas, because the gas first enters the air interlayer of the reverse combustion furnace from the lower part and participates in the reverse combustion of biomass from top to bottom, this characteristic can be intuitively observed from the figure 6.

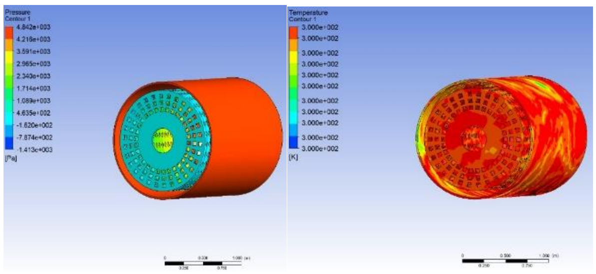

Figure 6: pressure cloud map and temperature cloud map

Therefore, in the use of the reverse combustion furnace with the inner and outer sandwich structure, the gas is timely supplemented with the oxygen required for the reverse combustion from top to bottom from the bottom up. Since the combustion furnace and pyrolysis furnace are high-temperature heating equipment, the heat distribution can be obtained from the figure 7 under the action of pores.

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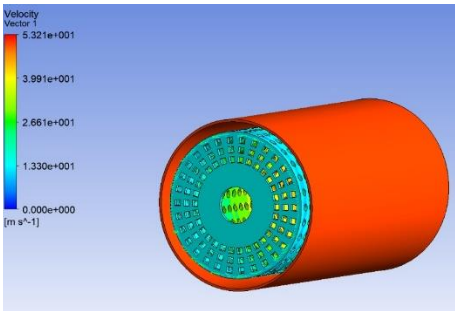

Figure 7: Speed cloud with vector graph

According to the simulation results, the gas velocity inlet into the reverse combustion furnace is the fastest, and the gas flow direction is reduced sequentially from top to bottom in the combustion furnace due to the blocking effect of biomass, and the vector diagram also shows the flow direction of the gas.

In summary, under the action of the air interlayer of the reverse combustion furnace, the reverse combustion oxygen supply of the furnace is sufficient, which improves the reaction rate of the biomass, reduces the incomplete reaction products, improves the heat released per unit time and promotes the hazardous waste pyrolysis efficiency of the internal pyrolysis furnace, which shows that it is feasible to use the principle structure of the reverse combustion furnace for biomass combustion and the heating of the pyrolysis furnace[3].

2.2 Compound pyrolysis furnace

After experimental research, the pyrolysis temperature is the most important parameter affecting the pyrolysis process of garbage, and with the rise of temperature, the gas generation rate increases rapidly, and the pyrolysis solution yield and semi-coke yield show a downward trend. Pyrolysis gas is mainly composed of CO, H2, CH4, CO2.

With the increase of pyrolysis temperature, the content of CO and H2 gradually increased. The calorific value of pyrolysis gas does not increase with the increase of pyrolysis temperature, but has a maximum value, with the increase of pyrolysis temperature, the calorific value of pyrolysis semi-coke shows an upward trend, most of the pyrolysis solution is moisture and volatile, fixed carbon and ash content is very low, the sum of the two is less than 3%.

Pyrolysis can convert the organic matter in solid hazardous waste into a storage energy mainly based on fuel gas, fuel oil and black carbon. The amount of exhaust gas produced by pyrolysis is small, which can treat difficult substances that are not suitable for incineration and landfill, and because it is decomposed by hypoxia, the exhaust volume is small, which is conducive to reducing the secondary pollution of the atmospheric environment.

From the pyrolysis kinetics:

$$\mathrm{A(solid)} \rightarrow \mathrm{B(solid)} + \mathrm{C(gas)} \tag{1}$$

$$\frac{\mathrm{da}}{\mathrm{dt}} = \mathrm{kf}(\propto) = \mathrm{k}(1-\propto)^n \tag{2}$$

$$\mathrm{k} = Ae^{-\frac{E}{RT}} \tag{3}$$

$$\frac{d\propto}{\mathrm{dt}} = \mathrm{A}e^{-\frac{E}{RT}}(1-\propto)^n \tag{4}$$

$$\emptyset = \frac{\mathrm{dT}}{\mathrm{dt}} \tag{5}$$

$$\frac{\mathrm{d}\propto}{\mathrm{dT}} = \frac{\mathrm{A}}{\emptyset}e^{-\frac{E}{RT}}(1-\propto)^n \tag{6}$$

$$\ln\left(\frac{\frac{\mathrm{d}\propto}{\mathrm{dT}}}{(1-\propto)^n}\right) = \ln\left(\frac{\mathrm{A}}{\emptyset}\right) - \frac{\mathrm{E}}{\mathrm{RT}} \tag{7}$$

Most of the harmful components such as sulfur and heavy metals in the waste are solidified in solid carbon black, and less NOx, SOx, HCI, etc. are produced by pyrolysis. Since the pyrolysis process maintains the reduction conditions, Cr3+ and the like will not be converted into Cr6+, and the harmlessness is complete.

The core of this pyrolysis furnace is to pyrolyze hazardous waste by external heating under oxygen-free working conditions. Since there is no oxygen and no combustion in the furnace, the pyrolysis of

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garbage in a high-temperature confined space realizes continuous production without fly ash, eliminating the conditions for the generation of dioxins[4].

The combustible mixed gas produced by hazardous waste under the treatment mode of pyrolysis is burned to heat the reverse combustion furnace to promote the pyrolysis of biomass in the reverse combustion furnace, and then indirectly heats the composite pyrolysis furnace, and the combustible gas generated by the pyrolysis furnace can also be sent to the hot blast furnace, which can be used for drying cycle, so as to realize the complete recycling of heat energy, as shown in Figure 8.

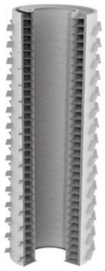

Figure 8: Speed cloud with vector graph

In order to improve the heating uniformity of hazardous waste in the pyrolysis furnace, a cylindrical vertical composite pyrolysis furnace is designed, that is, a circular through channel is designed at the center of the cylinder on the basis of the original vertical pyrolysis furnace, the pyrolysis furnace is still a fully enclosed space, the materials are put in from the top, and an inner grate is set in the pyrolysis furnace, so that the hazardous waste can be evenly distributed and heated. An outer grate is set on the periphery of the pyrolysis furnace to increase the heating area.

2.3 Exhaust gas treatment system

The exhaust gas treatment system is composed of four parts: exhaust gas buffer tank, quenching tower, exhaust gas absorption tower and spray liquid circulation pump. The exhaust gas generated by the heating furnace will enter the exhaust gas buffer tank for buffering, and the exhaust gas buffer tank mainly buffers the uneven rate of the exhaust gas generated by the exhaust gas furnace into a uniform rate of exhaust gas. The inside of the exhaust gas buffer tank mainly includes the tank body and the elastic expansion buffer tube.

When the exhaust gas enters the exhaust buffer tank will push the elastic expansion buffer tube for compression, the buffer tank is designed as a pressure sensor and solenoid valve exhaust gas outlet, when the exhaust gas pressure in the buffer tank reaches the threshold, the sensor will send a signal to the solenoid valve, and then the solenoid valve will open, the exhaust gas will be evenly passed out, when the gas pressure in the exhaust buffer tank decreases below the threshold, the solenoid valve will be closed again, and so on, so that the exhaust gas in the buffer tank is uniform.

The exhaust gas discharged from the exhaust buffer tank will enter the quench tower for cooling, and the quench tower exhaust gas cooling mainly adopts the evaporation method, by spraying a large amount of water mist into the quench tower, so that the water can quickly evaporate and absorb heat, so that the temperature of the exhaust gas will be rapidly reduced, so as to achieve the purpose of exhaust gas cooling in a short time.

Quenching tower cooling and discharging gas will enter the exhaust gas absorption tower for processing, when the gas into the exhaust gas absorption tower, the spray device above the exhaust gas absorption tower will start to work, the spray device will mainly spray lye, the main harmful gas of the tail gas is hydrogen chloride gas and sulfuric acid droplets and nitric acid gas, these are acid gases, the use of lye spray can treat these acid gases well, the sprayed liquid will enter the spray circulation pump.

The spray circulation pump will collect the liquid after spraying, and then a part of the liquid will be circulated to the exhaust gas absorption tower and continue to combine with the lye liquid as the spray liquid, and the other part of the liquid will be tested by PH value, if the PH value reaches the discharge standard, it will be directly discharged, otherwise the PH value will continue to be adjusted until the discharge standard is reached.

The sprayed gas will be adsorbed by activated carbon to remove harmful gases, and then the dust in the remaining treated gas is removed by using the filter function of the bag filter, so as to reduce the

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emission of floating particles, so that the final exhaust gas meets the emission standard, and the purpose of harmless emission of the entire device is realized.

3. Feasibility analysis

3.1 Mathematical model of material distribution in the axial bed in a rotary kiln

$$\frac{dh}{dx}=\frac{3\tan\theta}{4\pi V}F_V\left[R^2-(h-R)^2\right]^{-1.5}-\frac{\tan\varphi}{\cos\theta} \tag{8}$$

h is the height of the bed;

X is the axial length;

θ is the dynamic resting angle of the material;

V is the volume of the rotary kiln;

F_V is the feed volume flow;

R is the radius of the rotary kiln;

$\varphi$is the tilt angle of the rotary kiln.

The cone top of the insulation and carbonization area is the charcoal outlet of the furnace body of the carbonization equipment, which needs to be connected with the discharge conveying spiral, the size should not be too large, the design inner diameter is 500mm, the inner diameter of the cone bottom and the design value of the cone height are 860 and 820mm, the discharge frequency is 1 time / hour, and the maximum production capacity of the equipment is 152kg/h.

3.2 Reserve and demand calculations

$$m_2=\frac{1}{4}\rho_2\pi\left(D_2^2-D_1^2\right)h_2 \tag{9}$$

$$m_2\geq\frac{m_1}{\mu} \tag{10}$$

m_2 is the mass of the material in the drying area, kg;

ρ_2 is the bulk density of pellet fuel, 600kg/m^3;

D_2 is the diameter of the furnace in the drying area, m;

D_1 is the outer diameter of the drying cylinder, m;

h_2 is the effective height of the drying zone, m;

μ is the biochar yield of the equipment.

The inner diameter of the furnace body is designed to be 980mm, and when the inner diameter and height of the drying drum are 600 and 1650mm respectively, the total mass of pellet fuel that can be accommodated in the drying area is 467kg. The biochar yield μ of the equipment is 0.33, and the minimum material requirement corresponding to the insulation and carbonization area is 462kg, which can meet the design requirements.

3.3 Heat consumption in the drying section

Including the heat consumption of pellet fuel heating, the heat consumption of water evaporation, the sensible heat carried away by the exhaust gas and the heat dissipation of the furnace body, because the proportion of heat dissipation of the furnace body is very small, it is negligible.

$$I=I_I+I_s+I_g \tag{11}$$

$$I_1=(q-M_s)\times(T_{I2}-T_{I1})\times C \tag{12}$$

$$I_s=M_s\gamma \tag{13}$$

$$I_g=G_g\left(T_{g2}-T_{g1}\right)c_p \tag{14}$$

I_I is the heat consumption of pellet fuel heating, KJ/h;

I_s is the heat consumption of water evaporation, KJ/h;

I_g brings out sensible heat for exhaust gas, KJ/h;

q is the production capacity of the drying section, 462Kg/h;

M_s is the amount of evaporation water in the drying section hour, kg/h;

T_{I1} is the original temperature of the material, 20 ℃;

T_{I2} is the maximum temperature after the pellet fuel is heated, 550 ℃;

C is the specific heat capacity of pellet fuel, 1.5KJ/(kg ·K);

γ is the heat consumption of evaporating 1Kg of water, 2596KJ/kg;

G_g is the mass air volume of air, 528kg/h;

T_{g2} is the temperature of exhaust gas discharge, 45 ℃;

T_{g1} is the atmospheric temperature, 20 ℃;

C_p is the specific heat capacity of air, KJ/(Kg ·K)

The heat consumption of the drying section is the heat required for the drying of the raw material corresponding to the charcoal at one time, which also includes the heat consumption of the material heating in the pyrolysis zone, the moisture content of the raw material is calculated according to 7%, the total heat consumption is 450727.9KJ, the calorific value of pellet fuel is 18000KJ/kg, and the amount of pellet fuel to be burned is 25.04kg, accounting for 5.4% of the total raw material.

The discharge interval is 1h, and the calculation formula of the hourly net productivity of the equipment is:

$$Q=\frac{W(1-H)}{t(1-12\%)} \tag{15}$$

Q is the working hour productivity, kg/h;

W is biochar mass, kg;

H is the water content of biochar, %;

t is the time interval between charcoal, h.

3.4 Biochar yield

The mass ratio of biochar yield to the required amount of raw materials is calculated as:

$$D=\frac{W(1-H)}{V(1-J)}\times 100\% \tag{16}$$

D is the yield of biochar, %;

V is the quality of the raw material, g;

J is the water content of raw materials, %.

The electrical energy required for the unit output of biochar is calculated as follows:

$$G_n=\frac{G_{nz}(1-12\%)}{1000W(1-H)} \tag{17}$$

G_n is tons of carbon electricity consumption, kW ·h;

G_{nz} is the total power consumption, kW ·h;

According to the consumption of the material can maximize the guarantee of biomass fuel reverse combustion to provide the maximum heat for the pyrolysis reaction, the calculation of heat consumption can be calculated by calculating the heat required for drying, the heat of drying can calculate the charcoal yield of biotechnology, the two subtraction can calculate the heat that can be provided to solid waste pyrolysis, and then calculate how much mass of flammable gas can be produced according to the calorific value difference of the product before and after pyrolysis.

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4. Conclusion

The heat provided by the biomass fuel in the reverse combustion furnace is enough for the complete reaction of hazardous waste in the pyrolysis furnace, and the combustible gas generated by the pyrolysis reaction in the pyrolysis furnace is supplied to the biomass fuel through the pipeline circulation and the drying operation of the hot blast furnace, which makes better use of biomass fuel while thoroughly harmless treatment of hazardous waste, and realizes heat recycling in the overall device.

1) The combustible gas combustion cycle heating method is adopted, and the heat generated by combustion will be pyrolyzed and dried for recycling, so as to realize the complete recycling of the heat energy of the system.

2) Using the reverse combustion principle to process biomass fuel pellets, provide heat for the pyrolysis furnace, one system to process hazardous waste and biomass fuel at the same time.

3) Using the composite pyrolysis furnace structure, the temperature in the pyrolysis furnace is increased and the heating of hazardous waste in the pyrolysis furnace is more uniform, and the treatment rate of hazardous waste is improved.

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