Discussion on waste incineration power generation and its process calculation

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Abstract. Waste incineration power generation not only can reduce the pollution caused by the landfill, and can replace part of fossil fuels, has a dual effect to reduce emissions. Science of garbage incineration method has the advantages of less land, reduction and harmless. In this paper, on the basis of a lot of reading related literature both at home and abroad, discusses in detail the principle of waste incineration power generation technology, equipment, processes, and development situation at home and abroad, made more comprehensive for its preliminary feasibility study. On this basis, the waste incineration power generation technology is expounded in detail.

1. Introduction

Sanitary landfill, incineration and high-temperature compost are the main methods for urban waste disposal. Although the sanitary landfill method is easy to implement and has a large amount of processing, it causes secondary pollution to the natural resources such as soil, atmosphere, and groundwater. The use of the composting method to dispose of rubbish requires a high organic content of the rubbish. It is difficult to reduce the rubbish, and it occupies a large amount of precious land resources, which has a great destructive effect on ecological balance (1-3). In contrast, the incineration method is the most effective method. It can basically realize the resource-based, low-harmful and reduced-quantity requirements for the treatment of municipal solid waste (4). The incineration method burns combustible components in the garbage at a high temperature (800°C. to 1000°C.), and the combustible components are fully oxidized and eventually become harmless and stable ash. Incineration generally allows for a substantial reduction in waste, greatly reducing land occupation and recovering thermal energy for heating and power generation. Incineration is a kind of urban domestic waste treatment technology widely used in some developed countries in the world.

After incineration treatment, waste can be reduced by 80% and reduced in volume by more than 85%. Furthermore, high-temperature incineration can eliminate a large number of pathogenic bacteria and toxic substances, and reduce the degree of harmful bacteria contaminating the environment; the ash residue obtained after waste treatment can be used as Paving materials for roads can also be processed into building materials, turning waste into treasure; the heat energy generated by the waste incineration process can be collected and used for heating, cooling, and power generation (5-7). This will not only reduce the cost of waste disposal, but also enable the comprehensive utilization of energy. In short, in the environment where the environmental situation is increasingly severe and environmental protection is becoming increasingly urgent, the prospects for waste incineration are bright.
2. Status of waste incineration power generation

2.1. Foreign Waste Incineration Power Generation Status

Garbage incineration has a history of over 100 years. In 1896 and 1898, Hamburg, Germany and Paris, France, successively established the world's first domestic waste incineration plant, and began the engineering application of domestic waste incineration technology. Since the late 1970s, there have been controlled incineration projects, integrated smoke and dust treatment, and waste heat reuse. Urban waste power generation is a new technology developed in the past 30 years. Starting from the 1970s, with the resource and energy crisis, developed countries have adopted a “resources” strategy for waste disposal. Therefore, waste power stations are rapidly developing in developed countries.

2.2. Domestic waste incineration power generation status

Because of the practice of waste incineration power generation in foreign countries and the increasingly prominent problem of “garbage besieging” in urban development, China’s waste incineration power generation capacity has developed rapidly in recent years. According to statistics, by the end of 2010, 120 waste incineration plants have been built across the country, of which 66 were built and 54 were under construction. More than 70% of incineration plants are concentrated in the economically advanced and densely populated areas in the east. The top four cities in Guangdong, Zhejiang, Jiangsu, and 4 municipalities directly account for nearly 60% of the national total.

3. Design goals

The design task of this design is to complete the incineration plant waste incineration conditions and limited oxygen conditions design and material balance, heat balance diagram and the calculation of power generation.

3.1. Process calculation

3.2. Normal oxygen combustion calculation

3.2.1. Theoretical air requirement

Taking solid-state carbon combustion as an example, 1kmol of O₂ is required for complete combustion of 1kmol of C (ie, 12kg of carbon), because in the standard case, 1kmol of O₂ has a volume of 22.4Nm³.

For other flammable components, the theoretical air volume is as shown in the following table.

| Combustible ingredients | The amount of oxygen required \( V_{ox}^0 /\text{Nm}^3/\text{kg} \) | Theoretical air volume \( V_h^0 /\text{Nm}^3/\text{kg} \) |
|-------------------------|--------------------------------|--------------------------------|
| C \( C_{ar} \)         | \( \frac{22.4}{12} = 1.866 \) | \( \frac{1.866}{0.21} = 8.89 \) |
| H \( H_{ar} \)         | \( \frac{0.5 \times 22.4}{2.016} = 5.55 \) | \( \frac{5.55}{0.21} = 26.5 \) |
| S \( S_{ar} \)         | \( \frac{22.4}{32} = 0.7 \) | \( \frac{0.7}{0.21} = 3.33 \) |
From this it can be calculated that the amount of air required for complete combustion of 1 kg of garbage is

\[ V_k^0 = 8.89 \frac{C_w}{100} + 26.5 \frac{H_w}{100} + 3.33 \frac{S_w}{100} - 3.33 \frac{O_w}{100} \text{ Nm}^3 / \text{kg} \]

\[ = 0.0889(C_w + 0.375S_w + 0.265) - 0.0333O_w \]

\[ V_k = 0.0889(24.19 + 0.375 \times 1.55 + 0.265 \times 0.19 - 0.0333 \times 9.23) = 2.2602 \text{ Nm}^3 / \text{kg} \]

3.2.2 Actual air supply calculation

In the design, the actual air consumption is calculated as \( V_k \).

The oxygen content of the flue gas is 6%, and the air excess coefficient is \( n=1.400 \), the actual air consumption is:

\[ V_k = \alpha \cdot V_k^0 = 1.4 \times 2.2602 = 3.1643 \text{ Nm}^3 / \text{kg} \]

3.2.3. Material balance calculation during incineration

According to the law of conservation of mass, the mass of material that is fed into the combustion system is equal to the mass of material that is output. The formula is as follows:

\[ M_{1, \text{input}} + M_{2, \text{input}} + M_{3, \text{input}} + M_{4, \text{input}} = M_{1, \text{output}} + M_{2, \text{output}} + M_{3, \text{output}} + M_{4, \text{output}} + M_{5, \text{output}} \]

3.2.3. Oxygen-limited combustion pyrolysis gasification material balance

Table 2 1000kg garbage temperature pyrolysis component table / kmol

| CH₄   | CO    | CO₂   | H₂    | N₂    | H₂S   | H₂O   |
|-------|-------|-------|-------|-------|-------|-------|
| 1.9227| 4.3266| 1.4422| 7.6906| 0.2107| 0.0594| 20.6111|

If the carbon reduction rate is set to 5%, then the total amount of carbon reacted during the entire gasification process is 95%. The subsequent reaction carbon amount is:

\[ 1000 \times \frac{C_w}{12} \times 95\% \times CO_{\text{heating}} - CO_{\text{heating}} - CH_4 \text{heating} = 1000 \times \frac{24.19}{12} \times 0.95 \times (1.9227 - 4.3266 - 1.4422 - 7.6906) = 11.459 \text{kmol} \]

Change in composition caused by combustion reaction

Table 3 after combustion reaction gas component table / kmol

| CH₄   | CO    | CO₂   | H₂    | N₂    | H₂S   | H₂O   |
|-------|-------|-------|-------|-------|-------|-------|
| 1.9227| 8.0053| 6.6582| 7.6906| 0.2107| 0.0594| 20.6111|

3.2.4. CO2 Reductive reactions and changes in components caused by steam decomposition reactions. The gasification agent added during the reaction was air, and the air content was assumed to be 21% O2, 79% N2.

The volume of gas produced is converted to the standard volume:

\[ V_{\text{Gas}} = 22.4 \times n_{\text{Total}} = 22.4 \times 59.935 = 1231 \text{Nm}^3 \]

This shows that when the O/C molar ratio is 0.7, 1t waste pyrolysis gas production is 1231Nm³.

3.2.5. Oxygen-limited pyrolysis gas calorific value calculation

Combine the content of gas components into the above formula

\[ Q_{\text{net}} = 16.33 \times 10.797 + 3 \times 35.832 + 21.57 \times 12.697 = 5.7411 \text{MJ/Nm}^3 = 5741 \text{kJ/Nm}^3 \]

Oxygen-limited pyrolysis conditions heat balance

According to the literature, the pyrolysis temperature is 1100-1200°C, set at 1100°C, the mixed fuel inlet temperature is 40°C.

3.3. Calculation of power generation

3.3.1. Hourly waste-derived fuel RDF throughput

As mentioned earlier, the amount of daily garbage handled is 500t/d. In order to increase the calorific value of garbage, garbage is used as a derivative fuel RDF.

Generates 35% of RDF Recycled Fuel 500×35%=175t/d

Disposal of waste per hour \( G = 500 \times 1000 / 24 = 20833.33 \text{kg/h} \)
RDF throughput per hour: 
\[ G_{\text{RDF}} = 500 \times 35\% \times 1000 / 24 = 7291.67 \text{ kg/h} \]

3.3.2. Calculate heating value of RDF regenerative fuel \( Q_{\text{net,ar}} \)

The calorific value of RDF is at least 2500 kcal/kg, that is,

\[ Q_{\text{net,ar}} = 2500 \times 4.1868 = 10467.0 \text{ kJ/kg} \]

Heat release per hour of RDF regenerative fuel:

\[ Q_{\text{RDF}} = Q_{\text{net,ar}} \times G_{\text{RDF}} = 10467.0 \times 7291.67 = 7632.19 \times 10^4 \text{ kJ} \]

3.3.3. Thermal fluid volume and heat transfer calculation

According to the results of the material balance, 1t of waste gasification is 1200 Nm\(^3\), set up two gasifiers, then the amount of heat fluid generated per hour is:

\[ V_{\text{Heat}} = nV = 40000 \text{ Nm}^3/h \]

Then, the mass of the hot fluid \( M_{\text{Heat}} = \rho V_{\text{Heat}} = 51800 \text{ kg/h} \)

3.3.4. Flue gas heat transfer load calculation

The necessary process parameters are as follows:
- The inlet temperature of the flue gas is taken as 600°C and the outlet temperature is 100°C;
- Water inlet temperature is 20°C, steam outlet temperature is 180°C;
- Imported gas heat capacity 1.214 kJ/(kg \cdot ^\circ \text{C})
- Export smoke heat capacity 1.068 kJ/(kg \cdot ^\circ \text{C})

Therefore, the heat input \( Q_1 \) of the flue gas is:

\[ Q_1 = C M_{\text{Heat}} t = 3773.11 \times 10^4 \text{ kJ/h} \]

The amount of heat emitted by the flue gas \( Q_2 \) is:

\[ Q_2 = C M_{\text{Heat}} t = 553.22 \times 10^4 \text{ kJ/h} \]

Therefore, the heat exchange load of flue gas is:

\[ Q_{\text{Exchange}} = Q_1 - Q_2 = 3219.89 \times 10^4 \text{ kJ/h} \]

3.3.5. Power generation and steam volume calculation

From the saturated steam enthalpy table, we can see that:
- 1.5MPa 280°C superheated steam enthalpy 702.90 kcal/kg = 2942.90 kJ/kg;
- 2.4MPa saturated steam enthalpy 743.59 kcal/kg = 3113.26 kJ/kg

Then the heat load of flue gas can produce 1.5MPa 280°C. The amount of superheated steam is:

\[ M_{1.5} = Q_{\text{Exchange}} / h_{1.5} = 10941.21 \text{ kg/h} \]

This means that the single line available process steam volume is:

\[ M = 10941.21 \text{ kg/h} \]

Can produce 2.4MPa 280°C superheated steam:

\[ M_{2.4} = Q_{\text{Exchange}} / h_{2.4} = 10342.50 \text{ kg/h} \]

According to experience, the steam consumption rate \( u = 5.46 \text{ kg/kW/h} \)

Calculating the amount of electricity that turbine power can generate is:

\[ P_{\text{Calculation}} = M / u = 2003.89 \text{ kW/h} \]

Therefore, it is possible to select a hydrogen-cooled turbine with a rated power of 1500-1300 kW/h. 96% of turbine power generation can be connected to the grid, so the power of the Internet is:

\[ P_{\text{Internet}} = 1500 \times 96% = 1440 \text{ kw/h} \]

Assuming that the power generation steam consumption is 9000 kg/h, the amount of steam that can be used after the generation steam is deducted is:

\[ M_{\text{Technology}} = (10941.21 \times 2 - 9000) / 2 = 6441.21 \text{ kg/h} \]

When steam is designed to generate 8,000 continuous power generation hours per year, the actual amount of electricity that the steam turbine can use is 2003.89kw/h.

Therefore, the amount of electricity that can be generated online every year is:

\[ P_{\text{Internet}} = 2003.89 \times 8000 = 1603.11 \times 10^4 \text{ kw/h} \]

3.3.6. Oxygen limit- gas calorific value \( Q_{\text{net,ar}} \) and gas heat release

The calorific value of gas-fired power generation is at least 1000 kcal/kg. The gas-fired heat value has been calculated to be 5741 kJ/kg,

The hourly process gas volume is:

\[ V = 12802.4 \text{ Nm}^3/h \]

The amount of heat released per hour of gas is:

\[ Q_R = Q_{\text{net,ar}} \times G_R = 5741 \times 12802.4 = 65893.95 \text{ MJ} \]
3.3.7. Gas generator power generation

It is known that the rated load heat rate is 12MJ/kwh, so the calculated power generation power is

\[ P_c = \frac{Q_R}{12} = \frac{65893.95}{12} = 5491.16 \text{kw/h} \]

Follow the gas generator parameters in the following table.

| Engine rated power (Kw/h) | 400.00 |
|---------------------------|--------|
| engine model              | 8300D/M|
| Generator Model           | 400GFM |
| Basic power (Kw/h)        | 400.00 |
| Internet power (Kw/h)     | 400.00 |

Let’s set the number of gas generators to be \( n \):

\[ n = \frac{P_c}{400} = 13.7 \]

Therefore, 14 gas-fired generators are set up, and the amount of electricity that can be generated on the grid is \( P_{\text{Internet}} = 5600 \text{kw/h} \)

3.3.8. Thermal fluid volume and heat transfer calculation

According to the results of the material balance, the amount of heat fluid generated per hour is

\[ V_{\text{Heat}} = 36473.32 \text{Nm}^3/h \]

Then, the quality of the hot fluid \( M_{\text{Heat}} = \rho V_{\text{Heat}} = 1.295 \times 36473.32 = 47232.94 \text{kg/h} \)

3.3.9. Flue gas heat transfer load calculation

The necessary process parameters are as follows:

- The inlet temperature of the flue gas is 550°C and the outlet temperature is 100°C.
- Water inlet temperature is 20°C, steam outlet temperature is 180°C.
- Imported gas heat capacity 1.214kJ/(kg·℃)
- Export smoke heat capacity 1.068kJ/(kg·℃)

Therefore, the heat input \( Q_1 \) of the flue gas is:

\[ Q_1 = C M_{\text{Heat}} = 3153.74 \times 10^4 \text{kJ/h} \]

The amount of heat emitted by the flue gas \( Q_2 \) is:

\[ Q_2 = C M_{\text{Heat}} = 504.45 \times 10^4 \text{kJ/h} \]

Therefore, the heat exchange load of flue gas is:

\[ Q_{\text{Exchange}} = Q_1 - Q_2 = 2649.29 \times 10^4 \text{kJ/h} \]

3.3.10. Power generation and steam volume calculation

Saturated steam enthalpy table can be seen,

- 1.5MPa 280°C superheated steam enthalpy 702.90 kcal/kg=2942.90kJ/kg;
- 2.4MPa saturated steam enthalpy 743.59 kcal/kg=3113.26 kJ/kg

Then the heat load of flue gas can produce 1.5MPa 280°C. The amount of superheated steam is:

\[ M_{1.5} = \frac{Q_{\text{Exchange}}}{9002.31} \text{kg/h} \]

This means that the amount of process steam that can be used is:

\[ M = 9002.31 \text{kg/h} \]

Can produce 2.4MPa 280°C superheated steam \( M_{2.4} = \frac{Q_{\text{Exchange}}}{8509.70} \text{kg/h} \)

According to experience, the steam consumption rate is \( u = 5.46 \text{ kg/kw/h} \)

Calculating the amount of electricity that turbine power can generate is:

\[ P_{\text{Calculation}} = M/u = 1648.77 \text{kw/h} \]

Therefore, a hydrogen-cooled turbine with a rated power of 2000 kw/h can be selected. Turbine can be converted to online electricity 2000×96%=1920kw/h

Then gas power generation combined with steam power generation is

\[ P_{\text{Combine}} = 5200 + 1920 = 7120 \text{ kw/h} \]

The design of steam generates 8000 hours of continuous power each year.

\[ P_{\text{Internet}} = 7120 \times 8000 = 5696 \times 10^4 \text{ kw/h} \]
4. Conclusion

Garbage is an inevitable product of human industrial production and daily life. On the one hand, it poses a serious threat to the urban environment and human health. It is growing at a rate of 10% per year. On the other hand, rubbish is a growing resource. After research, the heat generated from burning 2t of rubbish is equivalent to 1t of coal (that is, about 400MW of electricity can be obtained by burning 1t of rubbish)\(^{(14)}\). The use of waste in power generation is fully and effectively used, and its "resource efficiency" is extremely impressive. At the same time, waste power generation is a "green" industry with huge potential. It is an increasingly compelling topic worthy of in-depth research. How to deal with municipal solid waste is one of the major environmental issues facing all countries in the world, and it is also an outstanding environmental issue in China. With the rapid development of China's economy, the large increase in urban population, the ever-increasing scale of the city, and the continuous improvement of people's living standards, the amount of domestic waste generated has increased year by year, and inevitably a large amount of waste has been discharged.

After the waste is incinerated, heat energy is released and smoke and solid residues are generated at the same time. The heat energy must be recovered, the flue gas must be purified, and the residue must be decomposed. This is an indispensable process for incineration. With the incineration method, care must be taken not to cause secondary air pollution.

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