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Mixed Waste Combustion Test Research and Calculation of Activation Energy

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Abstract. Thermo gravimetric combustion experiments [1] of the easy chopsticks, food bags, cotton and its mixed components were investigated, by the mixture experiment design program [2]. Then combustion characteristics curves of thermo gravimetric and thermo gravimetric differential, and each group point average activation energy [3] were obtained. Base on the average activation energy of each waste component combustion, the activation energy calculation empirical correlation which fits in various mixed waste combustion calculation can be set up through three Scheffe polynomials. In addition to the three vertices of the gravity method, which were used to conduct the mixed waste combustion test, and the results of mixed waste activation energy agree well with the activation energy calculated from the empirical correlation. Thus, the activation energy is correct. Application of this method plays an important role in the direction for the design of waste incinerator actually [4] and the waste combustion adjustment.

1.Introduction

Most domestic waste which was applied to combustion was composed by mixed solid waste of typical components. Among the mixed solid waste parameters of combustion characteristic, high or low activation energy dominated smooth ignition and stable combustion [5-7]. Thus, how to easily and accurately calculate the activation energy of mixed solid waste research was necessary. This paper built up a mixture test method, and carried out the mixed waste test by this method and the mixed solid waste was composed by chopsticks, cotton, food bags. And obtained an empirical correlation which could calculate mixed solid waste combustion activation energy by three times Scheffe polynomial. Finally the validation for this experience correlation had been done to get the convenience and available experience correlation of calculating mixed solid waste activation energy, and provide a direction for practical waste combustion engineering design.

2.Scheme design of mixed municipal solid waste combustion test

It is called a mixed material problem [8] in mathematics of the assorted properties of the compounds. By which the problem carried out is through the method of mixed material design. In order to optimize the experimental scheme, as well as to decrease the work load, the said scenario, which based on the principle of experimental design [4], was proposed. Mixed material problem is in fact a problem

concerning the distribution ratio. The problem is addressed frequently in industrial production, aside from agricultural production and scientific research. Mixed material refers to a mix or compound of assorted ingredient, such as concrete, medicine, feed, pesticides and so on. It is ingredients or components of mixed materials that make up mixed material, the former acting as experimental factors in mixed material experiment.

Through mixed material experiment design, ingredients should be at least three kinds, whose content expressed strictly in percentage. Apparently, each content should not be subtractive, and the sum of these factors should be 1. y the test indicator, X_1, X_2, ..., XP the percentage of each gradient, respectively.

There is

$x_j \geq 0$ $(j=1, 2, ..., p)$, and $x_1 + x_2 + ... + x_p = 1$

The above logical constraint is a mixed material condition. Apparently, these experimental factors are neither dimensional, not relating to the total amount of material. The design of mixed material [9] is subjected to particular constraints. Therefore, experiments are carried out prudently to decrease the number of experimental sites. With a wide use in reality, there comes in divers of design methods. Single-focus of mixed material design method is applied in this paper.

Simplex refers to the number of nodes equal to the coordinate space dimension of convex polygon. Design of the Simplex mixed material, simplex is usually used, like triangle, tetrahedron etc. In the design of mixed material, component X_J ranges from a height of 1 p-dimensional Simplex. Vertex represents a single composition, which constitutes mixed material. Dots on the edge represent mixed materials which are components of two compositions, points on the plane represent more than two but less than p kinds of mixed materials, however, interior point of a simplex is representative of all P elements composed of mixed materials. Due to crucible capability of the thermobalance is limited, this article only proposed research of three typical waste components (toilet paper, chopsticks, food bag) a study of the combustion characteristics of mixed materials. This following talk is more about p=3 mixed materials design.

Three-dimensional-simplex is a triangle ABC in the plane, when p=3. Three vertices of the regular triangle (A, B, C) represent mixed materials of single component, the points of AB, AC, BC on three sides represent mixed materials of two kinds of components, while the point within the equilateral triangle represent of mixed materials three kinds of components. Obviously, the triangle is the point set of three-component mixing materials. Then define X_1, X_2 points are the distance from $R(X_1, X_2, X_3)$ to the side BC, AC, AB in the equilateral triangle ABC separately.

It is clear that the X_1, X_2, X_3 met $X_j \geq 0$ (j=1, 2, 3), $X_1 + X_2 + X_3 = 1$

Therefore, the point R (X_1, X_2, X_3) of the equilateral triangle ABC represent the proportion of three-component mixing materials, that is to say, region detection of the mixed-material is the equilateral triangle.

In this triangle, any two vertices compose a new edge, and the halfway point of the edge is the centre of it, it is called two vertex centers of gravity. Triangle center of gravity, called the gravity of three vertices. The focus of each vertex is vertex itself, known as the vertex weight. It is called single-focus mixed materials design, if you only take the vertex weight as a testing point, when such a design will be done.

This article uses the design of 3 ingredients (p=3) single-centre gravity mixed material, test points: N=2p-1=7, the following test point consisting of test plan:

One vertex center of gravity: (1, 0, 0), (0, 1, 0), (0, 0, 1);

Two vertex centers of gravity: (0.5, 0.5, 0), (0.5, 0, 0.5), (0, 0.5, 0.5);

Three vertex centers of gravity: (1/3, 1/3, 1/3).

This seven typical experimental conditions can be represented in all kinds of working conditions by this three kinds of waste component, and can be applied to the empirical formula, which can calculate the mixing waste activation energy of all different ratio, using data processing, according to the mixed materials principle of design above.

3.Combustion testing process and results

Typical composition of the waste can be divided into several cases, the ones included cotton cloth, convenient chopsticks and food, the ones included food bags and convenient chopsticks, the ones included cotton and food bags, the ones included convenient chopsticks and, cotton cloth, and another included cotton cloth, chopsticks and food bags. Quality of experimental samples is 10mg, temperature rise rate is 20 ℃/min. Oxygen was injected into the combustion chamber combustion in the test with 60 mL/min. Specific test conditions were listed at Table 1. Base on the blend material test method, this investigation employed the mixed materials design program for a single gravity experiment, and was showed in table2.

Table 1. Testing condition

Testing condition	Fuel types	Fuel quality (mg)	Speed of temperature rise(°C/min)	End test Temperature(°C)	atmosphere (pure O_2, ml/min)
1	Cotton cloth	10	20	900	60
2	Convenient chopsticks	10	20	900	60
3	Food bags	10	20	900	60
4	Convenient chopsticks Food bag ,	10	20	900	60
5	Cotton cloth, Food bag	10	20	900	60
6	Convenient, chopsticks Cotton cloth	10	20	900	60
7	Convenient chopsticks, Cotton cloth, Food bags	10	20	900	60

Table 2. Testing condition

Test number	Test point	Cotton cloth	Convenient chopsticks	Food bags
1	Vertex center of gravity	1	0	0
2	Vertex center of gravity	0	1	0
3	Vertex center of gravity	0	0	1
4	Two vertex centers of gravity	0.5	0.5	0
5	Two vertex centers of gravity	0.5	0	0.5
6	Two vertex centers of gravity	0	0.5	0.5
7	Three vertex centers of gravity	1/3	1/3	1/3

The TG curve and DTG curve of all component garbage test could be seen at figure 1 to figure 14, W_0 is the initial quality of the specimens (mg), W is the quality of combustion of the sample at a specific time (mg).

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Cotton cloth was preheated when the temperature is 100 above, and combustion is begun from 200. When temperature is arrive 315, the curve of the combustion is the most severe. Until cotton cloth was burn out, the temperature reached 400. Its TG curve and DTG curve as showed in figure1 to 2:
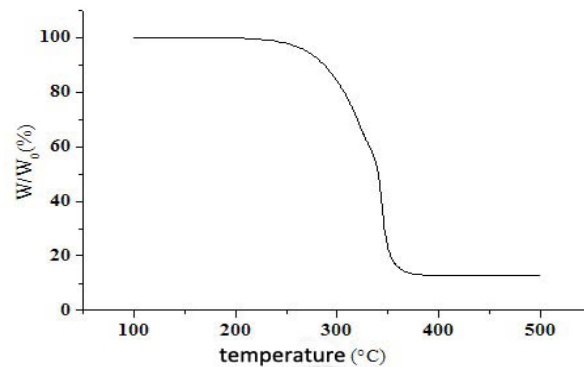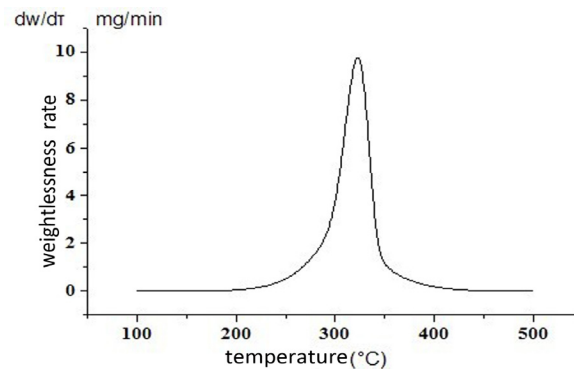
Figure 1. mass ratio VS temperature for cotton cloth

Figure 2. weightlessness rate VS temperature for cotton cloth

Convenient chopsticks was preheated when the temperature is 100℃, and the combustion is begun from 150 above, when temperature is arrive 300 the combustion is the most severe. Until convenient chopsticks was burn out, the temperature is 350. Its TG curve and DTG curve as showed in figure3 to 4:
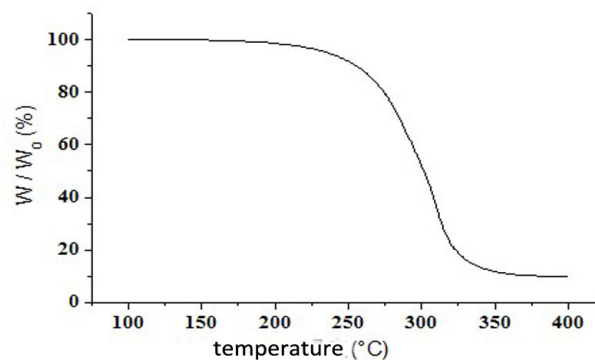
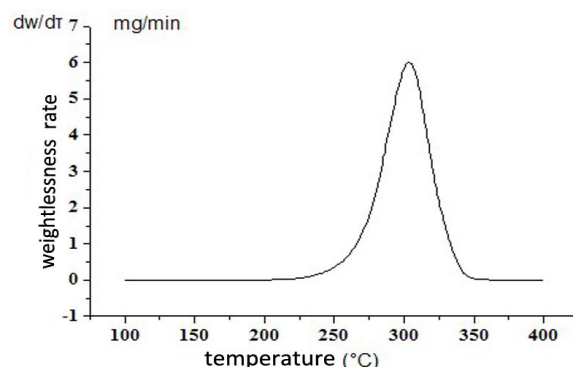Figure 3. mass ratio VS temperature for convenient chopsticks

Figure 4. weightlessness rate VS temperature for convenient chopsticks

Food bags was preheated when the temperature is 100,and combustion is begun from 215 above, when temperature is arrive 375 the combustion is the most severe Until food bags were burn out,the temperature is 450. Its TG curve and DTG curve as showed in figure5 to 6:
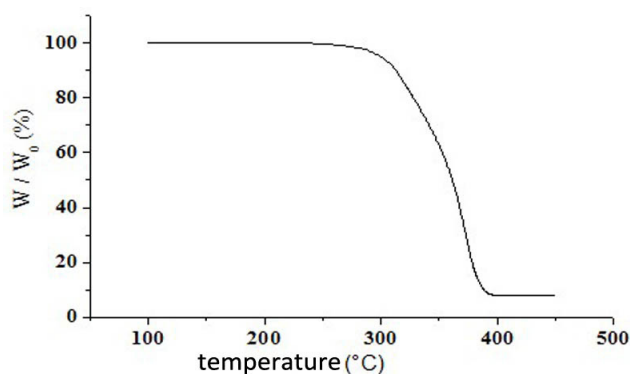

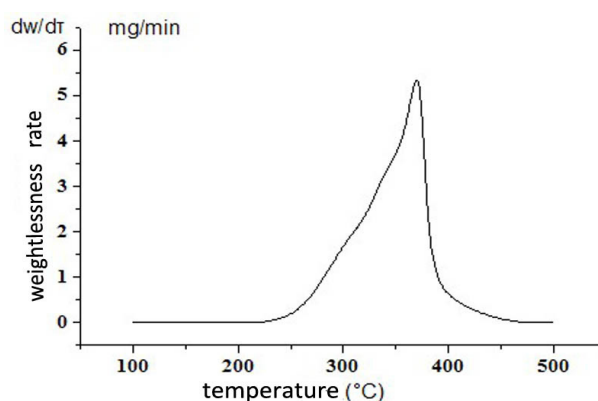Figure 5. mass ratio VS temperature for food bags

Figure 6. weightlessness rate VS temperature for food bags

Convenient chopsticks and cotton cloth were preheated when the temperature is 100, and combustion is begun from 115 above. When temperature is 315 the combustion arrive the first peak, which is the convenient chopsticks severe burns. When the temperature is 350 the cotton cloth will burn out while the food bags has begun to burn ,when the temperature is 375 the combustion arrive the second peak, which is the cotton cloth severe burns, until they all burn out, the temperature is 450.The TG curve and DTG curve as showed in figure7 to 8:
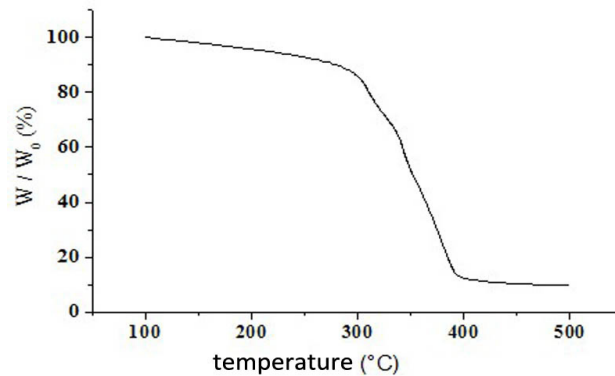
Figure 7. mass ratio VS temperature for convenient chopsticks and cotton cloth
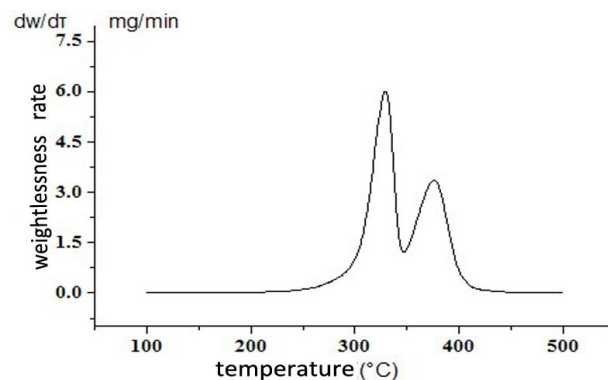

Figure 8. weightlessness rate VS temperature for convenient chopsticks and cotton cloth

Cotton cloth and food bags were preheated when the temperature is 100, and combustion is begun from 150 above. When temperature is 330 the combustion arrives the first peak, which is the cotton cloth severe burns. When the temperature is 350 the cotton cloth will burn out while the food bags have begun to burn .when the temperature is 375 the combustion arrive the second peak, which is the food bags severe burns, until they all burn ,out the temperature is 450.The TG curve and DTG curve as showed in figure9 to 10:
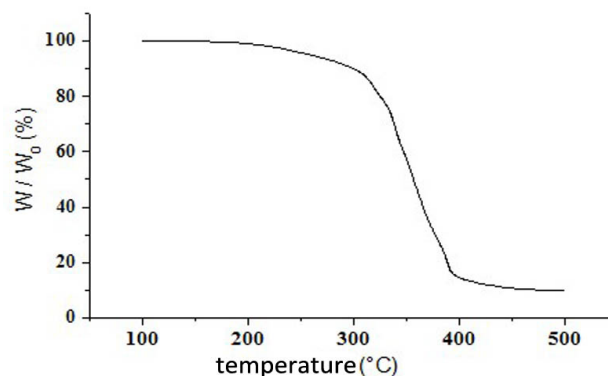

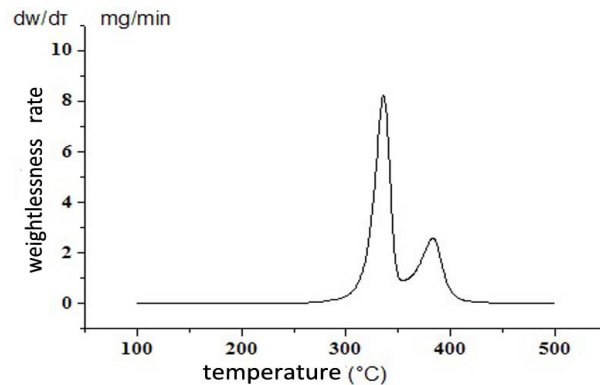Figure 9. mass ratio VS temperature for cotton cloth and food bags

Figure 10. weightlessness rate VS temperature for cotton cloth and food bags

Convenient chopsticks and food bags were preheated when the temperature is 100, and combustion is begun from 150 above. When temperature is 315 the combustion arrive the first peak, which is the convenient chopsticks severe burns. When the temperature is 335 the cotton cloth will burn out while the food bags have begun to burn .When the temperature is 345 the combustion arrive the second peak, which is the food bags severe burns, until they all burn out, the temperature is 400.The TG curve and DTG curve as showed in figure11 to 12:
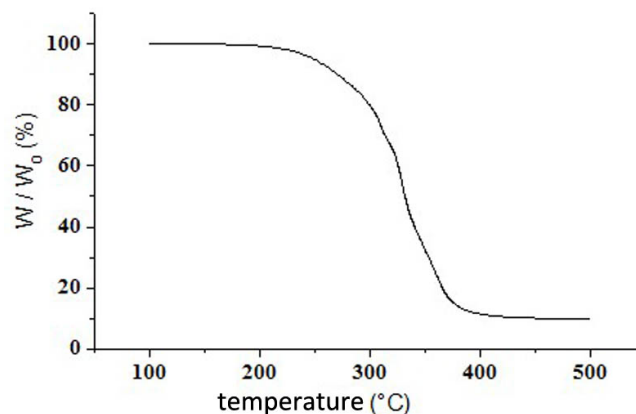

Figure 11. mass ratio VS temperature for convenient chopsticks and food bags

Figure 12. weightlessness rate VS temperature for convenient chopsticks and food bags

Convenient chopsticks, cotton cloth and food bags were preheated when the temperature is 100, and combustion is begun from 150 above. When temperature is 315 the combustion arrives the first peak, which is the convenient chopsticks severe burns. When the temperature is 335 the cotton cloth will burn out, while the cotton cloth has begun to burn, when the temperature is 345 the combustion

arrives the second peak, which is the cotton cloth severe burns. When the temperature is 370 the cotton cloth will burn out, while the food bags has begun to burn .When the temperature is 380 the combustion arrive the third peak, which is the food bags severe burns ,until they all burn out, the temperature is 450.The TG curve and DTG curve as showed in figure13 to 14:

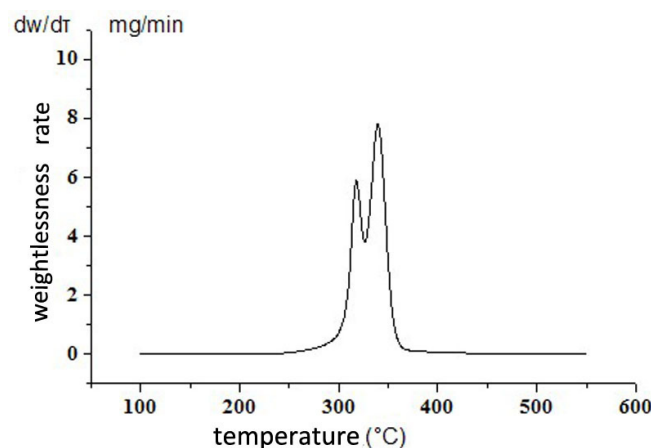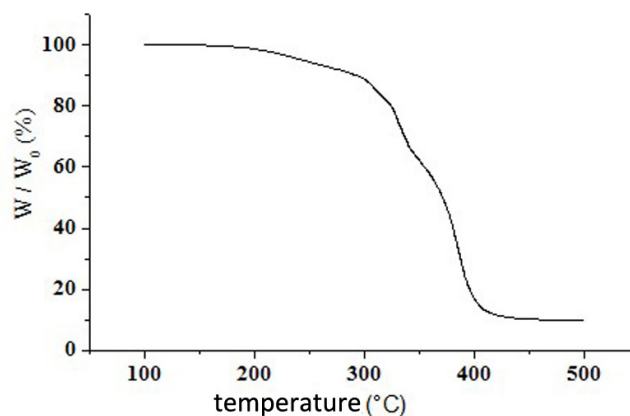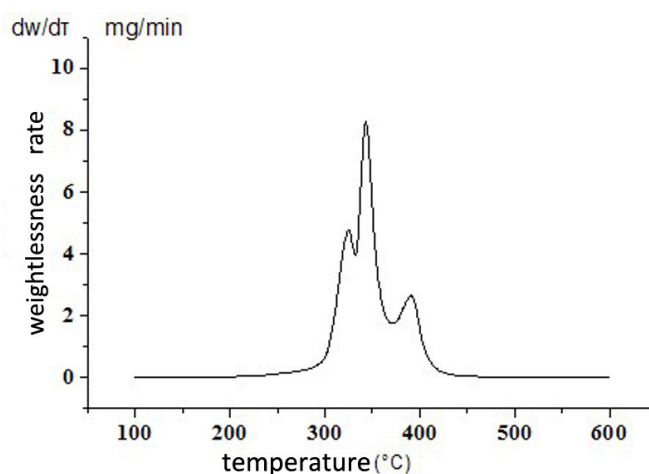Figure 13. mass ratio VS temperature for convenient chopsticks , cotton cloth and food bags

Figure 14. weightlessness rate VS temperature for convenient chopsticks , cotton cloth and food bags

According to each component of waste combustion characteristic, the average activation energy of each component under the condition of the test could be obtained, which was listed in Table 3.

Table 3. Testing result

Test t number	Test point	Cotton cloth	Convenient chopsticks	Food bags	y(Average Y energy, kJ/mol)
1	Vertex center of gravity	1	0	0	113.07
2	Vertex center of gravity	0	1	0	123.47
3	Vertex center of gravity	0	0	1	120.22
4	Two vertex centers of gravity	1/2	1/2	0	88.86

Table 3. Testing result (continued)

Test t number	Test point	Cotton cloth	Convenient chopsticks	Food bags	y(Average Y energy, kJ/mol)
5	Two vertex centers of gravity	1/2	0	1/2	93.77

| 6 | Two vertex centers of gravity | 0 | 1/2 | 1/2 | 103.01 |
| 7 | Three vertex centers of gravity | 1/3 | 1/3 | 1/3 | 83.52 |

Table 4. Test and calculation of results

Test number	Test point	Cotton cloth	Convenient chopsticks	Food bags	Average activation energy(kJ/mol)
1	Vertex center of gravity	1	0	0	113.07
2	Vertex center of gravity	0	1	0	123.47
3	Vertex center of gravity	0	0	1	120.22
4	Two vertex centers of gravity	1/2	1/2	0	88.86
5	Two vertex centers of gravity	1/2	0	1/2	93.77
6	Two vertex centers of gravity	0	1/2	1/2	103.01
7	Three vertex centers of gravity	1/3	1/3	1/3	83.52

4.Calculation model of mixed waste activation energy

Frequency factor (K_0) and activation energy (E) [10] values can be calculated according to coordinates of burning the distribution curve. But the compositions of actual waste are widely different. The percentage of all kinds of components is not the same also. Therefore, it is necessary to establish a simple and practical formulae which can calculate different ratios of waste activation energy as a reference for researchers. Due to the crucible volume of thermobalance is limited, this article only has carried on the experiment for mixed waste which is composed by chopsticks, cotton cloth, food bags, aimed at to find out the thinking about mixed waste activation energy.

Generally, using Scheffe polynomial from [4] for the regression equation of p components of mixed materials design. In most cases, using three Schaffe polynomials which can fully meet the precision requirements, its expression is:

$$y = \sum_{j=1}^{p} b_j x_j + \sum_{h\langle j} b_{hj} x_h x_j + \sum_{h\langle j} b_{hj} x_h x_j (x_h - x_j) + \sum_{h\langle j\langle k} b_{hjk} x_h x_j x_k \tag{1}$$

For three kinds of components of mixed solid waste of this article research, the ternary cubic form regression equation you want as follows:

$$y = \sum_{j=1}^{3} b_j x_j + \sum_{h\langle j} b_{hj} x_h x_j + b_{123} x_1 x_2 x_3 \tag{2}$$

Regression equation of the regression coefficient calculating formula is:

$b_j = y_j$, (j=1,2,3); $b_{hj} = 4y_{hj} - 2(y_h+y_j)$,(h, j=1,2,3 h<j);

$b_{123}=27y_{123}+3(y_1+y_2+y_3 - 12 (y_{12}+y_{13}+y_{23})$

Specific expression of regression coefficients are as follows:

$b_1 = y_1$, $b_2 = y_2$, $b_3 = y_3$, $b_{12} = 4y_{12} - 2 (y_1+y_2)$;

$b_{13}=4y_{13} - 2 (y_1+y_3)$, $b_{23} = 4y_{23} - 2 (y_2+y_3)$;

$b_{123}=27y_{123}+3(y_1+y_2+y_3) - 12 (y_{12}+y_{13}+y_{23})$

X_J is the percentage of each component, y_{hjk} is activation energy of result in seven different testing conditions in table 3. Put the parameters into the formula (2), draw the empirical formula as follows:

$y=113.07X_1+123.47X_2+120.22X_3 - 117.64X_1X_2 -91.5X_1X_3 - 75.34X_2X_3 - 103.56X_1X_2X_3$ $\tag{3}$

X_1 is the percentage of convenient chopsticks in this equation, X_2 is the percentage of food bags, X_3 is the percentage of cotton cloth, y is activation energy of mixed waste in different ratios, kJ/mol.

As the component of the mixed waste is far more than three, so If there is more conditions that should experimental study on mixing waste with more components, to find out the formulas of more wider adaptability, But the method of regression and data processing of the formula is the same.

5.Experimental verification of mixed municipal solid waste experience
In order to confirmation empirical formulas (3) which were calculated above correct or not. Under the present experimental conditions, this article has done the experiment for the next three kinds of working conditions, and the comparison between experimental and calculating results as showed in Table 4, the measured weight TG curve sees Figure 15.
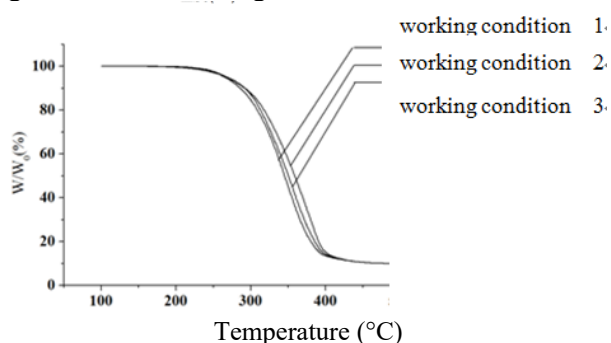

Figure 15. Combustion process of cotton cloth, convenient chopsticks, food bags TG curves

From table 4 and figure 15, the test results and calculation results fit very well, maximum deviation between experimental and calculated values is not more than 5%, so this formula has greater credibility, so it can be widely applied. Because the test of mixing waste activation energy is very complexity, so it's a convenient and practical good way of using this empirical formula to calculate the activation energy of mixed waste, under the condition of knowing activation energy of all kinds of a single component. Moreover, it has important guiding significance for adjustment of garbage incinerator and garbage combustion process, through the application of calculation theory of activation energy of mixed waste.

6.Conclution
1. A design of three different wastes and mixed materials combustion test of the simplex centroid was established, which was based on a mixed-materials testing method. Seven typical experimental conditions could include the various combinations of the three kinds of waste components.

2. The investigation of thermogravimetric combustion for the mixture of cotton cloth, convenient chopsticks, food bags was carried out. The differential thermal combustion characteristic curve and thermo gravimetric curve and all components, and each component of the average activation energy was obtained.

3. According to three Scheffe polynomials and waste combustion components, the average activation energy, an empirical correlation which was available to calculate mixed municipal solid waste activation energy of various mixing ratio had been established.

4. With the gravity method of three vertices, a test of mixed waste with various mixing ratio of cotton cloth, chopsticks and food composition had been done. . According to the mixed municipal solid waste combustion test values, calculated values of activation energy and TG curves of different mixture components. It could be found that the test results were agreeing well with the calculation. The empirical correlation was available to calculate the activation energy of mixed municipal solid waste.

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