DEVELOPMENT OF AN INCINERATION SYSTEM FOR THE LOW-LEVEL RADIOACTIVE SOLID WASTE

Ryota Nakanishi, Mamoru Suyari, Tsuyoshi Noura, Akiyoshi Yamane KOBE STEEL, LTD., JAPAN

ABSTRACT

In Kobe Steel Ltd., an incineration system for processing low-level radioactive polymeric solid waste has been developed, which was necessary from the viewpoint of waste volume reduction in Japan. The furnace of this incineration system has the following features:

- A controlled air type fix-bed furnace with a unique grate design.
- In order to control dioxins emission, the furnace wall is refractory-lined to maintain the furnace temperature at 1273K or higher.
- For reduction of CO emission, which has correlation with dioxins, the incinerator adopts air-stage combustion and control of combustion air, which is injected separately into the primary combustion zone from the grates and the secondary combustion zone from the second airports.
- This incinerator adopts intermittent supply (batch supply) and the storage box is fed as it is.

This paper introduces concepts of the new incineration system, acquisition of evaluation data for design of the furnace in a pilot test and an estimation of the performance of a commercial plant. In the pilot test, combustion characteristics of plastic and rubber wastes were evaluated including the combustion rate and emissions of unburned combustible contents. Although the combustion rate of plastics is higher than rag paper and cloth, the pressure fluctuation is not excessive which shows that it can be controlled. Moreover, there is only slight emission of unburned contents.

A new grate for plastics incineration was also developed. In the pilot test, tests were done for the following points: cooling performance, sticking of unburned combustible contents and leak of plastic wastes through the grate after melting. The new grate performed well under the test conditions, which shows that the grate can be of practical use. In the pilot test, process performance was evaluated, and the following results were obtained. In a secondary-air controlled test for reduction of dioxins, good results were obtained which gave rise to optimism that an emission rate of 0.1ng/Nm3TEQ can be achieved. Estimation of pressure fluctuation can be predicted from the furnace temperature and pressure loss at the flue gas duct. As for prediction of the performance of a commercial plant, prediction of furnace pressures fluctuation, evaluation of operation pattern and evaluation of the scale up of the furnace by clinker trouble were carried. Finally, operating temperature guidelines for a commercial plant were obtained, as the primary combustion zone is between 923K and 1373K and the furnace exit temperature was over 1123K.
INTRODUCTION

In Japan, low-level radioactive solid waste, consisting mainly of rag paper and cloth, is usually incinerated, but polymeric waste including rubber, polyethylene and polyvinyl chloride plastic are securely stored without incineration. It is difficult to guarantee security of a site for long term, and it is also necessary to incinerate such polymeric waste from the viewpoint of waste volume reduction. Though incineration of polyvinyl chloride (PVC) have difficulty of hydrochloric acid treatment, volume reduction is necessary because storage costs is high in Japan.

The combustion characteristics of rubber and polymeric waste is different from other waste such as the heating value is high and pyrolysis rate is high. The following problems will arise:

- Pressure fluctuation in the furnace may be moderately large.
- Dioxins emission level will be high.
- Plastic waste will melt in the furnace and leak through the grate.

Use of a water-cooling wall is one measure of the problem of furnace pressure fluctuation (1). Such a furnace lowers temperature in the furnace and can control the pressure fluctuation associated with combustion. A batch supply is preferred not to be adopted, because it may be occurred the pressure fluctuation. However, there is another problem in that the emission of dioxins will be high under low temperature conditions.

Also, in the incinerator for plastic waste, which melts before the incineration, wastes is incinerated by burner on the cup made of refractory (2). However, there is a problem that the amount of unburned carbon will be high as the waste is not burned with sufficient air.

In Kobe Steel Ltd., an incineration furnace was developed to solve the above problems. This incinerator adopted each batch input method, because pressure fluctuation could be controlled by the combustion method and waste handling system would be simple and there would be less trouble.

The rubber and plastic waste have a more heating value and more combustion rate than the small chips of wood and cloth, which causes furnace pressure fluctuation. Therefore, the following technique was used.

**Adopting air-stage combustion (3,4)**

In air stage combustion, combustion air is separately supplied into the furnace as primary air and secondary air and burns in each zone as the primary combustion zone and the secondary combustion zone. In part of the primary combustion zone that has input and air supplied from the grate, some of the waste burns and pyrolytically decomposes with air through the fire grate at the bottom of the furnace. In the secondary combustion zone, pyrolytic gas from primary zone burns completely with air from secondary airports at the middle of the furnace. When primary combustion air decreases in the primary combustion zone, waste pyrolyzes due to insufficient air and which brings about a heat dissolution condition and mild combustion and the temperature drops comparatively. If the secondary combustion air is injected to the pyrolysis gas from the primary
combustion zone and burns, it is possible to control furnace pressure fluctuation and achieve comparatively little fluctuation condition on combustion. As this technique does not need to lower the temperature with a water cooling wall and furnace temperature can be kept high, emission of dioxin will be minimal.

The furnace has a refractory wall with high temperature secondary combustion zone

Secondary combustion air is injected at three levels and improves the mixing rate of air with pyrolysis gas in the following way, swirl, straight to radius direction, reverse swirl. If the mixing rate increases it is possible to reduce the emissions of CO and dioxin.

The discharge of ash after incineration is investigated

The grate can be opened and closed so that the bottom ash can be discharged from the bottom. New fire grate has the box frame, because plastic waste may melt in the furnace and leak through the clearance of the grate.

Explanation and the test result of the design concept, test device of the test purpose and the furnace of the pilot test are introduced below. The performance prediction of a commercial plant is reported last.

This paper describes the results of the pilot tests and the estimation of the performance of the commercial plants.

THE PILOT TESTS

In order to evaluate even the fundamental combustion characteristics of the waste in the pilot test, the following were investigated:

- Effects of kinds and size of waste on combustion characteristics
- Amount of unburned carbon in bottom ash
- Dust concentration in flue gas
- Pressure fluctuation results on batch supply
- The emission of dioxin by the control test of secondary air flow rate
- DF performance evaluation of the ceramic filter
- Durability of grate
- Clinkering of ash in the furnace

EXPERIMENTAL APPARATUS

Figure 1 shows the system flow of the pilot plant and the new fire grate. The experimental apparatus consists of the incinerator (air stage combustion), the secondary combustion furnace (in order to prevention of CO emission in bad test condition), the ceramic filter test equipment, the flue gas treatment system and measuring instruments. The secondary combustion furnace is a cylindrical furnace with a LPG burner. The flue gas treatment system consists of the gas cooler, the cyclone separator, the bag filter, the induced air fan and the stack.
Details of the incineration furnace and measuring are given below.

The incineration furnace is upright with refractory. Throughput is 16kg/hr which is one eighth of a commercial plant (130Kg/hr) There is a fire grate at the bottom of the furnace and there is a waste supply port slightly below the center of the furnace. There is secondary airport above the center of the furnace and there is a flue gas port on top of the furnace. Also, there are 5 windows for observation and five holes for temperature measurement, pressure and gas sampling open toward the axis. The furnace size has a diameter of 250 mm at the fire grate, the secondary combustion zone has a diameter of 500 mm and the height of 2000 mm. The refractory is a 3-layer structure of 100 mm, 100 mm and 50 mm from the inside.

The simulated waste is packed into the paper box. The simulated wastes are supplied from the waste supply port into the furnace through an airtight damper and a radiation shielding damper. The waste supply duct is water cooled so that waste will not melt and stick on the duct.

Furnace pressure is kept at negative pressure so that gas cannot blow out from the furnace. Leaking air is prevented by opening the airtight slide damper open alternately. Also, a radiation shielding damper protects the entrance from the heat radiation in the furnace. Also, the input path is water cooled so that waste does not to adhere to the path while the waste is being inputs

In the furnace there are two zones, the primary combustion zone and the secondary combustion zone. There are two burners for each zone to heat up and control temperature. 1-zone burner aims at about 100mm upper grate, which can ignite waste. In the horizontal direction, the burner aimed at a point offset from the center, then the burner gas flow comes off to the upper part with a little swirl. Also, there is the work that secures the combustion temperature in the secondary air recordings and the burners of the secondary combustion zone are aimed at the centers of the secondary combustion zone.

The fire grate has a nozzle with 3 steps, the nozzle hole faces to the side as shown in figure 1, so that melting materials and ash do not close the hole. Primary combustion air is injected with 3 levels so that the mixture of combustion air and waste are good, even if ash accumulates on the grate.

Also, the grate can open and close with the center so that incombustible s and ash can be discharged through the fire grate. However, because plastic waste may melt in the furnace and leak through the clearance of the grate, the fire grate is attached to the box frame. The fire grate is cooled with combustion air.

A 3-level way of air injection (the upper stand: swirl, the middle of the stairs: radius direction, lower berth: a reverse swirl) was designed because it has been shown to achieve low dioxin with the incineration system of municipal waste.(4) In the secondary combustion zone air was introduced to the unburned gas. This is done so that the mixing becomes as well as possible, because combustion is not complete if it does not improve the mixing.

There are 4 injection ports on periphery and the nozzle diameter is designed so that air velocity is over 10 m/s.
For temperature measurement, 6 places, the duct:
Six sheath K thermocouples were put into the furnace every 50mm. along the axis direction of the furnace.

Gas analysis:
The sampling of gas from the duct: Concentration measuring $O_2(\%)$, $CO_2(\%)$, $CO(ppm)$
Sampling gas out of the furnace: Concentration measuring of $O_2(\%)$, $CO_2(\%)$, $CO(\%)$

Pressure within the furnace

Fig. 1. Flow diagram of the pilot plant and the illustration of the grate

ANALYSIS OF SIMULATED WASTE

The results of the proximate analysis and ultimate analysis and reduced heating value are presented in Table I. Each component was put in the paper box before the combustion test.
Table I. The results of the proximate analysis and ultimate analysis and heating value

<table>
<thead>
<tr>
<th>proximate analysis</th>
<th>wood chip</th>
<th>PE</th>
<th>rubber 7mm</th>
<th>rubber 2mm</th>
<th>rubber glove</th>
<th>pvc</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.M. %</td>
<td>12.40</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ash %</td>
<td>0.50</td>
<td>0.00</td>
<td>35.60</td>
<td>24.80</td>
<td>1.7</td>
<td>0.2</td>
</tr>
<tr>
<td>V. M. %</td>
<td>83.00</td>
<td>100.00</td>
<td>45.00</td>
<td>55.80</td>
<td>98.4</td>
<td>93.2</td>
</tr>
<tr>
<td>F.C. %</td>
<td>16.50</td>
<td>0.00</td>
<td>19.40</td>
<td>19.40</td>
<td>0</td>
<td>6.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ultimate analysis</th>
<th>C%</th>
<th>H%</th>
<th>N%</th>
<th>S%</th>
<th>O%</th>
<th>Cl%</th>
</tr>
</thead>
<tbody>
<tr>
<td>C%</td>
<td>50.10</td>
<td>84.20</td>
<td>45.30</td>
<td>49.00</td>
<td>82.7</td>
<td>47.2</td>
</tr>
<tr>
<td>H%</td>
<td>6.40</td>
<td>15.99</td>
<td>3.78</td>
<td>3.98</td>
<td>11.9</td>
<td>6.44</td>
</tr>
<tr>
<td>N%</td>
<td>0.07</td>
<td>0.02</td>
<td>0.17</td>
<td>0.19</td>
<td>0.5</td>
<td>0.09</td>
</tr>
<tr>
<td>S%</td>
<td>0.04</td>
<td>0.00</td>
<td>1.68</td>
<td>1.65</td>
<td>0.88</td>
<td>0.01</td>
</tr>
<tr>
<td>O%</td>
<td>42.87</td>
<td>0.68</td>
<td>13.46</td>
<td>20.37</td>
<td>2.49</td>
<td>9.17</td>
</tr>
<tr>
<td>Cl%</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.03</td>
<td>36.89</td>
</tr>
</tbody>
</table>

| heating value kcal/kg | 3743 | 11040 | 4306 | 4414 | 10035 | 5338 |

THE RESULTS OF THE EXPERIMENT

Effects of kinds and size of waste on combustion characteristics

In the experiment, using one component and mix such as wood chip, rubber, polyethylene and polyvinyl chloride, the effect of the kind and size of waste such as block or pellet or sheet on combustion rate was investigated.

Combustion rate (unit time) is shown in Figure 2 and also the time change of the combustion rate of the main wastes (the small wood chips, polyethylene, rubber, simulated waste) is shown in each case.

It is understood that the time change of combustion rate differs with the kind of waste. The small wood chip burns immediately because the surface area is large. As for rubber, the volatile matter burns at once and the remainder burns slowly, as combustion rate arises at once and decrease by slow degrees.

From figure 2, plastic does not burn like rubber and it burns regularly because pyrolysis gas burns after melting and pyrolysis. Combustion rate of plastics hits the peak in the figure because feed rate was constant on weight and combustion air was not sufficient in this condition. But it was understood that polyethylene burned after melting from that combustion rate increase slowly at the first batch supply and the time change of combustion rate was almost symmetry on the every supply. The combustion rate of rubber and plastic and different sizes and shape were shown in figure 2. The thin pieces of rubber will burn as fast as wood chip, there was the influence of size and surface area. But combustion rate didn’t increased in proportion as surface area, because waste did not put in the furnace with completely dispersing.

There is no influence of shape in the polyethylene case because the plastics waste burned after melting and settling into shape.
Fig. 2. The characteristics of combustion such as kind of waste and size and shape
Amount of unburned carbon in main ash

The amount of unburned carbon in the main ash of the simulation waste in the following condition is shown in Table II. This condition was selected because there is no unburnt component on the polyethylene condition and there was some unburnt piece and there was a difficulty of sampling ash on the 20mm cube rubber condition.

Table II unburned carbon of main ash

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>1st Air (Nm3/h)</th>
<th>Free C (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber</td>
<td>7*20</td>
<td>70</td>
</tr>
<tr>
<td>Rubber</td>
<td>2*20</td>
<td>70</td>
</tr>
<tr>
<td>PVC20%+Simulated</td>
<td>70</td>
<td>4.5</td>
</tr>
<tr>
<td>PVC50%+Simulated</td>
<td>70</td>
<td>5.7</td>
</tr>
</tbody>
</table>

The simulation waste used was 40% polyethylene, 30% rubber and 30% wood chip.

There was no unburnt in main ash of the rubber case, and there was some unburnt component in the test case include PVC. The reason for the unburnt deposit was as follows. However it was heated with the flame radiation and the furnace wall, the ash deposit was cooled with the combustion air from the fire grate, that was at normal temperature. If combustion rate was low as PVC char, the unburnt component did not burn continuously when it moved to the bottom of the ash. As PE heat dissolution temperature was not high and upper grate temperature was high, the plastic burnt completely with no unburnt deposit remaining. Because the char porosity of wood was high and it burnt out easily, there was not any unburnt deposit on the grate.

Amount of fly ash

The amount of fly ash in each experiment condition is shown in Table III.

Table III. Amount of fly ash in each experiment condition

<table>
<thead>
<tr>
<th>No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>%</td>
<td>10</td>
<td>30</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>1st Air</td>
<td>Nm3/h</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>2nd Air</td>
<td>Nm3/h</td>
<td>auto</td>
<td>auto</td>
<td>auto</td>
<td>auto</td>
</tr>
<tr>
<td>Gas Flow Rate</td>
<td>m3/h</td>
<td>650</td>
<td>620</td>
<td>610</td>
<td>580</td>
</tr>
<tr>
<td>Gas Temperature</td>
<td>K</td>
<td>1045</td>
<td>1051</td>
<td>1132</td>
<td>1075</td>
</tr>
<tr>
<td>Dust Concentration</td>
<td>g/Nm3</td>
<td>0.174</td>
<td>0.339</td>
<td>0.720</td>
<td>0.410</td>
</tr>
<tr>
<td>Amount of Dust</td>
<td>g/h</td>
<td>113.1</td>
<td>121.0</td>
<td>243.2</td>
<td>237.8</td>
</tr>
<tr>
<td>C in Dust</td>
<td>%</td>
<td>5.9</td>
<td>17.3</td>
<td>15.6</td>
<td></td>
</tr>
<tr>
<td>Amount of C</td>
<td>g/h</td>
<td>67</td>
<td>364</td>
<td>685</td>
<td></td>
</tr>
</tbody>
</table>

There was a lot of fly ash when the burner combustion and grate air was high. In these cases, as gas velocity was higher than other cases, fly ash accompanied the flue gas and was carried out from the furnace. As the temperature was over 873K in the primary combustion zone, the waste was able to ignite itself and it was possible to decrease the amount of fly ash without 1st-burner and
with a low flow rate of primary air. Also, the primary zone excess air ratio (input air/ equivalent air volume of waste) is around 0.6 and it was small when it compared with the conventional furnace. The following test results about fly ash were obtained:

- As the ash density of the wood chip was low, the ash was almost all carried out.
- There was hardly any ash of plastic and the main component of the unburned was soot.
- When there was a lot of calcium as a filling materials in the rubber, there was hardly any fly ash.

**Pressure fluctuation results on batch supply of solid wastes**

The experiment was done with a supply interval of every 6 minutes with 1.6 kg and 0.8 kg. The furnace pressure fluctuation was below 500Pa. It was shown that plastic burns moderately in the case of only plastics regarded as hard combustion, because the combustion rate depends on the heat transfer of waste to flame and the furnace wall and melting and pyrolysis were not hard. When the amount of pyrolysis gas from primary combustion zone and the combustion load fluctuates, the secondary combustion zone temperature fluctuates accordingly.

![Fig. 3. Pressure fluctuation results](image)

The time changes of the temperature fluctuation in the secondary combustion zone and furnace pressure fluctuation are shown in Figure 3. It is understood that there is much correlation.

This furnace pressure fluctuation is considered as follows. As the flue gas volume increases due to rising of gas temperature, the pressure loss increases due to the increase of the gas velocity the flue gas duct. The furnace pressure increased as much as pressure loss increased in the flue gas duct, if the exit pressure of the induced fan is almost constant. The furnace pressure fluctuation can be controlled by prediction of pressure loss of the flue gas duct and the fluctuation of flue gas temperature.
Also, in consideration of the whole flue gas system, the temperature fluctuation occurred at the high temperature zone, and pressure fluctuation decreased with the flow, because the temperature of flue gas decreased with the flow due to heat capacity and heat loss of the duct.

It is easy to control pressure fluctuation, if it is designed so that there is little pressure loss at high temperature, because pressure fluctuation is caused by temperature fluctuation in the duct with a large pressure loss.

Also, there is an advantage in that temperature control of the secondary combustion zone works as follows. (When the secondary combustion zone temperature rises, heat input by the burner is decreased by temperature control and that is action for decreasing the pressure fluctuation.)

In the commercial plant, establishing the secondary combustion furnace after the incineration furnace aims at further reduction of CO.

When incineration furnaces and the secondary combustion furnace are connected with the simple duct and the secondary combustion furnaces applies the temperature control to temperature fluctuation, there is the characteristic that the pressure fluctuation decreases further.

The result of the emission control test of the dioxin by the secondary combustion air control operation

The air-stage combustion was adopted so that the secondary combustion air was controlled with furnace exit oxygen concentration. The secondary combustion zone temperature was maintained at 1173K.

The results of analyzed dioxins of flue gas at the furnace exit, by using the solid waste with 20% polyvinyl chloride mixed in the test was shown in Table IV.

Table IV. Dioxins measurement result

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>20</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>%</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Primary Air</td>
<td>Nm3/h</td>
<td>35</td>
<td>70</td>
</tr>
<tr>
<td>Feed Rate</td>
<td>kg/h</td>
<td>17.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Flue Gas Flow Rate</td>
<td>Nm3/h</td>
<td>440</td>
<td>580</td>
</tr>
<tr>
<td>Temp. of Flue Gas</td>
<td>K</td>
<td>1082</td>
<td>1075</td>
</tr>
<tr>
<td>Dust Concentration</td>
<td>g/Nm3</td>
<td>0.36</td>
<td>0.41</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ash</th>
<th>kg/run</th>
<th>40.0</th>
<th>44.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>amount of Supply</td>
<td>g/run</td>
<td>3320</td>
<td>4850</td>
</tr>
<tr>
<td>amount of Fly Ash</td>
<td>g/run</td>
<td>3320</td>
<td>4850</td>
</tr>
<tr>
<td>B-Ash/Supply</td>
<td>%</td>
<td>8.3</td>
<td>10.8</td>
</tr>
<tr>
<td>F-ash/Supply</td>
<td>%</td>
<td>0.40</td>
<td>0.53</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DXN</th>
<th>ng-TEQ/Nm3</th>
<th>8.52</th>
<th>3.42</th>
</tr>
</thead>
<tbody>
<tr>
<td>in Flue Gas</td>
<td>ng-TEQ/Nm3</td>
<td>1.42</td>
<td>0.07</td>
</tr>
<tr>
<td>in Fly Ash</td>
<td>ng-TEQ/Nm3</td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>
In the experiment, the residence time of flue gas in the furnace was about 1s and was not longer than a commercial plant. Because the residence time of flue gas will be designed over 2s in a commercial plant, dioxins will decrease to one tenth of that observed (5). Also, there is a bag filter in the commercial plant and the efficiency of filtering of dioxins will be over 90%. (6) Therefore, there is the prospect of achievement of 0.1ng-TEQ/Nm3 at the exit of incineration system of the scale up to commercial plant, as achieved under 10ng-TEQ/Nm3 by the secondary air control in the experiments.

**DF performance evaluation of the ceramic filter**

The performance test of the ceramic filter was done, using a slip stream of flue gas from the incinerator. The time variation of the pressure loss at the ceramic filter is shown in Figure 4. The pressure loss hardly changed with time. There was a small fluctuation of the pressure caused by a batch supply. Because there was a small amount of fly ash on the ceramic filter, the pressure loss did not occur and the ash deposit dropped out with the lump with an air pulse. It is possible to remove ash with the reverse washing of the pulse after incineration, and it is conceivable that maintenance is comparatively easy.

Also, it was confirmed that the ceramic filter had not clog up, although rubber gloves ash adhered to the surface in the case of chloride generation of low boiling point metals such as Zn and Pb etc. The results of the DF test was about 2.56E-6(Cs) and 8.33E-5(Co) that used not radioactive cesium and cobalt as the chemistry tracer. Although there was data spread caused by the spread of dust concentration upstream, it is understood about 10E-5 of performance could be secured.

![Fig. 4. Pressure drop on ceramic filter](image-url)
Durability of the grate

The fire grate was cooled by combustion air as shown in Figure 1. Through all pilot tests, the fire grate was sufficiently cooled even at 1500K and there was no trouble such as warp and melting down. It was demonstrated that even waste that melts before combustion such as polyethylene, did not leak through the joint of the opening and closing fire grate and could burn, because the box frame was attached on the fire grate.

The air supply hole of the fire grate was completely healthy; there were only a few melted unburnt deposits of polyvinyl chloride and rubber attached. The fire grate seemed to be over 673K with radiation from the flame despite being cooled by air from thermal estimation. There was hardly any unburnt component of plastic waste, because the temperature of grate was not low and it burned slowly. The grate hole was unstuffed and healthy because combustion air was injected at a high velocity and had the pressure loss at the fire grate for uniform distribution even though the ash layer was not uniform.

The effect of incombustibles such as glass on grate performance was also investigated. As the temperature of the upper primary combustion zone of the fire grate rises to about 1273K, silicate glass and Pyrex glass melt. But it did not stick to the grate and could be removed easily during normal operation. Usually there was some ash on the grate and the grate temperature was not so high with cooling air and melting glass did not stick to the grate. Generally melting and sticking occur with the thermal conduction rate being low such as the refractory surface and at about the melting temperature of glass. It was found out that quartz glass was discharged as fed, because the fusion point was high 1573K.

Clinkering of ash deposit

Ash deposit clinkers at sintering temperatures over 1273K. The clinkering test was carried out using rubber that had high ash. The temperature of the primary combustion zone was kept at 1473K for several hours and the furnace was cooled after the combustion test and the grate was opened and the ash deposit was checked whether ash was sintered or not.

However the ash of the high layer did not discharge with the bridge, it was just pecked and was discharged, therefore it was not severe clinkering.

Clinkering was considered from the temperature profile of the ash deposit. As the upper layer of the ash deposit is high temperature with radiation of flame and wall, there may be easy clinker. But the under layer of the ash deposit is low temperature because of cooling by combustion air and easily discharges without clinkering. Therefore the upper layer of the ash deposit cannot be the bridge itself, because the furnace radius is large in a commercial plant.

However the temperature is kept below 1373K in the primary combustion zone, clinkering may occur because on other wastes and the operation time is long and kind of wastes is different from the pilot test in a commercial plant. Therefore there are the ash removal sticks in the furnace of the commercial plant.
THE DESIGN OF COMMERCIAL PLANT

Designs of the size of incinerator furnace

The size of incinerator of commercial plant was designed from the result of the pilot test. The design of the incinerator is as follows.

- The feed rate is evaluated by the furnace bed-load.
- The temperature of primary combustion zone is below 1373K to prevent clinkering.
- The residence time is secured 2 seconds after the injection of the secondary air.
- The furnace exit temperature is maintained of over 1123K for CO inhibition

It was investigated if throughput could be even higher than the bed load, as a result of the pilot test. (About 300 kg/m2hr: feed rate was 16 kg/hr, grate size was 250 mm)

Although the furnace bed-load is actually necessary, it is also required that the residence time of the gas in the furnace is examined from the volumetric load. When residence time is constant, it becomes tall if the bed load is high, or else it becomes large. There is the problem that the amount of fly ash increases as the gas velocity becomes high when the furnace is tall. Therefore the gas velocity is designed at 1-2 m/s.

Also, it is necessary to prevent clinkering of the ash when the operation temperature of primary combustion zone is below 1373K. But as the waste has a tendency to burn intensively in the lower part, there needs to be heat loss in the primary combustion zone.

The problem was solved by enlarging the size of the furnace. It was possible to burn from the experiment result, although the furnace bed load becomes comparatively small.

Prediction of the furnace exit temperature

The commercial plant will be operated during daytime and the prediction has done by numerical simulation of how the refractory is heated up, from the combustion load and heating time.

In the simulation, heat transfer was calculated between the flame and refractory by radiation and convection and furnace exit gas temperature was predicted by energy balance. At the furnace outside surface, the convection heat transfer with outside air was considered, while inside the refractory only thermal conduction was considered. Radiation heat flux of the flame was estimated from the pilot test and prediction of the emissivity and furnace exit temperature was also calculated. Prediction of the temperature within the furnace is possible when the heat transfer is considered at the time of semi-continuous operation.

However, it is expected that an optimal operation condition is sought with adjusting of the excess air ratio in the primary combustion zone and adjusting of the burner, because there is difference in the flame form by the change of a burner at a commercial plant.
Furnace pressure fluctuation prediction

The followings were obtained in the pilot test. As flue gas volume increases with a rise in the gas temperature, the pressure loss mainly increases by the increase of the gas velocity in some high part of the pressure loss along the flue gas duct. The furnace pressure increases as much as pressure loss increases in some part of the duct, if the exit pressure of the induced fan is almost constant. Therefore furnace pressure fluctuation can be controlled by prediction of pressure loss in the flue gas duct and the fluctuation of flue gas temperature. The pressure fluctuation is able to be numerically simulated with consideration of pressure loss at devices on the duct of a commercial plant. But this time, pressure fluctuation of the commercial plant is evaluated as follows, whether it becomes larger than on the pilot test.

There is some equipment such as an incineration furnace, the secondary combustion furnace, gas cooling towers and ceramic filters in the flue gas flow line of the commercial plant and there is nothing that has pressure loss such as a damper. Also, there are the temperature control systems in incinerator and the secondary combustion furnace, temperature fluctuation and the temperature are kept constant. Although there is the problem that the temperature rises by injection of the secondary air, pressure fluctuation will be decreased in a commercial system, because there are temperature controls in the incinerator and in the secondary combustion furnace and the pressure loss of the duct is small.

As the throughput of the commercial plant is 8-times larger than that of the pilot plant and the interval time becomes short and the size (amount of 1 batch input) of the box to the furnace becomes relatively small, then throughout will be averaged and temperature fluctuation can be reduced.

CONCLUSION

It was found that emission of dioxin could be decreased by controlling secondary combustion air, and the pressure fluctuation was controlled even with the plastic waste by this development.

In the development of the incinerator, a commercial plant of the concept was proposed and some design data of the commercial plant were accomplished by the pilot test. The concepts and operation conditions of the commercial plant that were obtained from the pilot test are summarized below.

- The air stage combustion was adopted and the burner was established in each combustion zone.
- A refractory furnace was adopted and the fire grate was established in the primary combustion zone and primary air was injected from the grate.
- For the reduction of emission of CO and dioxins, 3-level air injection method was adopted that is adopted on the incineration system for municipal waste.
- The fire grates consist of two pieces and open downward. A box frame was attached for prevention of leaks of melting plastic.
- The air ratio in primary combustion zone was decided in the test run of a commercial plant.
so that the temperature was not more than 1373K.

- 1-burner was operated so that the temperature of primary combustion zone was not below 923K
- 2-burner was operated so that the temperature of secondary combustion zone was over 1123K.

A commercial plant has now been designed in detail based on the pilot scale work.

REFERENCES

1. Japanese PAT 1906752
2. Japanese PAT.2045188
4. Japanese PAT.2714530