Treatment and energy recovery of waste in China
—-A paradox for municipal solid waste incineration in China

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Municipal solid wastes incineration

Food wastes anaerobic digestions for methane and hydrogen production

Sewage sludge anaerobic digestions for methane production

Biomass to energy by pyrolysis
Refuse quantity is huge in China, 170-200 M t/a collected in 661 cities, and over 50 M t/a for rural areas without collection.

Incineration is an option in terms of resource regeneration and energy recovery, with over 190 plants in operation in China, over 30 M t/a being incinerated, 30% of total MSW.
Over 700 sanitary landfills, 100 M t/a being landfilled, as a cost-effective method and storage venue of resource.

7 composting plants, 1 M t/a being treated, with limited way to go for the products due to its multi-components.

76 “integrated treatment plants”, with mechanical separation and landfill together.
Incineration styles

Both **fluidized bed** and **stoke grate** predominate, with a percentage of 40% and 51%, respectively and the priority of stoke grate incinerator
Stock grate incinerator suppliers

- **Overseas suppliers:**
  - Noell-KRC Corporation (Germany), Steinmuller Corporation (Germany), Basic Corporation (USA), Alstom Corporation (France), Seghers Corporation (Belgium), VonRoll (Switzerland), Missubishi Heavy Industries (Japan), Takuma Co. Ltd (Japan), Hitach Zosen Corporation (Japan)

- **Domestic suppliers:**
  - Weiming Group (WenZhou), New Century Energy (HangZhou), San Feng (ChongQing)
Most of incineration plants located in the East and South East China. Zhejiang Province and Guandong Province are the predominated area.

The distribution of incineration plants in mainland, China 2008.
Motivation driven for incineration

- Variation of waste composition
- The promotion activity of incineration plants
  - a power-for-money deal situation
  - a leading technology - “the face-saving project” or “achievement Project”
- The policy of tax preference, electricity price policies and compensation for refuse treatment: 0.5-0.7 Yuan RMB/kwh, higher than that of 0.25 Yuan RMB/kwh from coal power plant
Motivation driven for incineration

• Dominated companies” pushing” and “low cost” concepts, with over-negative towards to landfill

• Technological superiority
  — Volumn reduction: reduction rate 80%~90%
  — End-of-pipe disposal: 850℃~900℃, disinfection in high temperature
  — Waste-to-energy: generating capacity 300~350kwh per ton refuse, amount to 120~140kg standard coal
Cost and health worry

- Very expensive, complicated to operate, wasteful of resources and the release of some by-products
- One survey cited by China Daily:
  - 92% of residents thought the incinerator would harm their health, and 97% were opposed to its construction
Dioxins

- a high-level pollutant, and are listed by the International Agency for Research on Cancer as a level one carcinogen
- China new standard and EU DIRECTIVE 2000/76/EC about 0.1 ng-TEQ/Nm³
- Survey on 19 incineration plants
  - PCDD/Fs from 16 MSW incinerators were below the MEP regulation level of 1.0 ng -TEQ Nm³
  - only 6 systems were below the limit in EU Directive 2000/76/EC of 0.1 ng I-TEQ Nm³
Dioxins

- Low treatment fee from the local government: 5 US$, 8 US$, 10 US$, per ton waste!
- Use of little active carbon for dioxin absorption, and even use of a few lime for flue gas treatment
- Delay of the treatment fee payment from the authorities concerned
Moisture of wastes

- 60% moisture in the wastes
- Compression and bio-dewater for 5-7 days storage to convert the moisture to leachate
- 30% leachate of the wastes generated in the summer, with 20% in average yearly
- High cost for leachate treatment, leading to reduction of the profit
- The potential risk of explosion: \( \text{CH}_4 \) accumulating in leachate regulating pool
The potential risk of explosion: \( \text{CH}_4 \) accumulating in leachate regulating pool

Anxi Chuangguan Incineration Plant (600t/d):
3 killed and 2 wounded.

Concentrates of \( \text{CH}_4 \), \( \text{H}_2 \), \( \text{H}_2\text{S} \) reach to explosion limit

Shanghai Jiangqiao Incineration Plant (1500t/d):
3 killed and 4 wounded, A direct economic loss of 16.393 million yuan RMB.
The area of incineration plant should be large enough.

The area of most incineration plant is too small.

Leachate pool must be far from the workshops and office at the plant, e.g. 500 m away.

The potential risk of explosion: CH₄ accumulating in leachate regulating pool.
Pollutants in flue gas - Regulation limits

- only 10% in the flue gases to be limited to “standard”
- 90% pollutants discharged into the air, even EU limit
- A huge CO\(_2\) generated
- Environmental capacity load increase. In terms of environmental management, how many incineration plants does a city need? How to plan site selection and layout?
# Paradox of incineration plant

- **2000 t/d MSW incineration plant pollutant discharge**

400,000 m³/h x 24h x 365d x concentrations of pollutants

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Units</th>
<th>China GB18485-2001 limit</th>
<th>EU limits</th>
<th>Total discharge t/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm³</td>
<td>80</td>
<td>30</td>
<td>100-300</td>
</tr>
<tr>
<td>HCl</td>
<td>mg/Nm³</td>
<td>75</td>
<td>50</td>
<td>140-280</td>
</tr>
<tr>
<td>SO₂</td>
<td>mg/Nm³</td>
<td>260</td>
<td>300</td>
<td>300-350</td>
</tr>
<tr>
<td>NOₓ</td>
<td>mg/Nm³</td>
<td>400</td>
<td>—</td>
<td>500-600</td>
</tr>
<tr>
<td>CO</td>
<td>mg/Nm³</td>
<td>150</td>
<td>100</td>
<td>200-250</td>
</tr>
<tr>
<td>Dioxins</td>
<td>ngTEQ/Nm³</td>
<td>1.0</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
<td></td>
<td>300 – 350k</td>
</tr>
</tbody>
</table>
Paradox of incineration plant

Fly ash

- Promise to treat by the local government when signing the contract, but where to go?
- Scare landfills for the fly ash
- Melting for the fly ash? Too costly
- Dumping for fly ash in many incinerators!
- Mixing with the bottom ash and dumping at the MSW landfills
Paradox of incineration plant

Conflict: the public VS incineration partners

- **Local governments** un-doing not seriously listening to local residents’ ideas and opinions before setting up a project of incineration plants
- **Concerned community/residents** health worry afraid of the potential harm of their health and living environment and the devaluation of their properties
- **Real estate developer** depreciation for the land and properties worry about that their properties of building will stop appreciating after the site selection.
Nanjing Jiangbei Incineration Plant (1200 t/d)

Guangdong Panyu Incineration Plant (2000 t/d)

Guangzhou Huadu Incineration Plant (1500 t/d)

Against refuse incineration!

Shanghai Jiangqiao Incineration Plant (1500 t/d)
Solution for the obstacles

Source reduction at home and on site

- Extremely difficult, practiced for over 20 years
- Many scavengers and poor people as well as real estate keepers acted as the separators on sites
- Nothing valuables in the wastes to be landfilled and incinerated, and MUST be landfilled or incinerated
Solution for the obstacles

Dewatering of the wastes

• Separate collection of water melon and other high moisture wastes – seemingly difficult?

• Good cover for the garbage collection and storage bins - seemingly difficult?

• Modification for the incineration furnace to improve the high moisture wastes burning
Solution for the obstacles

Sitting

- 300 m away for the inhabitants dwelling from the incinerators for the new standard (draft) proposed, possible? Impossible!

- At least 3000 m, enough? Where to sit?

- Extremely difficult for sitting of new incinerators, with slow step for the incineration increase in recent 2 years
Application of MSW sorting in the whole MSW management process

- Source sorting - Something difficult
- Waste pickers - organized
- Mechanical separation process - applied as pretreatment process
Solution for the obstacles

Off-shore MSW Incineration Program

Yangtze Delta, Zhujiang Delta and Beijing-Tianjian-Tangshan Delta Incineration Plants, with 40,000 ton daily, 13 million kwh daily

All the facilities on land can be released!
Shanghai Incineration Plant Sitting Proposal

Use for 40,000 t/d incineration plant

Fly ash to be landfilled
Bottom ash to be used for land making
Served region: Yangtze River Delta
Food wastes anaerobic digestion

有机废物厌氧发酵
有机废物厌氧发酵 anaerobic digestion

• 厌氧发酵选择性高效产氢与产甲烷hydrogen and methane generation

• 高速、低温厌氧发酵accelerated and low temperature digestion

• 高温强化水解、碱预处理high temperature hydrolysis and alkaline treatment

• 生物质干法厌氧发酵dry digestion

• 沼液微生物浓缩回用bioliquid concentration and reuse
Pyrolysis or gasification of biomass
• Pyrolysis is suitable for single biomass or wastes

• Incineration is suitable for the complex wastes such as MSW

• For MSW, 330 kwh/t waste can be got, in comparison with a little net energy of pyrolysis in form of combustible gas and liquid and low heating value of the solids
回转炉热解反应器 Rotational Reactor

废物 wastes

燃烧室 burning

燃料气体再循环 recycling of gas

气体 gas

锅炉 boiler

蒸馏容器

废渣 slag

环 recycling of gas
Sewage sludge digestion

- Silt and sand present in the sludge
- Low organic contents
Refuse Incineration Technology Development for China

Prof. Dr. Zhao Youcai
Tongji University
Objective:
Development of refuse incineration technology complying with low heating value, high moisture, high inorganic matters in Chinese wastes
Findings
1. Dewatering of refuse

**Biological dewatering**

- After 10 d storage, moisture decreases from 72% to 53%
- After 5 d storage, the lower heating value increase around 30－40%
Weight loss at the incineration plant storage tank

30% moisture lost

Mechanical dewatering

<table>
<thead>
<tr>
<th>Weight</th>
<th>Results of filter pressing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before filter pressing</td>
<td>After filter pressing</td>
</tr>
<tr>
<td>4330 kg</td>
<td>3885 kg</td>
</tr>
<tr>
<td>455 kg</td>
<td>10.3%</td>
</tr>
</tbody>
</table>

Mechanical compression, with 10.3% leachate seeping out
Over 34% moisture can be removed from the refuse after 5 d storage and mechanical compression in the holding cell in the incineration plant.

The lower heating value increases from 3800 kJ/kg for the fresh refuse to 7200 kJ/kg for the dewatered refuse.
2. Air staged incineration

Air distribution layout

- Conventional air distribution: Phase I (drying) 15%, Phase II (combustion) 75%, Phase III (final incineration) 10%, with high organic matters content in the bottom ash (>5%)

- New air distribution: Phase I (drying) 25%, Phase II (combustion) 65%, Phase III (final incineration) 10%, with low organic matters content in the bottom ash (<3%)
Hot air incineration

Conventionally, room temperature air is injected into the furnace, resulting in a poor incineration.

Our design uses the air with 280°C in the Phase I air.

Also, the length of the furnace extended from 11 m to 14.43 m (250 ton/d for each furnace).
Cold water is used to wash the flue ags; NaOH solution is used if necessary, as the pollutants are slightly over the limits.
3. Incineration improvement

**Quantity of fly ash**

Fly ash is 1.5% of the refuse to be incinerated, in comparison with 3-5% for the original design.

The organic matters may be less 3% in the bottom ash, sometimes 1%.
# 4. Leachate

## Characteristics of refuse incineration leachate

<table>
<thead>
<tr>
<th>Items</th>
<th>Leachate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fresh</td>
</tr>
<tr>
<td>pH</td>
<td>4.7</td>
</tr>
<tr>
<td>NH$_3$-N(mg/l)</td>
<td>760.03</td>
</tr>
<tr>
<td>COD$_{Cr}$(mg/l)</td>
<td>56898</td>
</tr>
<tr>
<td>TOC(mg/l)</td>
<td>22300</td>
</tr>
<tr>
<td>TN(mg/l)</td>
<td>2108</td>
</tr>
<tr>
<td>Turbidity</td>
<td>1306.7</td>
</tr>
<tr>
<td>TP(mg/l)</td>
<td>181.6</td>
</tr>
<tr>
<td>Cl$^-$(mg/l)</td>
<td>4398.6</td>
</tr>
<tr>
<td>SO$_4^{2-}$(mg/l)</td>
<td>1920.3</td>
</tr>
<tr>
<td>TC(mg/l)</td>
<td>22420</td>
</tr>
</tbody>
</table>
Anaerobic digestion

Hydraulic retention time 8 d
COD load 5.8 kg COD/(m\(^3\)\cdot d)
Gas yield 2.885 L/(L\cdot d)

The gas injected into the furnace so that 1-2% more electricity can be obtained
<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>CODcr (mg/L)</th>
<th>BOD$_5$(mg/L)</th>
<th>NH$_4$-N(mg/L)</th>
<th>SS(mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>leachate</td>
<td>48000-71000</td>
<td>25000-30000</td>
<td>380-1500</td>
<td>3000-20000</td>
</tr>
<tr>
<td>4</td>
<td>Centrifugation</td>
<td>38000</td>
<td>20000</td>
<td>1500</td>
<td>2000</td>
</tr>
<tr>
<td>5</td>
<td>MBR removal (%)</td>
<td>98</td>
<td>99</td>
<td>99</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>MBR effluent</td>
<td>760</td>
<td>200</td>
<td>15</td>
<td>200</td>
</tr>
<tr>
<td>7</td>
<td>Set limit</td>
<td>1000</td>
<td>600</td>
<td>25</td>
<td>400</td>
</tr>
</tbody>
</table>
5. Fly ash and bottom ash

Diameters

- Partical size: 4-100µm ,  
  Average particle size: 19µm ,  
  <62 µm : 90%  
- Larger activity
### Mixing with Na$_2$S, 1% may be OK

<table>
<thead>
<tr>
<th>Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$_2$S·9H$_2$O (g)</td>
<td>0.1795</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>S$^{2-}$ (mol)</td>
<td>0.00075</td>
<td>0.00208</td>
<td>0.00416</td>
<td>0.00833</td>
<td>0.01665</td>
<td>0.02498</td>
</tr>
<tr>
<td>[Zn$^{2+}$+Pb$^{2+}$+…] (mol)</td>
<td>1.0301×10$^{-4}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S$^{2-}$/[Zn$^{2+}$+Pb$^{2+}$+…]</td>
<td>7.3</td>
<td>20</td>
<td>40</td>
<td>81</td>
<td>161</td>
<td>243</td>
</tr>
<tr>
<td>Leach liquor concentration (mg/kg)</td>
<td>Pb</td>
<td>72.65</td>
<td>27.37</td>
<td>12.65</td>
<td>7.3712</td>
<td>1.2579</td>
</tr>
<tr>
<td></td>
<td>Cd</td>
<td>1.2342</td>
<td>1.0659</td>
<td>0.95372</td>
<td>0.89752</td>
<td>0.53296</td>
</tr>
</tbody>
</table>

### Mixing with organic S chemicals, 0.5% may be OK

<table>
<thead>
<tr>
<th>Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiourea (g)</td>
<td>0.0460</td>
<td>0.0760</td>
<td>0.1649</td>
<td>0.3928</td>
<td>0.7950</td>
<td>1.5345</td>
</tr>
<tr>
<td>Thiourea (mol)</td>
<td>0.00060</td>
<td>0.00100</td>
<td>0.00217</td>
<td>0.00516</td>
<td>0.01044</td>
<td>0.02016</td>
</tr>
<tr>
<td>C=[Zn$^{2+}$+Pb$^{2+}$+…] (mol)</td>
<td>1.0301×10$^{-4}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thiourea/C</td>
<td>5.8</td>
<td>9.7</td>
<td>21</td>
<td>50</td>
<td>101</td>
<td>196</td>
</tr>
<tr>
<td>Leach liquor concentration (mg/kg)</td>
<td>Pb</td>
<td>35.72</td>
<td>12.56</td>
<td>9.798</td>
<td>5.589</td>
<td>0.9182</td>
</tr>
<tr>
<td></td>
<td>Cd</td>
<td>1.1220</td>
<td>1.0220</td>
<td>0.84152</td>
<td>0.67321</td>
<td>0.39271</td>
</tr>
</tbody>
</table>
Bottom ash of refuse incineration plant
(a) raw ash (b) plastics and metals sorting from raw ash

About 60% of bottom ash (ash a: 60.3%, ash b: 58.3%) consist of particles greater than 4mm. These particles are easy to be screened and washed. Secondary building materials.
Resource utilization of bottom ash

COD removals from livestock wastewaters using bottom ash

<table>
<thead>
<tr>
<th>Continue water distribution time/h</th>
<th>wet/dry weight ratio</th>
<th>Influent in run cycle/L</th>
<th>Influent concentration/mg/L</th>
<th>Effluent concentration/mg/L</th>
<th>Removal ratio/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1:11</td>
<td>4</td>
<td>712</td>
<td>53</td>
<td>92.5</td>
</tr>
<tr>
<td></td>
<td>1:8</td>
<td>4</td>
<td>687</td>
<td>66</td>
<td>90.4</td>
</tr>
<tr>
<td></td>
<td>1:5</td>
<td>4</td>
<td>692</td>
<td>86</td>
<td>87.5</td>
</tr>
<tr>
<td>6</td>
<td>1:11</td>
<td>6</td>
<td>734</td>
<td>72</td>
<td>90.2</td>
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<td>1:8</td>
<td>6</td>
<td>703</td>
<td>95</td>
<td>86.5</td>
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<td></td>
<td>1:5</td>
<td>6</td>
<td>721</td>
<td>131</td>
<td>81.8</td>
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<tr>
<td>8</td>
<td>1:11</td>
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<td>702</td>
<td>74</td>
<td>89.4</td>
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<tr>
<td></td>
<td>1:8</td>
<td>8</td>
<td>694</td>
<td>119</td>
<td>82.9</td>
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<tr>
<td></td>
<td>1:5</td>
<td>8</td>
<td>741</td>
<td>176</td>
<td>76.3</td>
</tr>
</tbody>
</table>

Bottom ash containing soluble Ca, Mg, Fe, etc, and useful for the removals of P and COD in the wastewaters
6. Incineration effects

Moisture effects

Simulative incinerator under laboratory conditions

Impact of moisture to volatilization of Pb, Zn and Cu oxidation state

As moisture increases, the volatility of oxides of Cu decreases, while increases for its chloride and elemental states, but decreases for the chlorides and elemental states of Pb and Zn
Presence of CaCl$_2$

- Volatility of Zn increases by 13.0%, Pb by 6.5%, Cr by 6.2% and Cu by 4.5%
The volatility of Zn, Pb and Cu increase by 11.2%, 18.4%, 12.0%, higher than the presence of CaCl$_2$, NaCl and FeCl$_3$; Cr volatility increases slightly.