Combating Corrosion in WTE Facilities - Theory and Experience

NAWTEC 14
Tampa, FL

Shang-Hsiu Lee
05/02/2006
Introduction

- Corrosion is a major factor of downtime and shutdown in the operation of WTE facilities.
- Represents a large percentage of the total maintenance cost.
- Understanding theoretical mechanisms, empirical data, and related corrosion factors should help to reduce corrosion.
Outline

- Corrosion cost analysis
- Major corrosion factors
- Current methods of protection
- Ongoing experimental research
- Conclusions
Corrosion cost analysis

  - 69 WTE facilities from four major WTE companies.
  - The survey includes 6 parts:
    - Basic information
    - Waterwall data
    - Superheater tube data
    - Furnace & boiler data
    - NOx control & tube cleaning
    - Corrosion cost
Corrosion cost analysis (cont.)

- Non-scheduled downtime due to corrosion of WTE plants
  - 0 ~ 20 days/yr

(A1, B1, etc. refer to different WTE facilities responding to the WTERT survey)
Corrosion cost analysis (cont.)

- Yearly maintenance cost per unit due to corrosion:
  - $18,000 ~ $1,200,000

(A1, B1, etc. refer to different WTE facilities responding to the WTERT survey)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Dollars/unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>N/A</td>
</tr>
<tr>
<td>A2</td>
<td>N/A</td>
</tr>
<tr>
<td>A3</td>
<td>N/A</td>
</tr>
<tr>
<td>A4</td>
<td>$220,000</td>
</tr>
<tr>
<td>A5</td>
<td>$200,000</td>
</tr>
<tr>
<td>A6</td>
<td>$400,000</td>
</tr>
<tr>
<td>A7</td>
<td>$600,000</td>
</tr>
<tr>
<td>A8</td>
<td>$800,000</td>
</tr>
<tr>
<td>A9</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Avg. = $220,000/unit
Yearly maintenance cost per ton of MSW combusted:

- $0.23 \sim $8.17 (avg. = $4.20)

(A1, B1, etc. refer to different WTE facilities responding to the WTERT survey)
Corrosion cost analysis (cont.)

- From interviews with engineers of major WTE companies:
  - The maintenance cost of a WTE facility was reported to be $10-20 per ton of MSW.
  - One-third of which was due to either replacing corroded materials or applying corrosion resistant coatings.

- Assuming maintenance cost = $15/ton of MSW
  - maintenance cost due to corrosion = $5/ton of MSW
  - Close to the average number of $4.2/ton of MSW from WTERT survey.

- In addition, if the revenue lost of shutdown due to corrosion is considered, the number will be higher.
Major corrosion factors

Major factors of affecting corrosion:

- Chlorine content in the flue gas
- Metal surface temperature
- Gas temperature
- Temperature fluctuation
- Molten salt deposits characteristics

<table>
<thead>
<tr>
<th>Component</th>
<th>% of component in MSW</th>
<th>Chlorine concentration in component, g/kg</th>
<th>Chlorine in MSW, g/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>29.4</td>
<td>2</td>
<td>0.59</td>
</tr>
<tr>
<td>Plastics</td>
<td>10.4</td>
<td>25</td>
<td>2.60</td>
</tr>
<tr>
<td>Organics</td>
<td>34.7</td>
<td>3</td>
<td>1.04</td>
</tr>
<tr>
<td>Textiles</td>
<td>4.4</td>
<td>12.5</td>
<td>0.55</td>
</tr>
<tr>
<td>Wood</td>
<td>2.7</td>
<td>12.5</td>
<td>0.34</td>
</tr>
<tr>
<td>Miss. Combustible</td>
<td>5.0</td>
<td>12.5</td>
<td>0.63</td>
</tr>
<tr>
<td>Glass</td>
<td>4.0</td>
<td>0.6</td>
<td>0.02</td>
</tr>
<tr>
<td>Metals</td>
<td>4.7</td>
<td>0.6</td>
<td>0.03</td>
</tr>
<tr>
<td>Miss. Non-Combustible</td>
<td>4.7</td>
<td>0.6</td>
<td>0.03</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td></td>
<td>5.82 (0.58%)</td>
</tr>
</tbody>
</table>

HCl ~ 500ppmv
Major corrosion factors (cont.)

- **Metal surface temperature:**
  - High temperature of metal surfaces due to high radiation fluxes results in the melting of metal chloride deposits and increases the corrosion rate.
  - Waterwall metal temperature: 300 °C (570 °F)
  - Superheater metal temperature: 450 °C (840 °F)

Typical corrosion problems
Major corrosion factors (cont.)

Gas temperature:

- The $\Delta T$ between gas temperature and metal surface temperature is a driving force for the condensation of vaporized species, such as metal chlorides, on the cooled surface.
- At a large $\Delta T$, diffusion rate of metal chloride to the metal surface increases, chloride concentration increases, and the melting point of salt deposits decreases.
- Also, thermal stresses induced by the $\Delta T$ across the deposit and the metal wall affect the adhesion of oxide scales on metal tubes.
Major corrosion factors (cont.)

- **Temperature fluctuation:**
  - The non-homogeneous composition of the waste fuel and the uneven temperature profile of combustion gas flow cause sharp fluctuations in gas temperature.
  - Experimental studies have confirmed that the corrosion rate increased several times because of temperature fluctuation.
Major corrosion factors (cont.)

- **Characteristics of molten salt deposits:**
  - The diffusion rate of corrosive gases through the cracks and pores of deposits dominates the corrosion rate.
  - The presence of HCl, SO₂, and alkaline and heavy metal components in deposits affects both chemical and physical properties of deposits such as gas permeability.
  - The corrosion rate also increases with an increase in thickness of deposits.
Current methods of protection

- **Primary measures:**
  - Eliminate corrosion by influencing the process conditions in the boiler

- **Secondary measures:**
  - Extend the lifespan of the boiler tubes
Current methods of protection (cont.)

- Adoption of Inconel 625 cladding and composite tubes:
  - Inconel 625 (21Cr-9Mo-3.5Nb-Ni base)

- Applied on Waterwall tubes:
  - Inconel 625 works perfectly with lifetime of about 10-20 years

- Applied on Superheater tubes:
  - Lifetime of Inconel 625 is unpredictable
  - Does not provide protection above 400 – 420 °C (750-840 °F)
  - At metal temperature of about 540 °C (1000 °F), the wastage rate of Inconel 625 is 0.2 μm/h (0.069 inch/year)
Current methods of protection (cont.)

- Different designs of boilers:
  - Vertical vs. horizontal designs
    - Space
    - Construction cost
    - Heat recovery efficiency
    - Past operating experience

- Regarding erosion-corrosion issues
  - Horizontal design with more gas passes is preferable because of lower gas temperatures and velocities
Current methods of protection (cont.)

- **Installation of Seghers Boiler Prism:** prism-shaped tubes with secondary air injected into the combustion gas
  - Limit the flue gas temperature
  - Ensure high turbulence and less temperature fluctuation
  - Avoid hot spots
  - However: it requires 6 months of shutdown for installation

(http://www.keppelseghers.com/waste2energy)
Recirculation of flue gas:

- In some of the most recent WTEs, e.g. the Brescia plant in Italy, part of the flue gas is recirculated through secondary tuyeres in the combustion chamber.
- This has similar beneficial effects (better mixing, increased turbulence, fewer hot spots) as those claimed for the Seghers Boiler Prism.
Current methods of protection (cont.)

- **Improvement of cleaning tube method:** existing methods include high pressure water washing, explosive cleaning to
  - Increase the heat exchange efficiency
  - Remove salt deposits to reduce corrosion
    - However: high pressure water may cause erosion-corrosion

- Improved cleaning technology: Targeted In-Furnace Injection (TIFI) by Fuel Tech, Inc.
  - Injection of MgO to make salt deposits more friable
  - Performance and cost effectiveness are highly improved
Ongoing experimental research

Objectives:

- Test the corrosion resistance of different commercial tubes and coating materials under different corrosive environments.
- Find better operating conditions for WTE plants to reduce corrosion problems.
- Develop processes for reducing concentration of active chlorine in combustion gases.
Extensive studies have been done to clarify the effects of corrosion factors without a temperature gradient (gas/metal temperature).

Maintaining a pre-set desired atmosphere simulating various conditions in the combustor.

A very well controlled thermal gradient across the test sample can be maintained for the duration of the experiments.

Furnace 1 is to provide the cooling air (e.g. 600°C) and furnace 2 is the major combustion chamber which provides the desired combustion gas temperature (e.g. 1200°C).
Ongoing experimental research (cont.)

Side view of furnace 2

High temp. combustion gas

Thermocouples

Test sample

Low temp. air

Metal tube
Actual salt deposits from WTE facilities are applied to the test coupons in order to ensure the real chemical make-up.
Conclusions

- Corrosion factors have overlapping effects, and these effects vary widely among WTE facilities.

- Improvement on primary protection methods:
  - Experimental research to analyze the overlapping effects of corrosion factors.

- Improvement on secondary protection methods:
  - More economical corrosion-resistant materials.
  - Advanced coating systems.
Acknowledgement

This corrosion research gratefully acknowledges the support from:

- Waste-to-Energy Research and Technology Council (WTERT)
- Integrated Waste Services Association (IWSA)
- American Society of Mechanical Engineers (ASME)
- Covanta Energy
- Montenay Power Corporation
- Wheelabrator Technology Inc.