IMPROVED TEMPERATURE SENSING IN SLAGGING GASIFIERS

James P. Bennett
Jasper Kwong

Rick Krabbe
Hugh Thomas
Outline

• Program goals
• Need for accurate temperature measurement
• Causes of sensor failure (thermocouples)
  - post mortem analysis of gasifier thermocouples
  - laboratory simulations
• Current research direction
  - Redesign of current sensors and how used
  - New approaches to signal transfer
• Conclusions
• Acknowledgement
Program Goals

Develop reliable sensors that will accurately monitor gasification temperature. Research to achieve this goal is being conducted by:

1) evaluating the causes of thermocouple failure
2) developing improved thermocouple designs
3) evaluating new sensors and/or communication devices
Need for Accurate Temperature Measurement in a Gasifier

Gasification Temperature
≈ 1325° to 1575°C

- Temperature control is critical during heating, idling, or cooling
- High gasification temperature accelerates slag/refractory liner wear – shorter campaign
- Low gasification temperature causes poor slag flow - can lead to gasifier shutdown
- Impacts thermal cycling - refractory spalling wear

Direct impact on gasifier operation/on-line availability
Thermocouple Failure
(*typical life is less than 120 days*)

Failure rates can be up to 50% within 15 days, 75% within 30 days
Causes of Thermocouple Failure

- Slag corrosion
- Mechanical shear
- Design/assembly/installation flaws
- Refractory liner

Different Lining Movement

[Diagram showing initial installation and during gasification with labeled components: Thermocouple, Gasifier Steel Shell, Insulating Refractory Brick, Backup Refractory Brick, Hot Face Refractory Brick.]
Causes of Thermocouple Failure

Thermocouple Failure

- Gasifier Issues
  - TC Placement *(location in gasifier)*
  - TC Installation *(hole size, depth)*
  - Mechanical *(shear, slag binding)* *
  - Operation

- Thermocouple Assembly
  - Design issues
  - Fabrication defects *
  - Material issues

- Chemical Corrosion *
  - Slag
  - Vapor
  - Metallic iron

* = Possible refractory related issue
Range of Chemistry Found in Over 300 U.S. Coal Slags Due to Mineral Impurities

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight Percent</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max.</td>
<td>Min.</td>
<td>Avg.</td>
<td>Std. dev.</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>68.5</td>
<td>7.1</td>
<td>43.6</td>
<td>16.4</td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>38.6</td>
<td>4.1</td>
<td>25.2</td>
<td>10.2</td>
<td></td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>69.7</td>
<td>2.1</td>
<td>17.0</td>
<td>11.2</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>45.1</td>
<td>0.5</td>
<td>5.8</td>
<td>6.6</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>8.0</td>
<td>0.1</td>
<td>1.2</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>3.5</td>
<td>0.2</td>
<td>1.4</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>6.5</td>
<td>0.3</td>
<td>0.9</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td>3.7</td>
<td>0.4</td>
<td>1.4</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>


Note: Petcoke slags contain V and Ni
## Chemical Composition and Physical Properties of High Chrome Oxide Refractory Materials

<table>
<thead>
<tr>
<th></th>
<th>Brick Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Chemistry (wt pct) - Cr₂O₃</td>
<td>90.3</td>
</tr>
<tr>
<td>- Al₂O₃</td>
<td>7.0</td>
</tr>
<tr>
<td>- ZrO₂</td>
<td>0.01</td>
</tr>
<tr>
<td>Bulk Density (gms/cc)</td>
<td>4.21</td>
</tr>
<tr>
<td>Porosity (pct)</td>
<td>16.7</td>
</tr>
<tr>
<td>CCS (MPa)</td>
<td>48.3</td>
</tr>
</tbody>
</table>
Slag/Refractory Interactions – Chemical Spalling and Corrosion of the Cr$_2$O$_3$-Al$_2$O$_3$ Refractory

Slag diffusion, corrosion, chemical spalling
Failed Thermocouples
*(shear, corrosion, slag and char penetration)*
Edge Spalling/Corrosion of Refractory Where the Thermocouple Enters the Gasifier
Generalized Thermocouple Assembly
Metallic Thermocouple
(Pt/Rh – type R, S, or B)

Positioning of thermocouple sensing tip by slag, gas, etc.

Thermocouple sensing tip (in gasifier)

Resistance bridge caused by the contact of gases, slag, metal, carbon, etc. with thermocouple wire

Positive thermocouple leg, Pt/Rh

Negative thermocouple leg, Pt

EMF (to temperature indicator)
Possible Slag/Pt Thermocouple Wire Interactions

Gasifier Slag

SEM Micrograph Showing FeS and Fe in Slag Particle

Fe – Pt Phase Diagram

Pt - S Phase Diagram

Binary Alloy Phase Diagrams, 2nd Ed., Editor T.B. Massalski, ASM International, 1990
Coal Slag Attack on Thermocouple Wire

Slag Thermocouple (In Slag)
Reference Thermocouple
Open Thermocouple (In Slag)

Gasifier Slag

Refractory Cr$_2$O$_3$/Al$_2$O$_3$
Test Assembly – Type “S” Thermocouple, 1500°C (goal), Ar
EMF Output – 1500°C, Ar
Thermocouple Wire Sample Exposure Test Conditions
(Preliminary Data)

Exposure Conditions

- 1450°C, 8 Hours hold at temperature
- 100 % Pt wire
- Ultra high purity Ar with C and Ti metal getters
- Samples covered with high purity alumina crucible caps and set on high purity alumina setter powder
- Test Slag: Coal ash
- Test Samples:
  - 99 % Al₂O₃
  - 90 % Cr₂O₃ - A
  - 90 % Cr₂O₃ - B
Cup – Top View, After Exposure

With Slag

Without Slag

$\text{Al}_2\text{O}_3$

$\text{Cr}_2\text{O}_3 - \text{A}$

$\text{Cr}_2\text{O}_3 - \text{B}$
Cup – Side View, After Exposure

With Slag

\[ \text{Al}_2\text{O}_3 \]

\[ \text{Cr}_2\text{O}_3 - \text{A} \]

\[ \text{Cr}_2\text{O}_3 - \text{B} \]

Without Slag
Current Research Direction

- Modifications in traditional thermocouple assembly
- New approaches to temperature sensing
  - Evaluating redesign of thermocouple sensors and how utilized in gasifiers
  - Exploring different approaches to thermocouple assemblies
  - Evaluating different ways to transfer signal information from the gasifier
Conclusions

- Current temperature sensors in gasifiers fail by a number of means (shear, material corrosion, sidewall spalling, contact with slag, ...). Post-mortem analysis difficult/impossible.
- Preliminary thermocouple data indicates contact with slag/refractory/or gasifier environment can lead to thermocouple failure or false temperature readings.
- Currently evaluating thermocouple redesign and how thermocouples are used in a gasifier.
- Evaluating ways to transfer signal information from the gasifier.

ACKNOWLEDGEMENT
Support for this research is provided by:
USDOE – NETL; Advanced Research - Materials