Self-Powered Wireless-Ready Electrochemical Sensor For In-Situ Corrosion Monitoring of Coal-Fired A-USC Boiler Tubes

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Project Objectives

➢ To develop a self-powered wireless high temperature electrochemical sensor for in situ monitoring hot corrosion under the harsh conditions present in coal-based power generation system.

➢ To develop thermal-electric based energy harvesting and telecommunication devices for the self-powered wireless ready sensor system.
Key Innovations of the Project

- Electrochemical Noise Based High Temperature Electrochemical Sensor Technology
- Wireless Communication Technology
- Energy Harvesting Technology (Thermoelectric Generator (TEG))
Conceptual Design of Self-Powered Wireless-Ready High Temperature Electrochemical Sensor
Self-Powered Wireless Sensing System for Concurrent Potential and Current Signals Measurement

- Thermoelectric Generator (TEG)
- Transmitters
- Signal Converters
- Potential Signal
- Potential Amplification System
- Current Signal
- Current Amplification System
High Temperature Corrosion Sensor Design for Concurrent Potential and Current Signals Measurement

Reference electrode

Working electrodes 1, 2 & 3

WE-1
WE-2
WE-3

Current noise

Potential noise

RE
## Experimental Conditions

<table>
<thead>
<tr>
<th>Corrosion condition</th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Materials</strong></td>
<td>IN 740-1</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>650-850°C</td>
</tr>
<tr>
<td><strong>The Flue Gas Composition</strong></td>
<td>With/without SO₂</td>
</tr>
<tr>
<td></td>
<td>15 CO₂ + 4 O₂ + 80 N₂ + 1 SO₂</td>
</tr>
<tr>
<td><strong>Coal ash thickness</strong></td>
<td>Uniform /Localized Thin film</td>
</tr>
<tr>
<td></td>
<td>89 % Ash +10% Alkali +1% NaCl</td>
</tr>
<tr>
<td><strong>Exposure time</strong></td>
<td>20 days</td>
</tr>
</tbody>
</table>
THREE Different Stages of Coal Ash Hot Corrosion Process

Oxidation in Cr,Ni-rich regions

External Sulfidation in Cr,Ni-rich regions

Internal Sulfidation in Ni,Cr-rich regions

Oxidation Stage

Sulfidation Stage

External

Internal

Coal Ash Hot Corrosion Process

Low corrosion (Noise signature IV)

Accelerated corrosion (Noise signature V)

External Sulfidation in Cr,Ni-rich regions
Oxygen and Sulfur Diffusion During Oxidation & Sulfidation Stages

- **Oxidation** in Cr,Ni-rich regions
- **External Sulfidation** in Cr,Ni-rich regions
- **Internal Sulfidation** in Ni,Cr-rich regions
Reproducibility of Potential and Current Signals During Oxidation and Sulfidation

IN 740-1 alloy + 850 °C + Thin coal ash + without /with SO₂
FIVE Typical Noise Signals Measured in the Coal Ash Hot Corrosion Process

**Electrochemical Potential Noise Signals**
- The noise signature of a gradual potential continuously changing in the negative region *(Noise Signature I)* corresponded with the Oxidation Stage.
- The noise signature of quick potential continuously approaching more positive values *(Noise Signature II)* correlated to the External Sulfidation Stage.
- The noise signature of positive potential fluctuating randomly in a narrow range *(Noise Signature III)* corresponded with the Internal Sulfidation Stage.

**Electrochemical Current Noise Signals**
- Signature of current fluctuating with no sudden spike correlated to the Low Extent of Oxidation/Sulfidation *(Noise Signature IV)*.
- The noise pattern of sudden change in current values followed by slow or no recovery corresponded with the Accelerated Oxidation/Sulfidation *(Noise Signature V)*. These signatures can be seen clearly at 750 °C, in the flue gas without SO₂ as well as deep coal ash.
Concurrent Transmission of Corrosion Potential and Current Signals

Under Uniform Thin Coal Ash Film

Under Localized Thin Coal Ash Film
Calculation of Corrosion Rate from Current Noise Signals

Corrosion Potential and Current

Corrosion Current and Corrosion Rate
Study of Localized Under-Coal Ash Deposit Corrosion (LUAC) using High Temperature Electrochemical Sensor
EIS Showing Oxidation and Sulfidation Stages During LUAC
EN Data Showing Oxidation Stage During LUAC

**Potential Noise Signal**

**Current Noise Signal**
EN Data Showing Transition from Oxidation to Sulfidation Stages During LUAC
EN Data Showing Sulfidation Stage During LUAC

Potential Noise Signal

Current Noise Signal
Three Different Stages of LUAC

- The oxidation stage was featured with the noise pattern of continuously changing potential approaching less negative values. The noise signature of current fluctuating with no sudden spike during oxidation indicates the low extent of corrosion.

- The transition stage from the oxidation to sulfidation was featured with the characteristic potential noise pattern of the continuous cyclic oscillations. In this stage, sulfidation initiated with significant increase of current.

- The sulfidation stage correlated to a characteristic noise signature of quick potential continuously approaching more positive values. The accelerated sulfidation can be evaluated with the noise signature of sudden change in current values followed by slow or no recovery.
Noise Resistance Values During LUAC

![Graph showing noise resistance values over time. The graph indicates three stages: the oxidation stage, the transition stage, and the sulfidation stage.](image)
Localization Index During LUAC

![Graph showing the localization index over time with stages: oxidation, transition, and sulfidation stages for localized corrosion, and uniform corrosion stages.](image)

- **Localized Corrosion**
  - The oxidation stage
  - The transition stage
  - The sulfidation stage

- **Mixed Corrosion**

- **Uniform Corrosion**

Time (h):
- 48, 96, 144, 192, 240, 288, 336, 384, 432, 480

Localization index:
- 0.01, 0.1, 1
Corroded Surfaces of LUAC after 20 days

- **Oxidation**
- **Sulfdiation**

After 10 days

After 20 days
Cross Sectional Corroded Surfaces of LUAC after 20 days

- **Oxidation** under coal ash uncovered area
- **Sulfidation** under coal ash covered area
- **Sulfidation** under area between coal ash uncovered and covered areas
Oxygen and Sulfur Diffusion
At Coal Ash-Uncovered Corroded Area
Oxygen and Sulfur Diffusion Near Coal Ash Covered Corroded Area
Oxygen and Sulfur Diffusion Inside Coal Ash-Covered Corroded Area
Testing Sensor in Industrial USC Boiler Setting
(Western Research Institute, Laramie WY)
Sensor Setting
Inside and Outside USC Boiler System
22 April 2015

Corrosion sensor

Wireless Sensing System
for Concurrent Potential and Current Signals Measurement
Conclusions

- A self-powered wireless sensing system has been successfully developed for concurrent transmission of potential and current signals from coal ash hot corrosion.

- Characteristic patterns in the wireless concurrent potential and current noise signals can clearly identify the oxidation and sulfidation stages of coal ash hot corrosion process after data smoothing.

- Localized under-coal ash deposit corrosion behaviour of Inconel 740 superalloy was studied using the sensor. The predominant stages during the LUDC process can be identified with three typical potential noise patterns and their extents of the corrosion can be evaluated with two characteristic current noise patterns.

- Analysis of electrochemical noise signals by power spectral density (PSD) was applied to coal ash hot corrosion study. PSD plots using coefficient 1000 of MEM show more reasonable information for mechanism of the oxidation and sulfidation processes.


6. Naing Naing Aung, Xingbo Liu: Study of local under-coal ash deposit corrosion of Inconel 740 alloy using high temperature electrochemical sensor, Corrosion (Under review)
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