WestVirginiaUniversity
Benjamin M. Statler College of Engineering and Mineral Resources

DoE Award No. DE- FE0005717

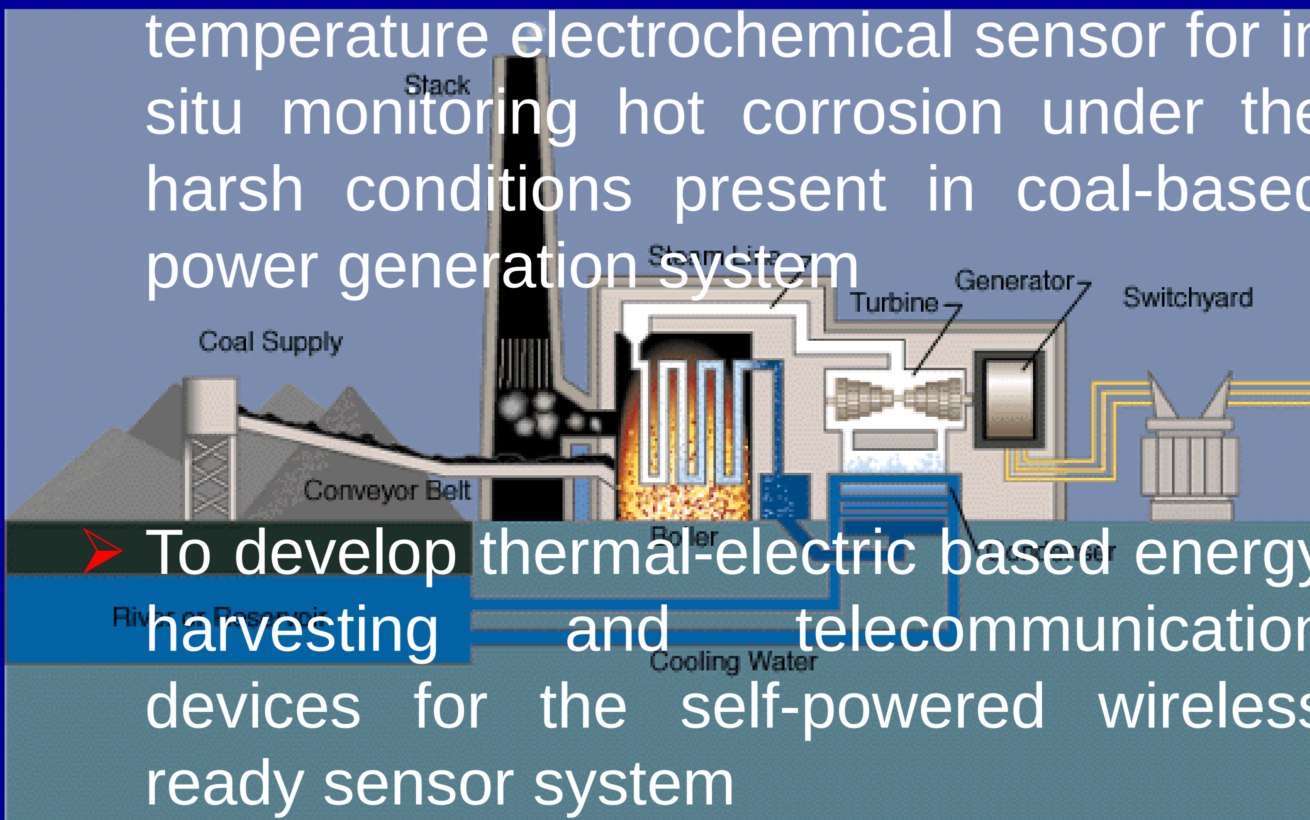
Development of Self-Powered Wireless-Ready High Temperature Electrochemical Sensor For In-Situ Corrosion Monitoring of Coal-Fired Boiler Tubes

Naing Naing Aung, Edward R. Crowe, Xingbo Liu

21st May 2014

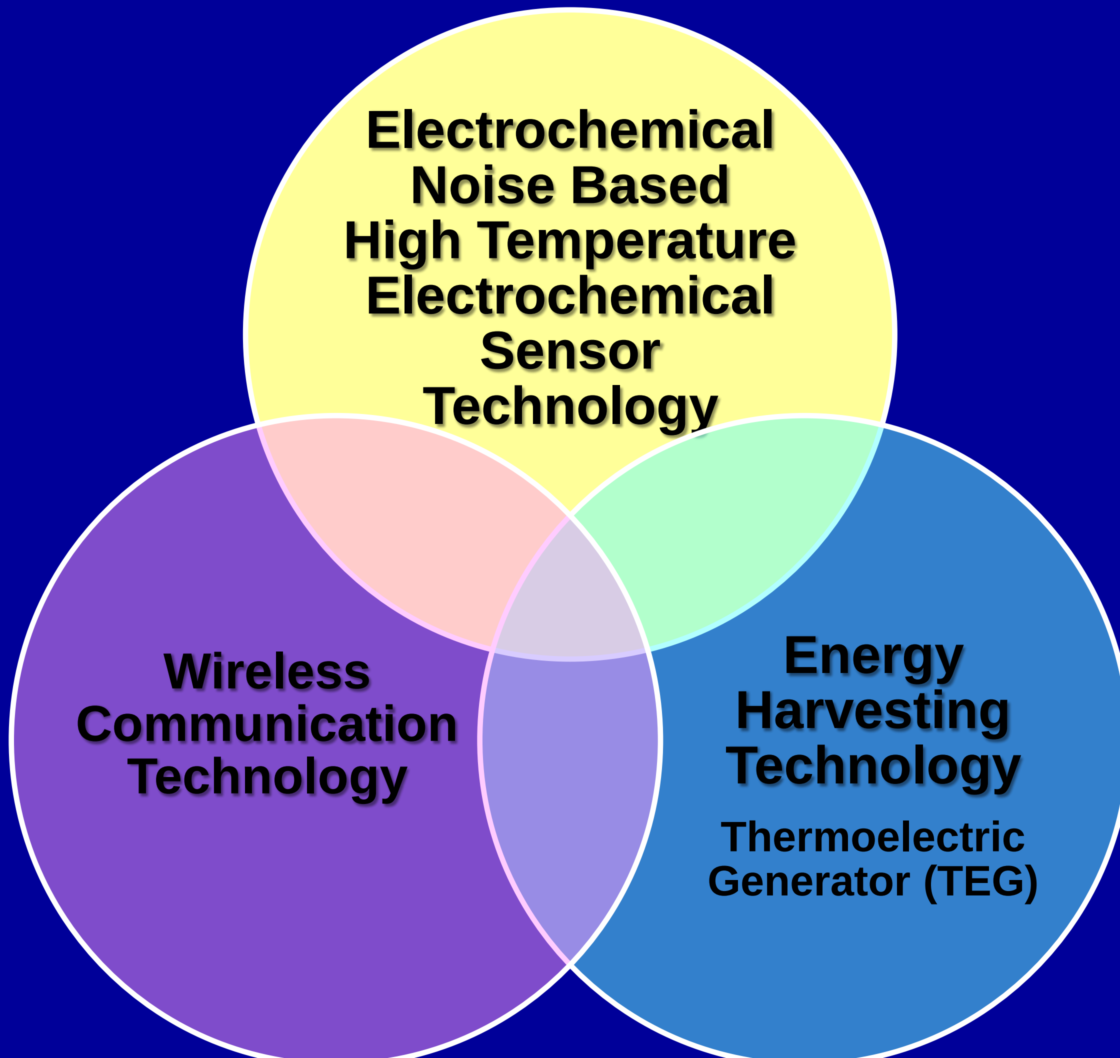
Project Objectives

- 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

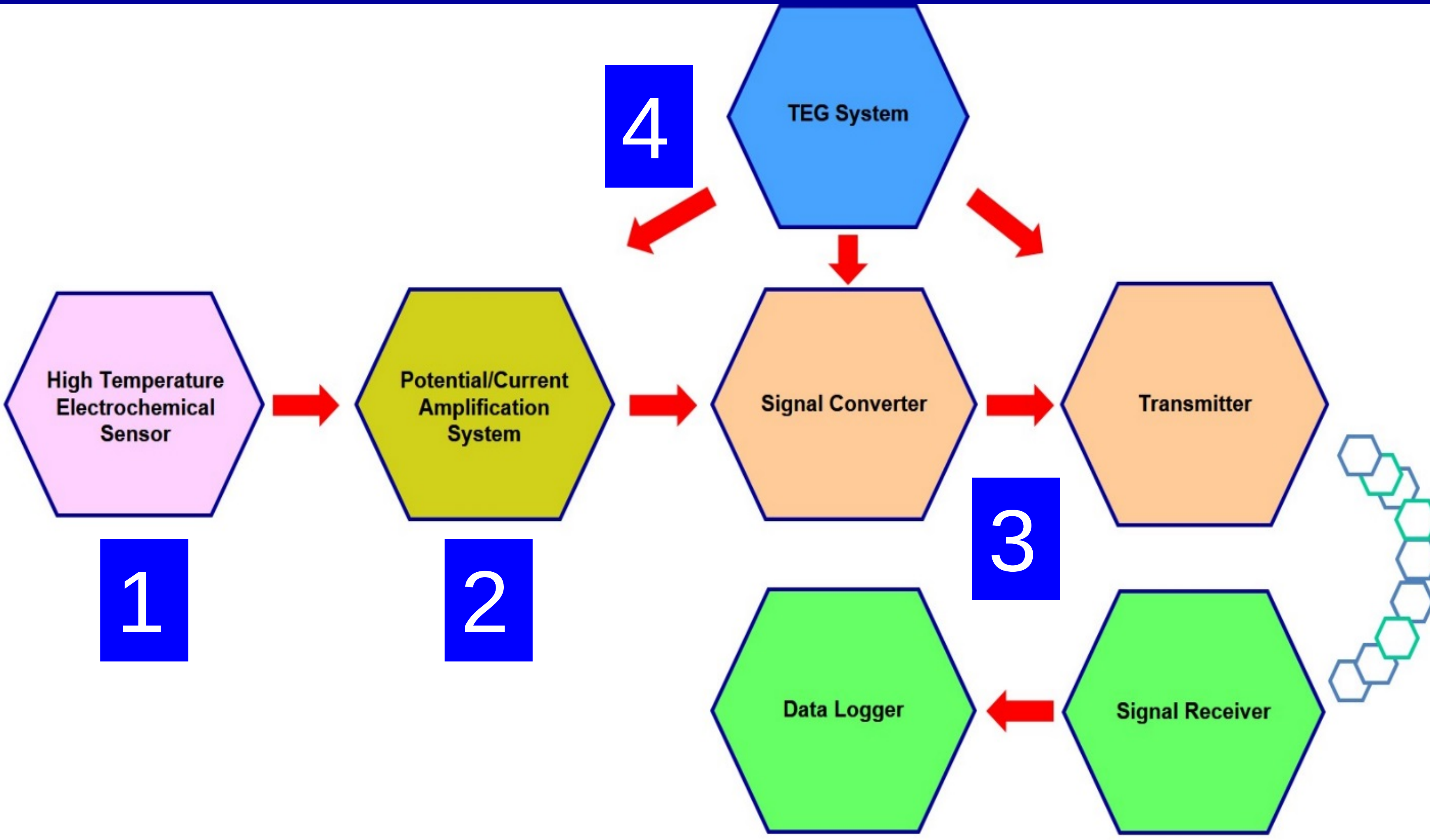


- To develop thermal-electric based energy harvesting and telecommunication devices for the self-powered wireless ready sensor system

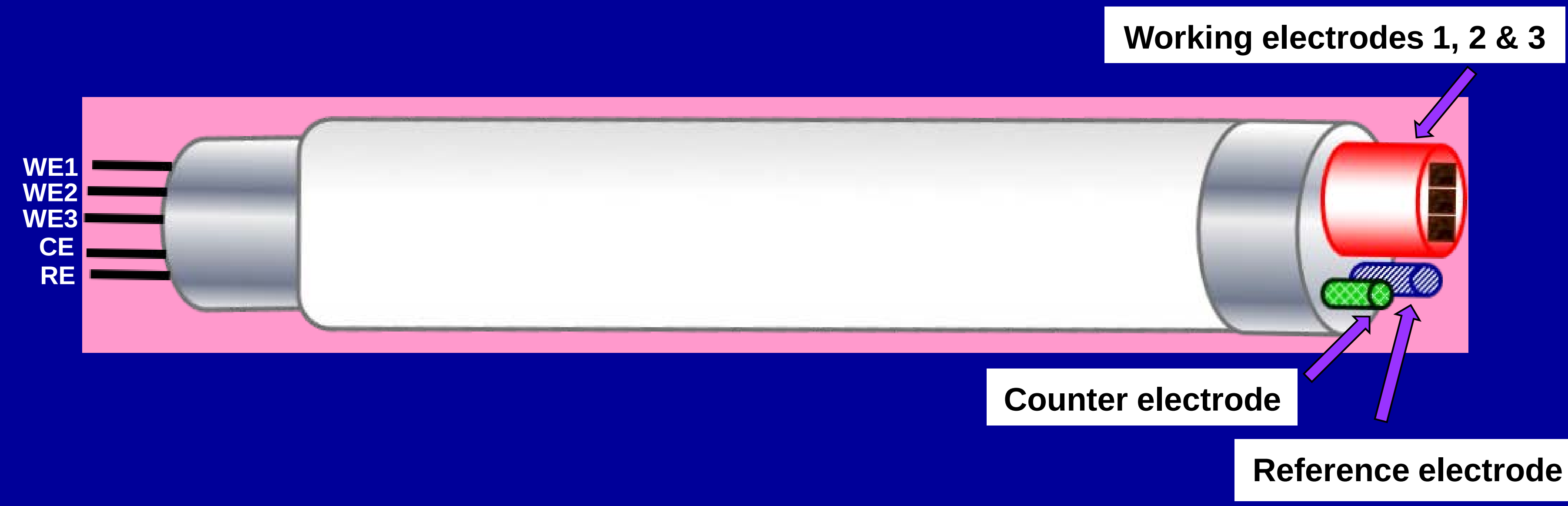
Key Innovations of the Sensing Strategy



Conceptual Design of the Sensing System



Our Developed High Temperature Corrosion Sensor



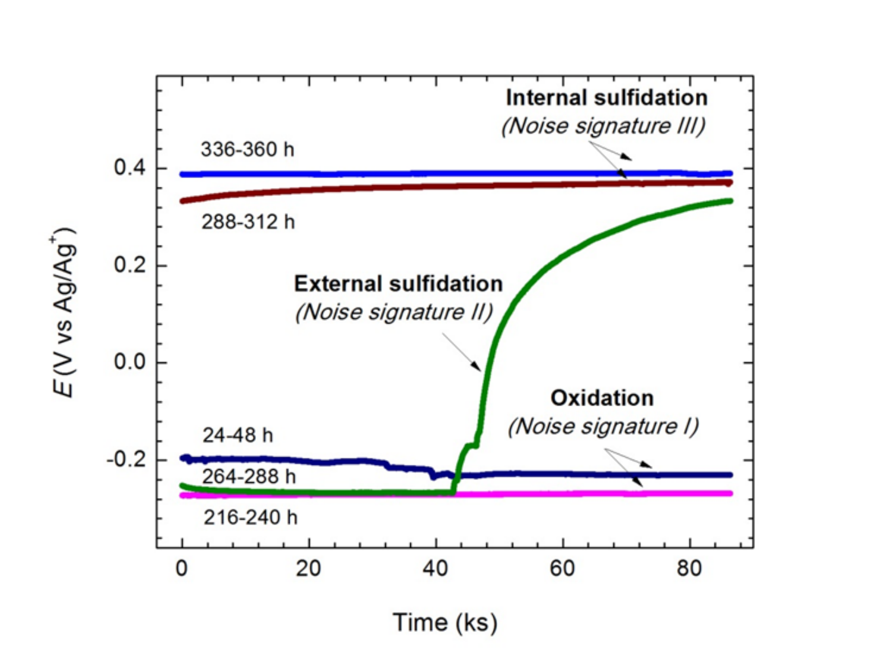
WE-1, WE-2	Current noise	WE-1, RE, CE	Potentiodynamic Polarization	WE-1, WE-2	EIS
WE-3, RE	Potential noise				

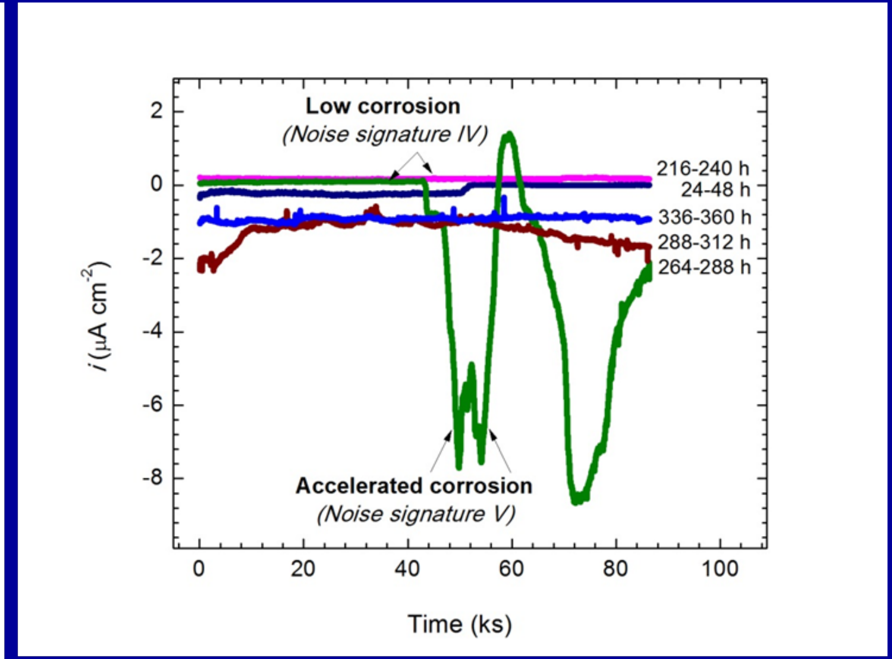
Sensibility Test of Self-Powered Wireless-Ready High Temperature Electrochemical Sensor Before Wireless Transmission

Experimental Conditions for Sensibility and Reliability Tests

Corrosion condition	
Materials	IN 740-1
Temperature	650-850°C
The Flue Gas Composition	With/without SO_2 15 CO_2 + 4 O_2 + 80 N_2 + 1 SO_2
Coal ash thickness	Thin film 89 % Ash +10% Alkali +1% NaCl
Exposure time	60 days

THREE Different Stages of Coal Ash Hot Corrosion Process





Coal Ash Hot Corrosion Process

↓

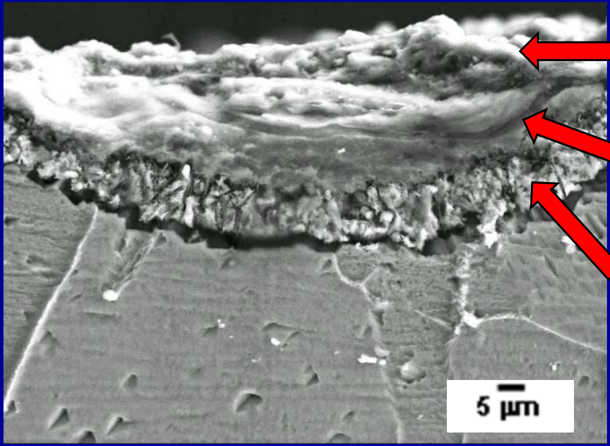
Oxidation Stage

↓

Sulfidation Stage

→ **External**

→ **Internal**

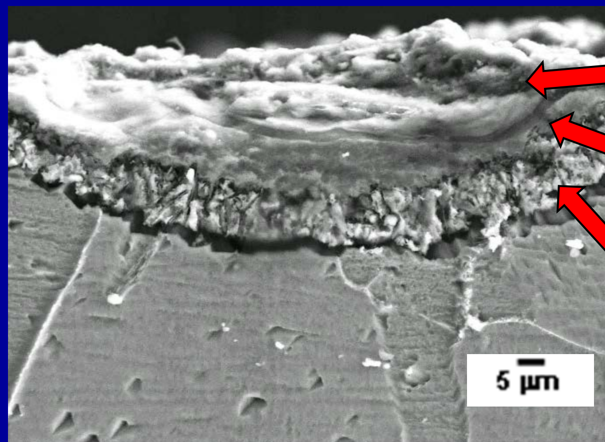


Oxidation in Cr,Ni-rich regions

External Sulfidation in Cr,Ni-rich regions

Internal Sulfidation in Ni,Cr-rich regions

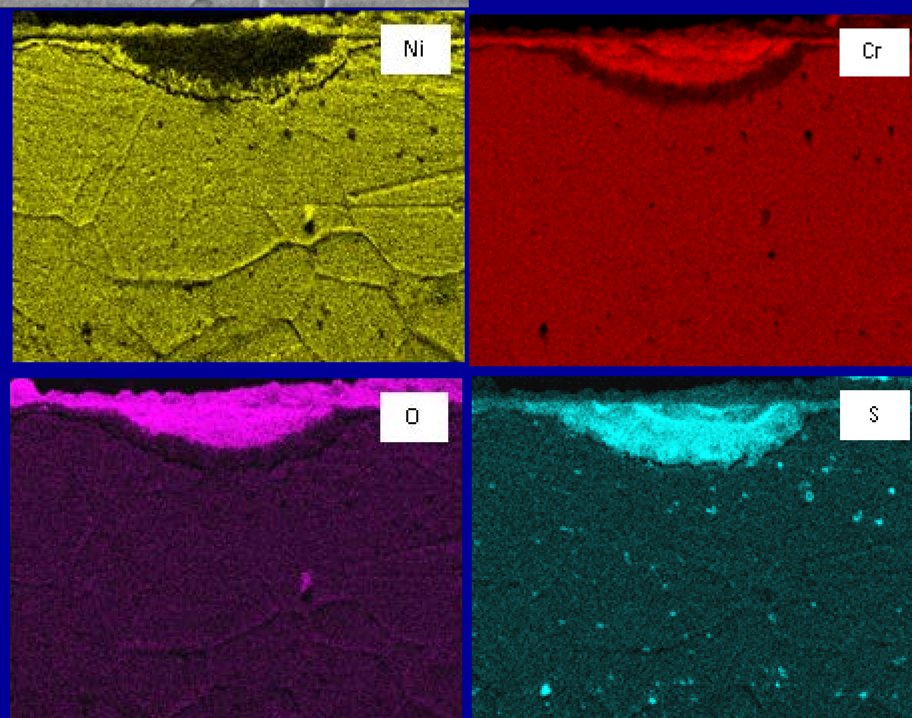
Oxygen and Sulfur Diffusion During Oxidation & Sulfidation Stages



Oxidation in Cr,Ni-rich regions

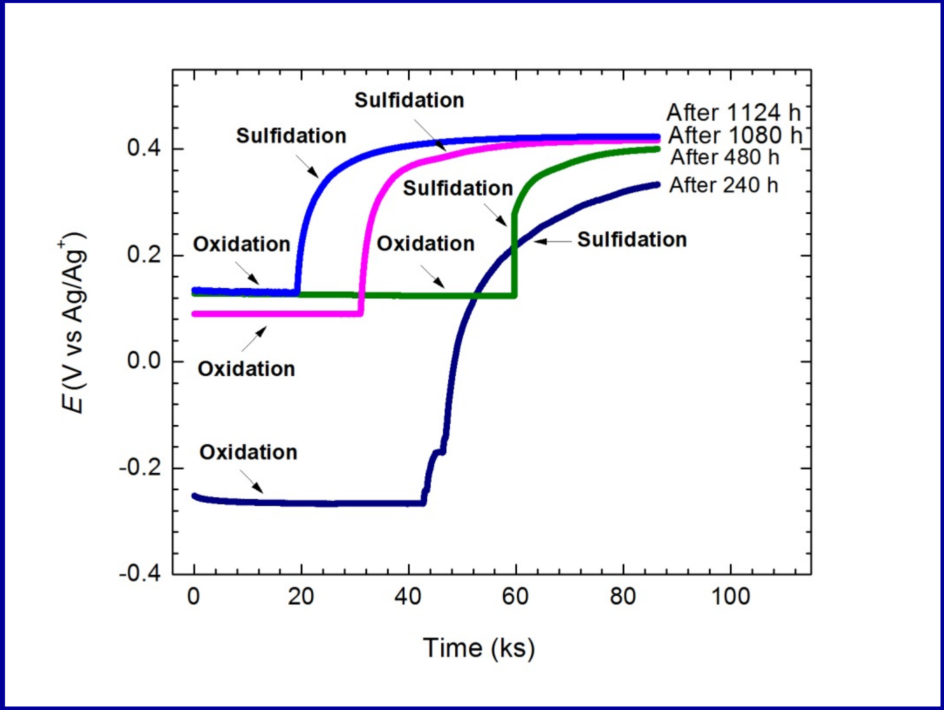
External Sulfidation
in Cr,Ni-rich regions

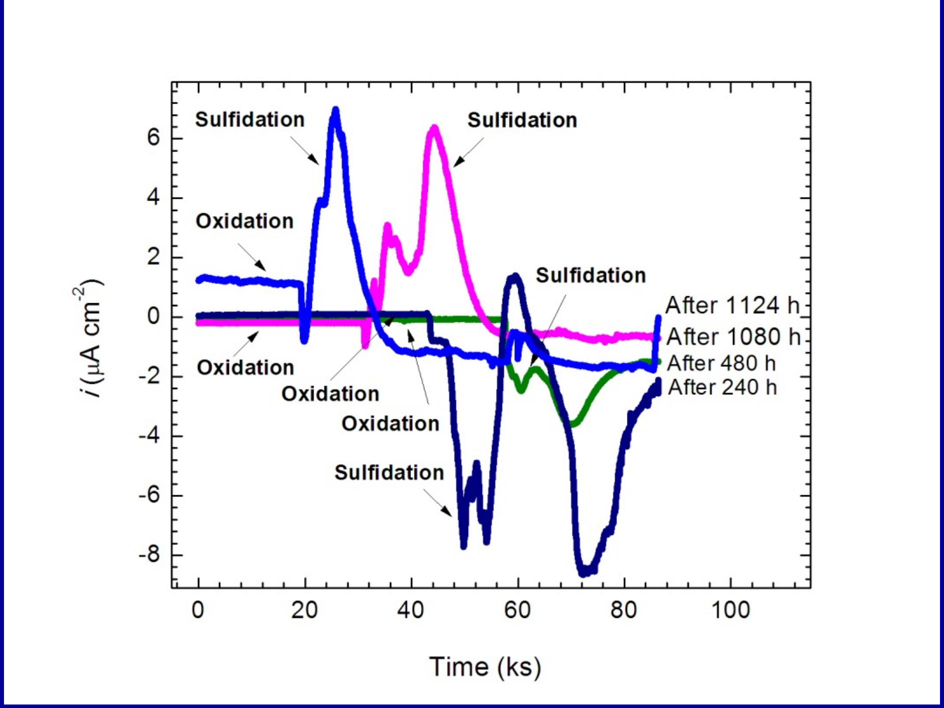
Internal Sulfidation
in Ni,Cr-rich regions



Reproducibility of Potential and Current Signals During Oxidation and Sulfidation

IN 740-1 alloy + 850 °C + Thin coal ash + without /with SO_2





FIVE Typical Noise Signals Measured in the Coal Ash Hot Corrosion Process

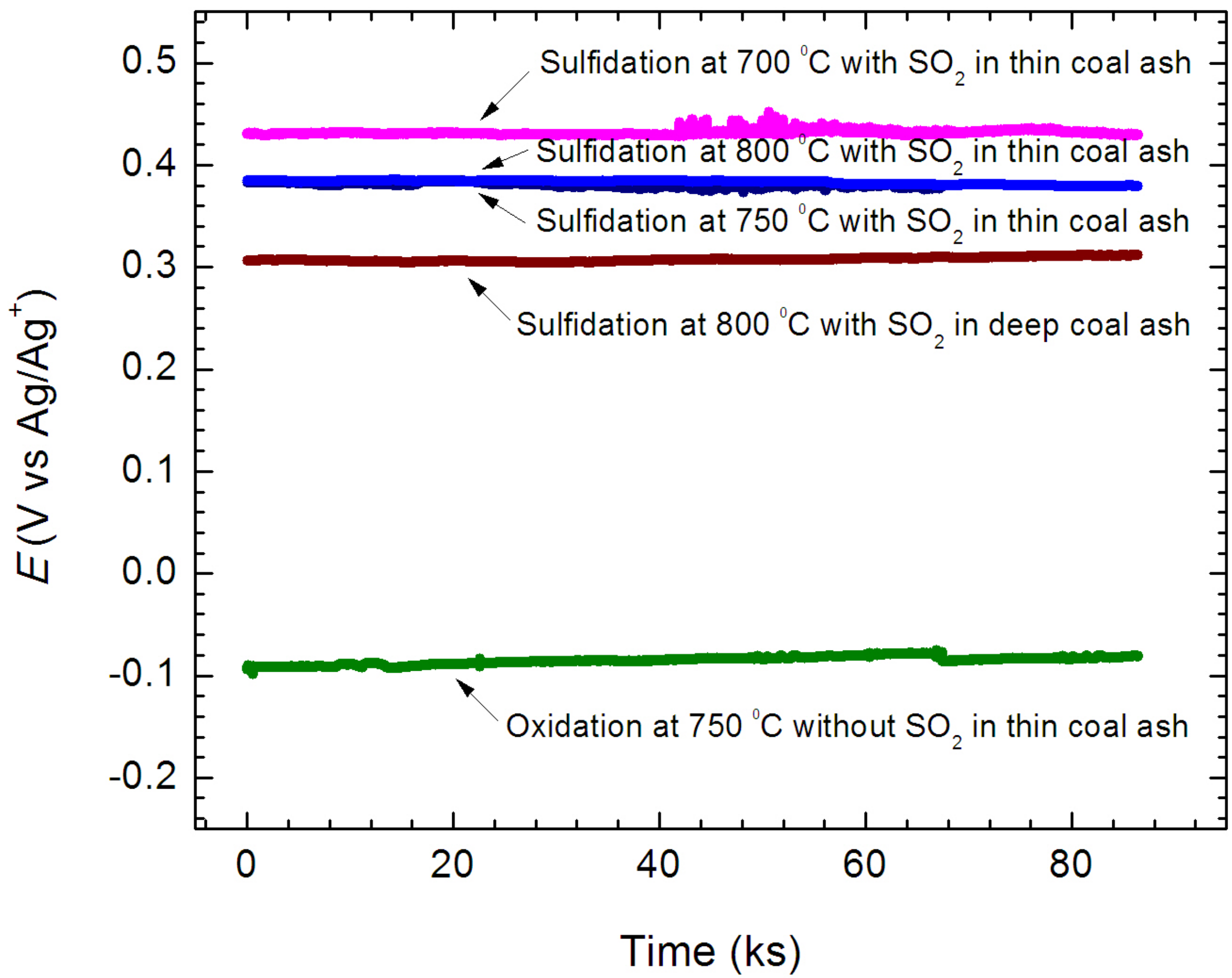
Electrochemical Potential Noise Signals

- 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

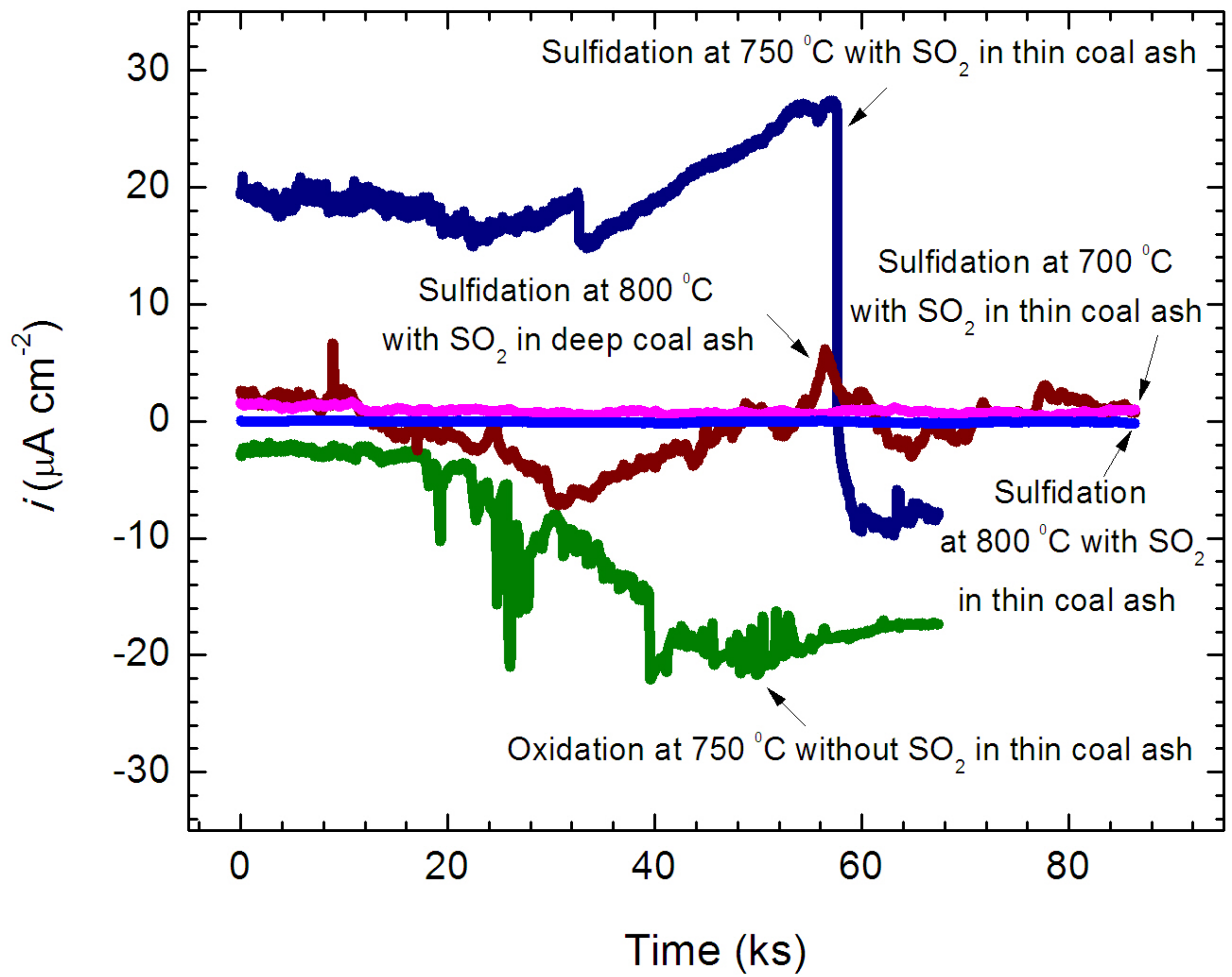
Electrochemical Current Noise Signals signature of current fluctuating with no sudden spike correlated to the Low Extent of Oxidation/Sulfidation *(**Noise Signature IV**)*.

- 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 SO_2 as well as deep coal ash.

Corrosion Potential Range in Different Coal Ash Hot Corrosion Conditions



Corrosion Current Range in Different Coal Ash Hot Corrosion Conditions



New Version of Faraday's Law Expression for Calculation of Hot Corrosion Kinetics

$$\text{Corrosion Rate, } \boldsymbol{R} = \frac{\mathrm{KM}}{\mathrm{n}\rho}\, \boldsymbol{i_{max}}$$

K = Constant for converting units

M = Atomic mass

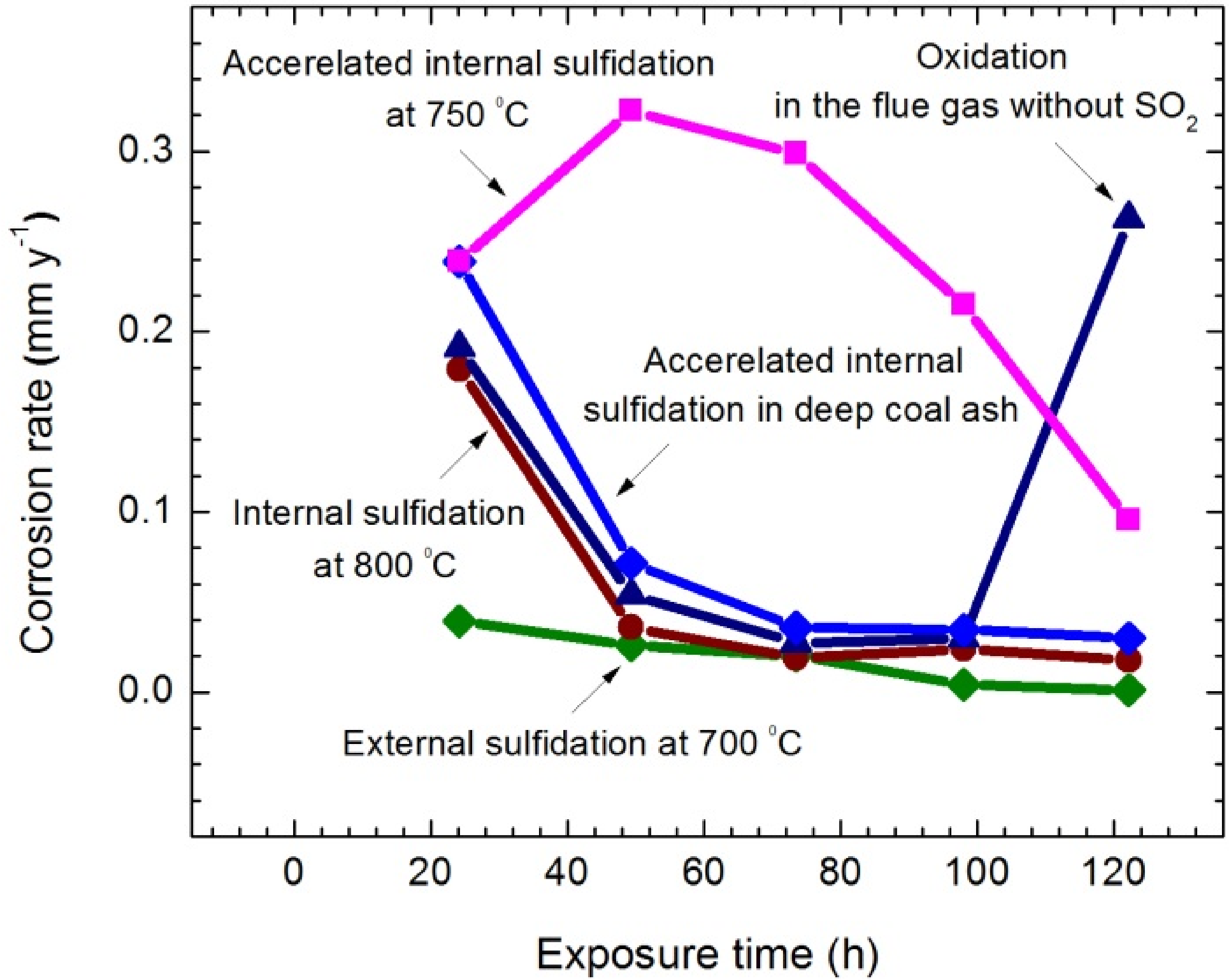
n = Number of electrons freed by the corrosion reaction

ρ = Density

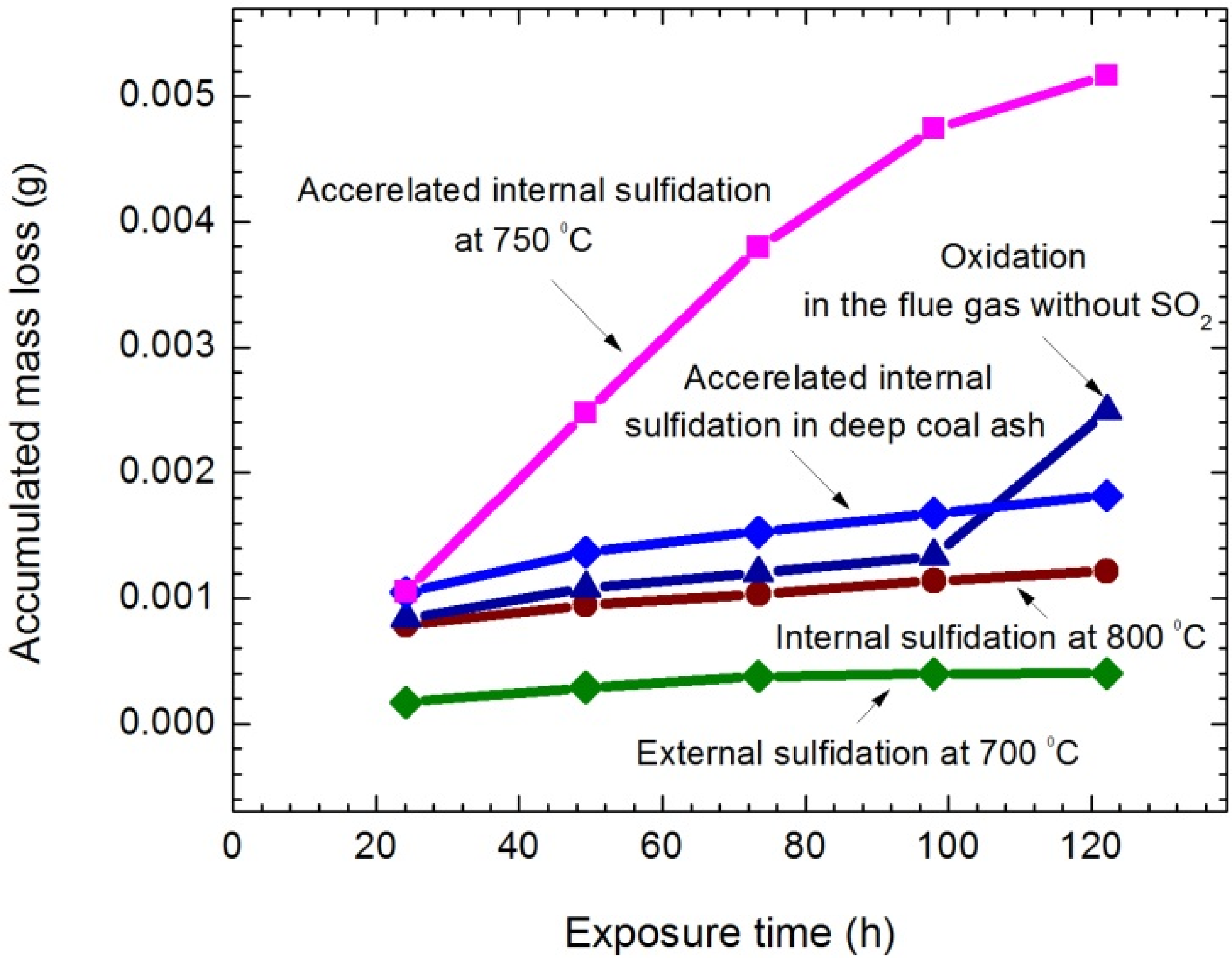
$$\text{Corrosion Depth, } \boldsymbol{D} = \mathbf{K} \times \boldsymbol{R} \times \mathbf{period}$$

where the period is normally 24 h and the corrosion rate is assumed to be constant

Evaluation of Corrosion Rates

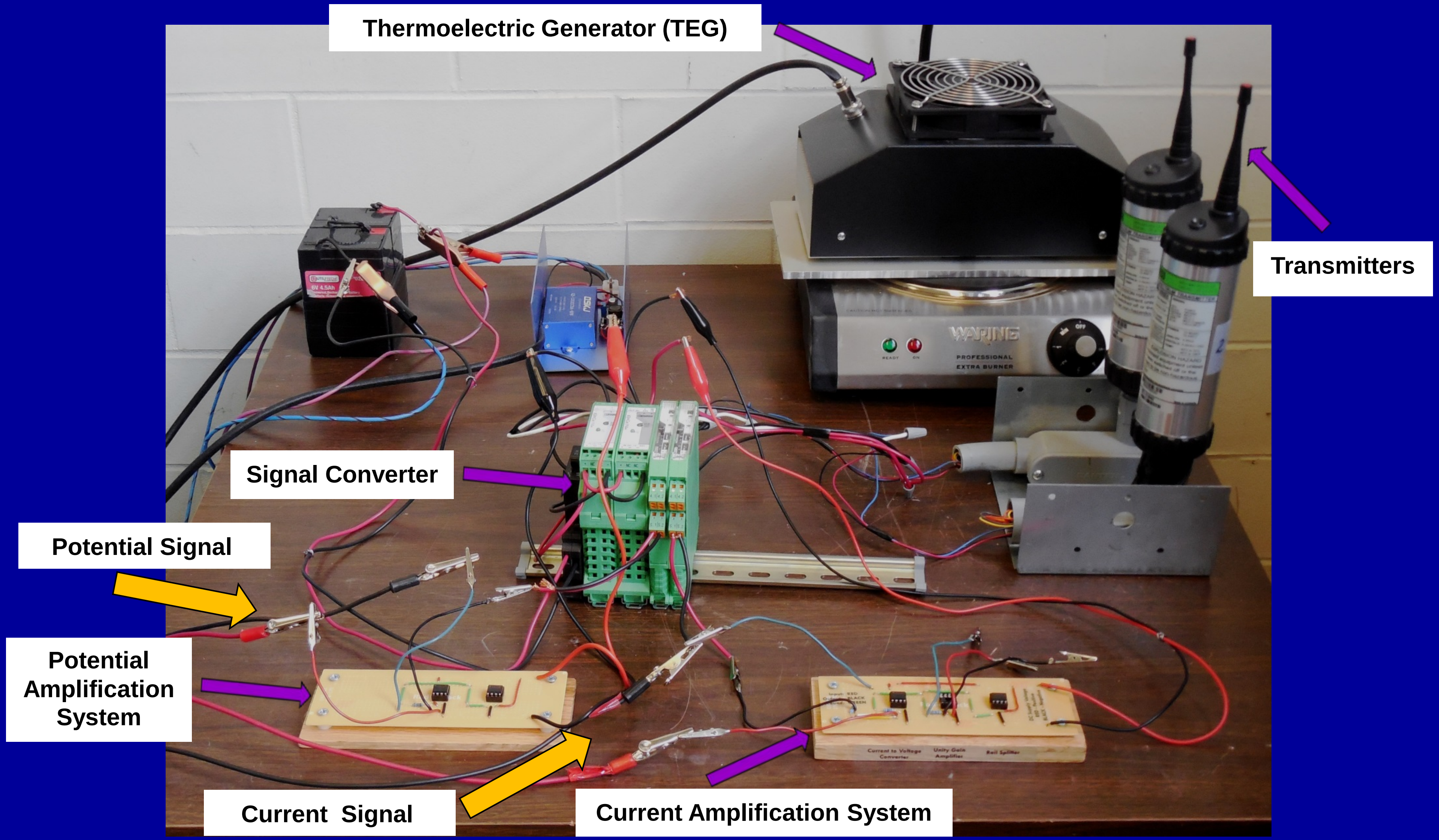


Evaluation of Metal Losses



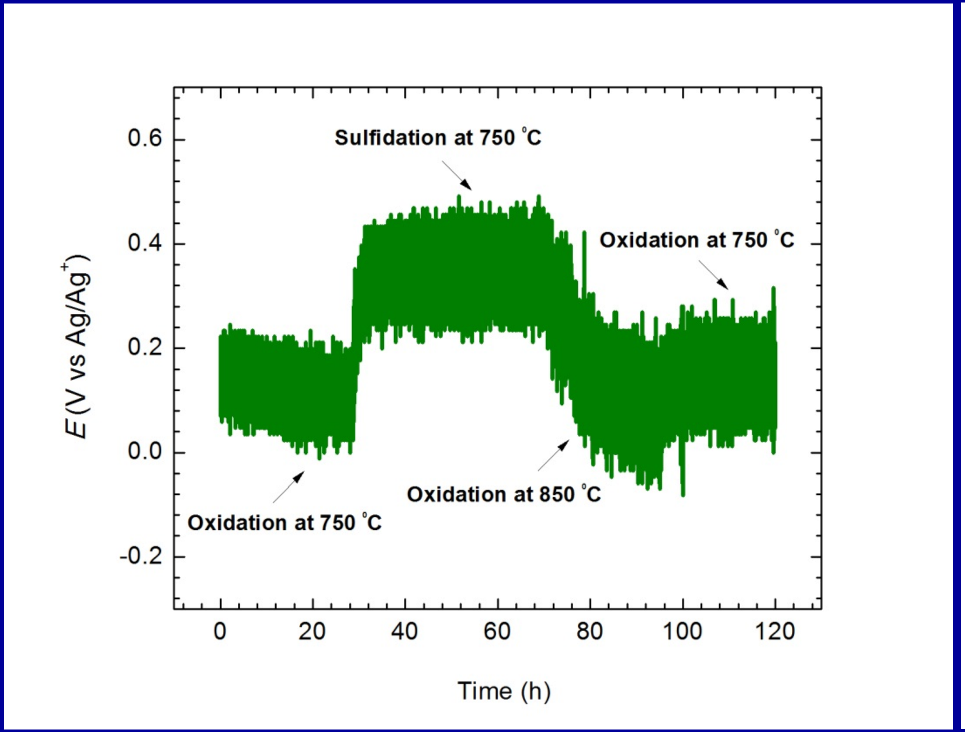
Sensibility Test of Self-Powered Wireless-Ready High Temperature Electrochemical Sensor After Wireless Transmission

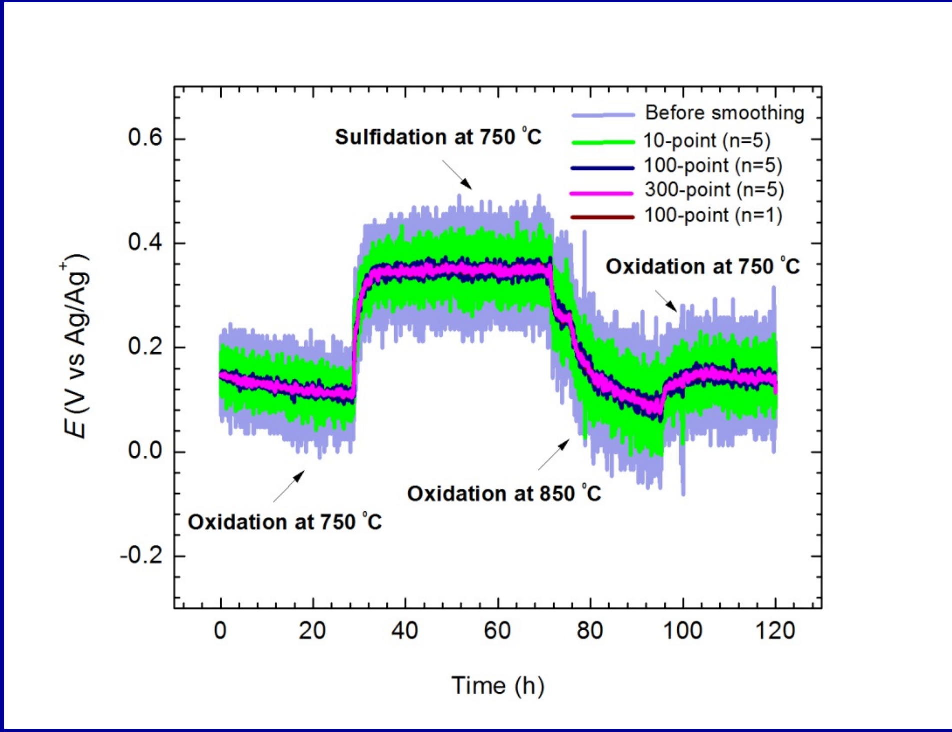
Experimental Set up for Self-Powered Wireless Sensing



Wireless Potential Signal from Oxidation & Sulfidation Stages

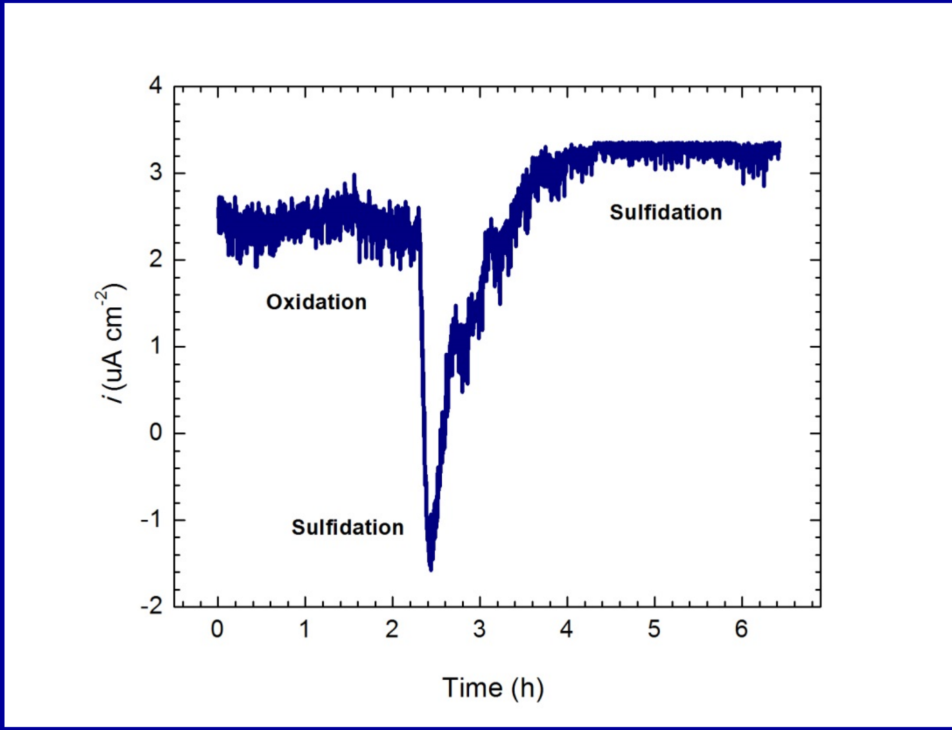
IN 740-1 alloy + Thin coal ash + with/withut SO_2

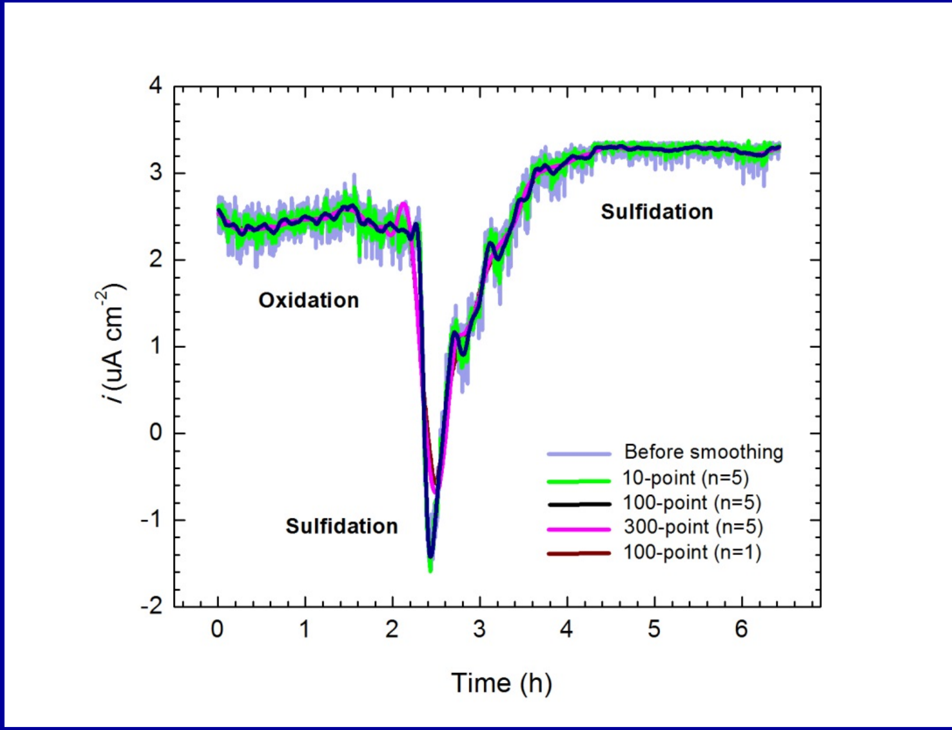




Wireless Current Signals from Oxidation & Sulfidation Stages

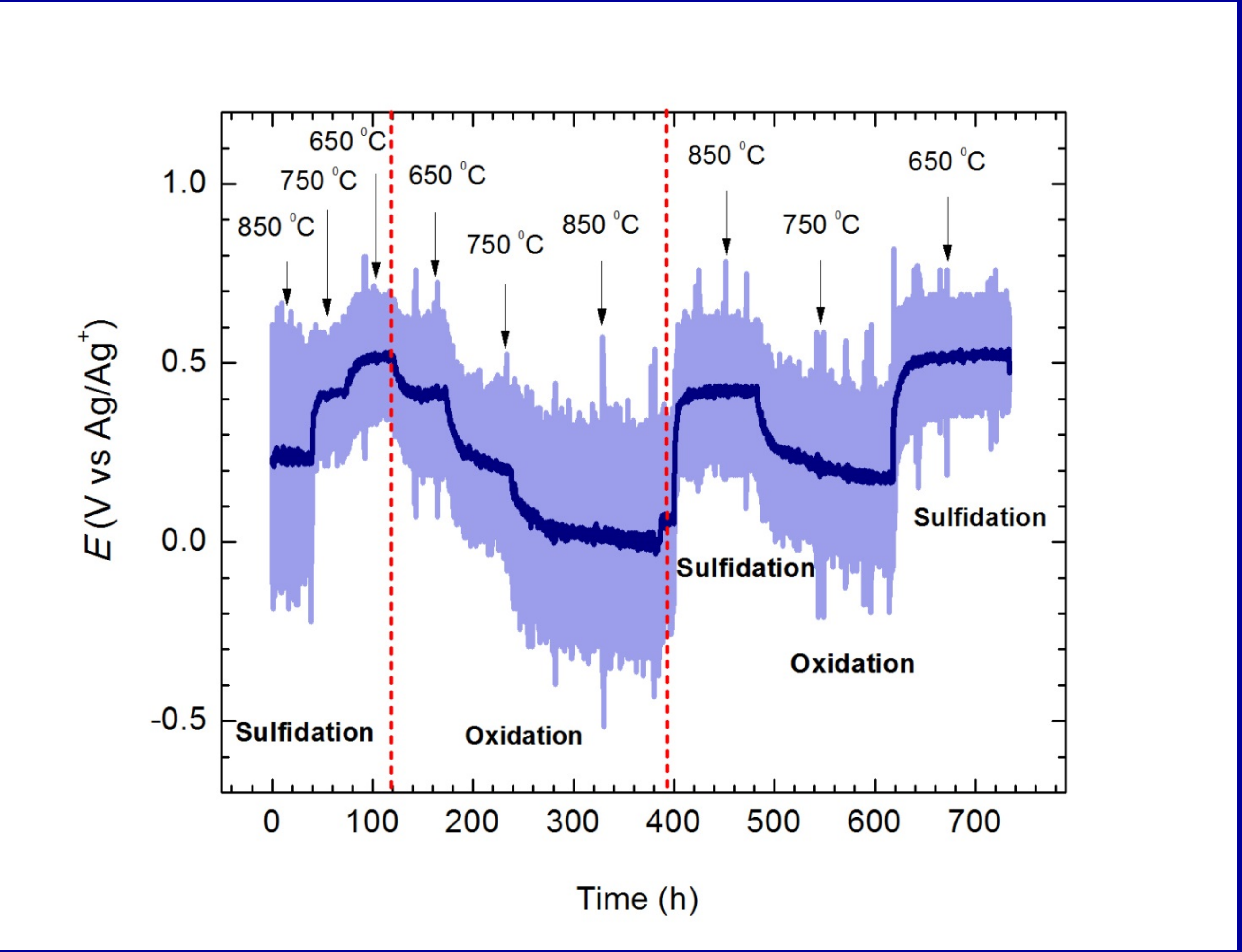
IN 740-1 alloy + Thin coal ash + with/withut SO_2





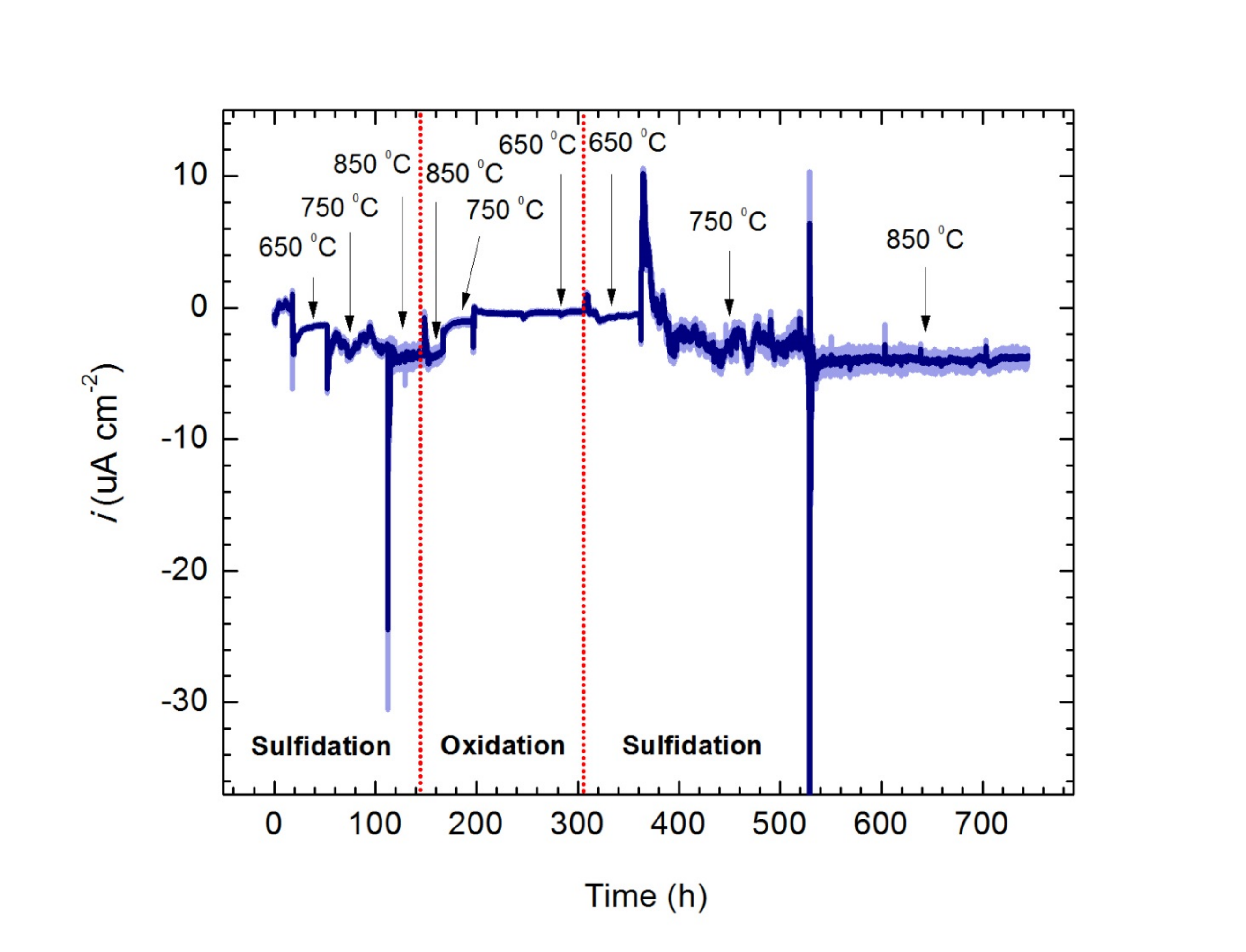
Potential Signal Transmission For 30 Days

IN 740-1 alloy + Thin coal ash + with/withut SO_2



Current Signal Transmission For 30 Days

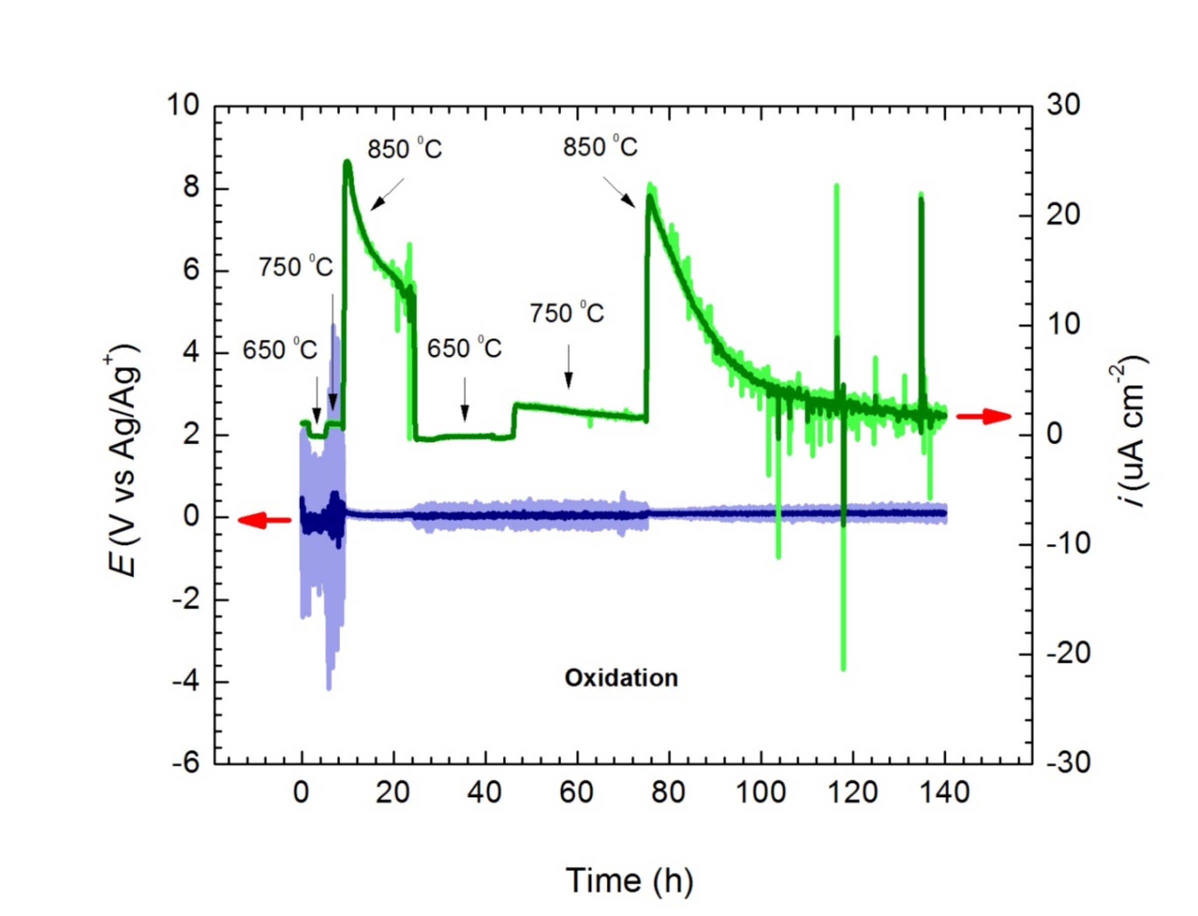
IN 740-1 alloy + Thin coal ash + with/withut SO_2



Concurrent Transmission of Potential and Current Signals

Oxidation at Different Temperatures

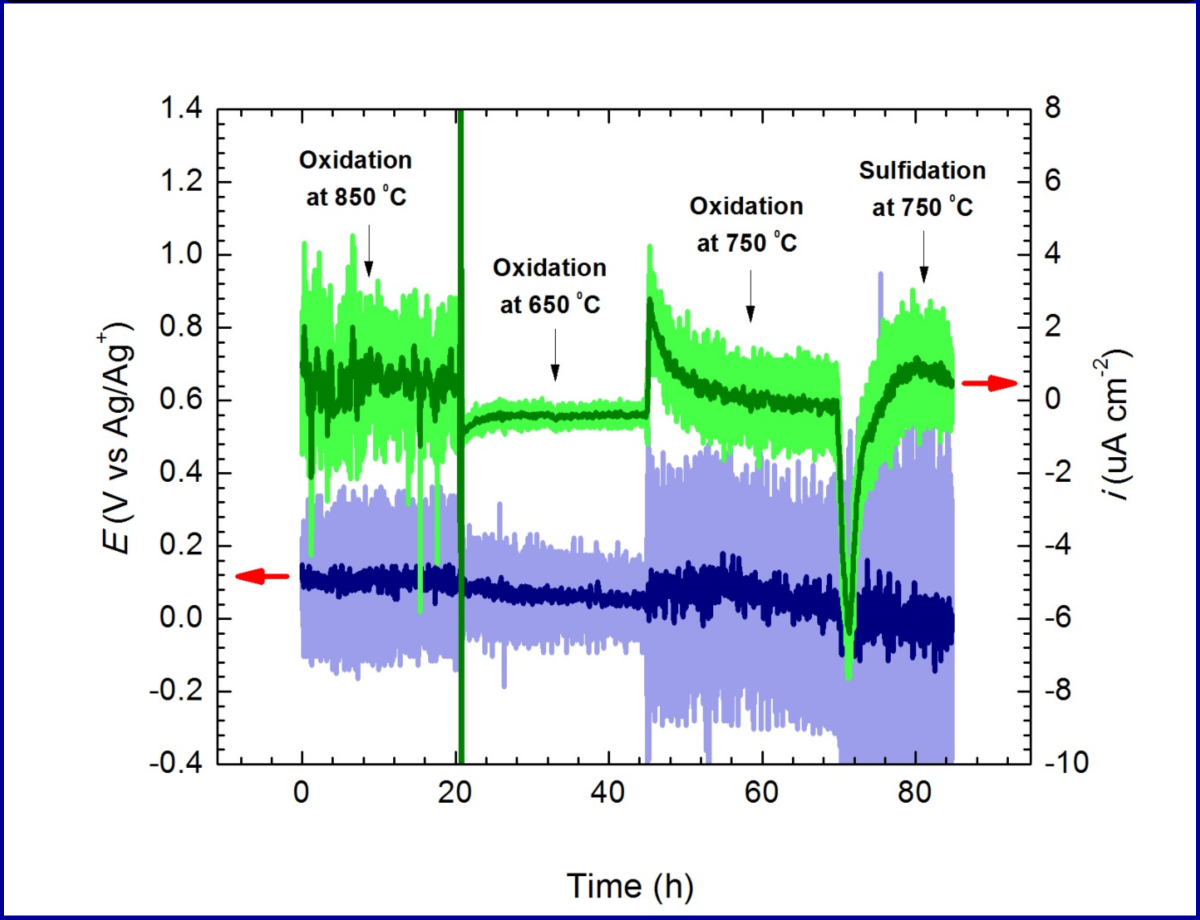
IN 740-1 alloy + Thin coal ash + withut SO_2



Concurrent Transmission of Potential and Current Signals

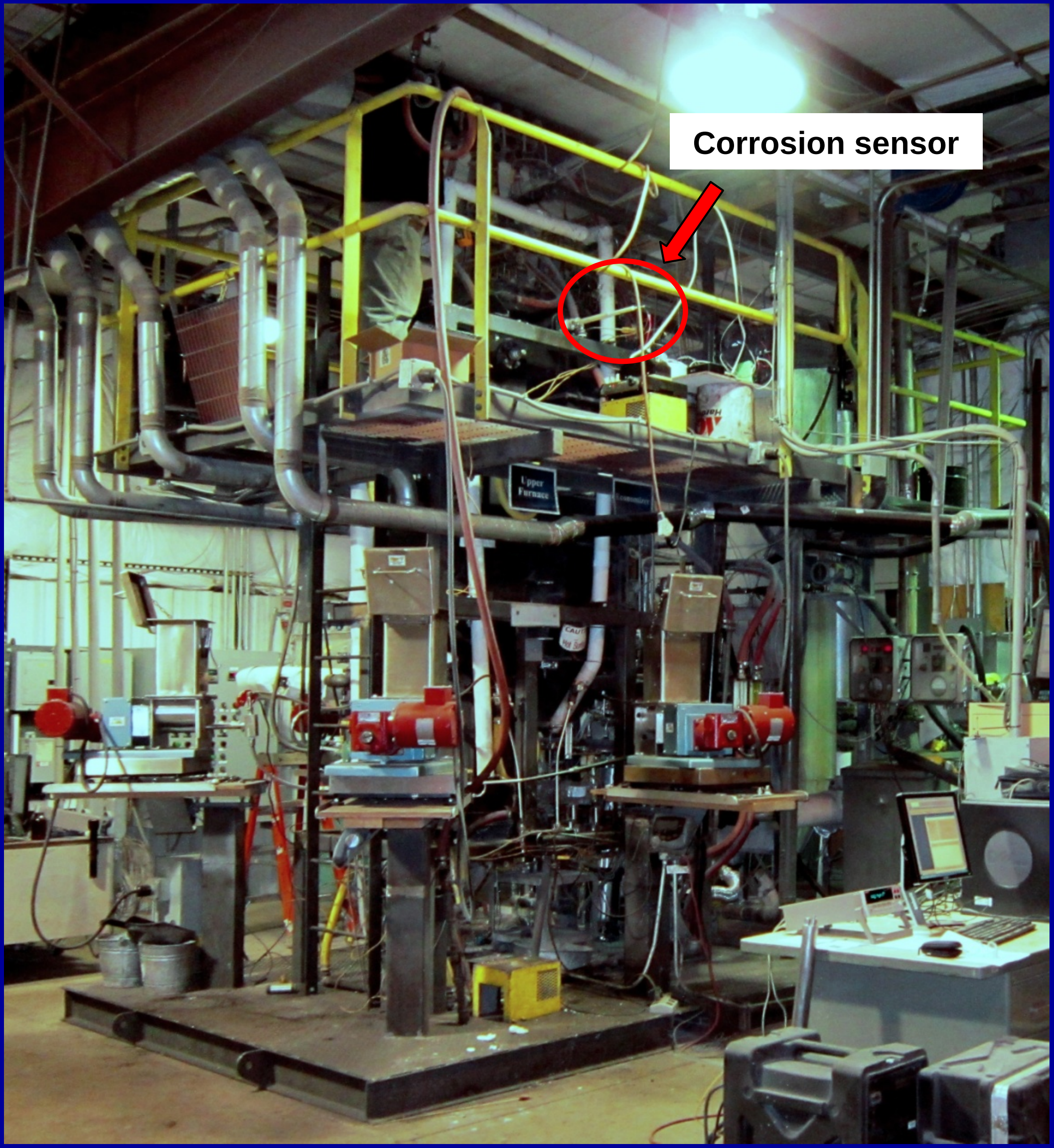
Oxidation & Sulfidation at 750 °C

IN 740-1 alloy + Thin coal ash + with/withut SO_2



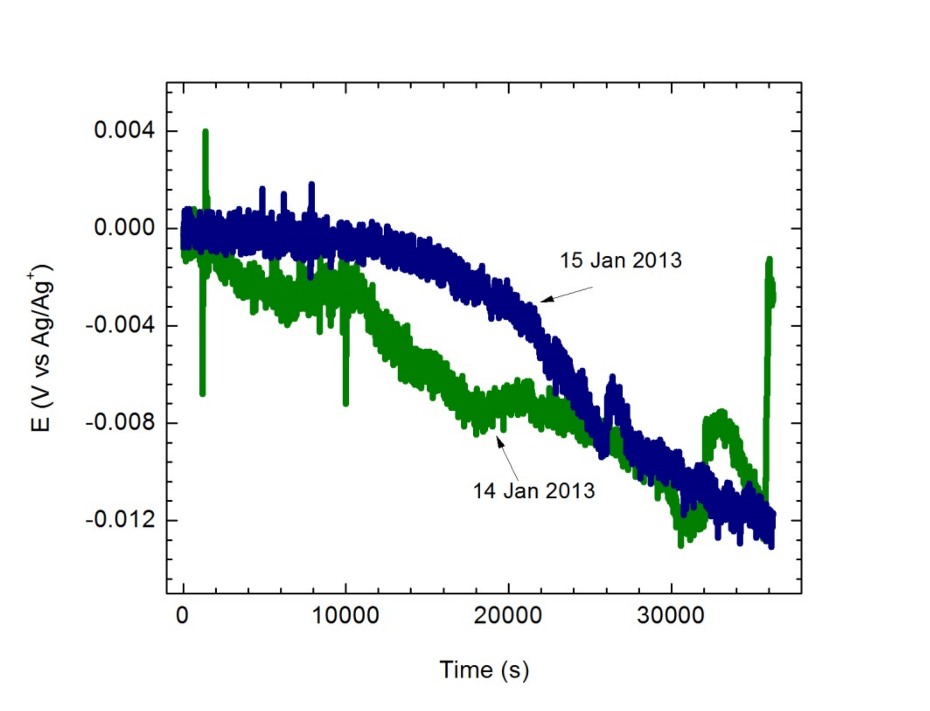
Testing Sensor
in Industrial USC Boiler Setting
(Western Research Institute, Laramie WY)

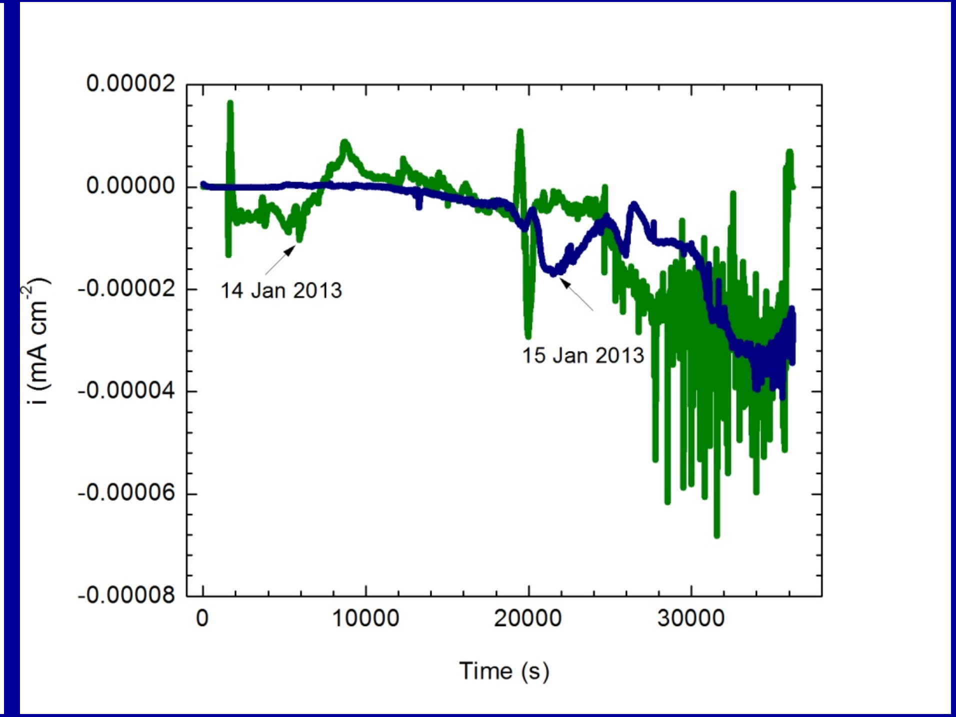
Sensor Setting inside Coal Combustion System



Sensor Setting inside Coal Combustion System

Potential/Current Signals Measured from Corrosion in the Coal Combustion System





Project Milestones

June 2011 to Dec 2013

- To develop the high temperature electrochemical sensor
- To demonstrate sensitivity and long term reliability of the high temperature electrochemical sensor
- To develop TEG and wireless communication system

January to June 2014

- To demonstrate sensitivity of the self-powered wireless high temperature electrochemical sensor

June to December 2014

- To demonstrate long term reliability of the self-powered wireless high temperature electrochemical sensor

January to June 2015

- To develop data/knowledge-base on coal ash composition effect on EN/corrosion signals

Publications

1. Naing Naing Aung, Xingbo. Liu, High temperature electrochemical sensor for in situ monitoring of hot corrosion, Corros. Sci. 65 (2012) 1-4.

2. Naing Naing Aung, Xingbo Liu, Effect of SO2 in flue gas on coal ash hot corrosion of inconel 740 alloy□a high temperature electrochemical sensor study, Corros. Sci. 76 (2013) 390-402.

3. Naing Naing Aung, Xingbo Liu, Effect of temperature on coal ash hot corrosion resistance of inconel 740 superalloy, Corros. Sci. 82 (2014) 227-238

4. Naing Naing Aung, Xingbo Liu, In situ monitoring coal ash hot corrosion using the combined high temperature electrochemical sensor with ENA method, Corros. Sci (Under review).

5. Naing Naing Aung, Edward Crowe, Xingbo Liu, Development of Self-Powered Wireless-Ready High Temperature Electrochemical Sensor for In Situ Corrosion Monitoring in Coal-Fired Power Plant, ISA Transactions (Submitted).

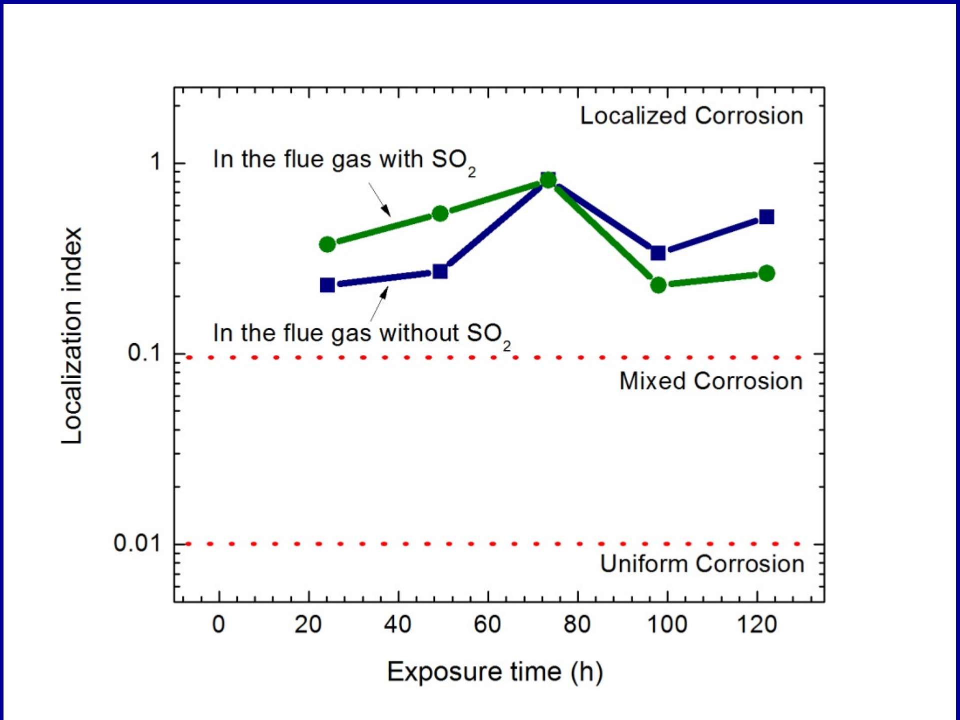
Conclusions

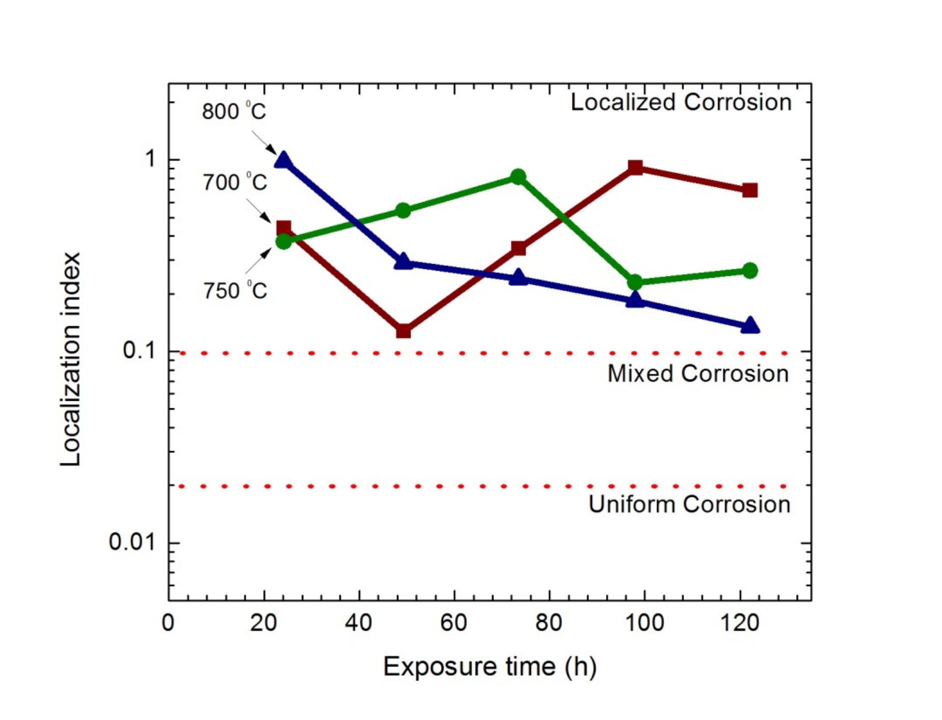
- A novel self-powered wireless high temperature electrochemical sensor technology has been developed to provide in situ corrosion information to assist in coal-fired power generation systems.

- Electrochemical potential and current noise signals from a simulated coal ash hot corrosion process were wirelessly transmitted and recorded for approximately two months to evaluate the sensibility of the sensor.

- The high sensibility and the reproducible lab-scale experimental results demonstrate the reliability of the sensor for long-term stability in commercial coal-fired boiler applications.

Localized Corrosion Identification





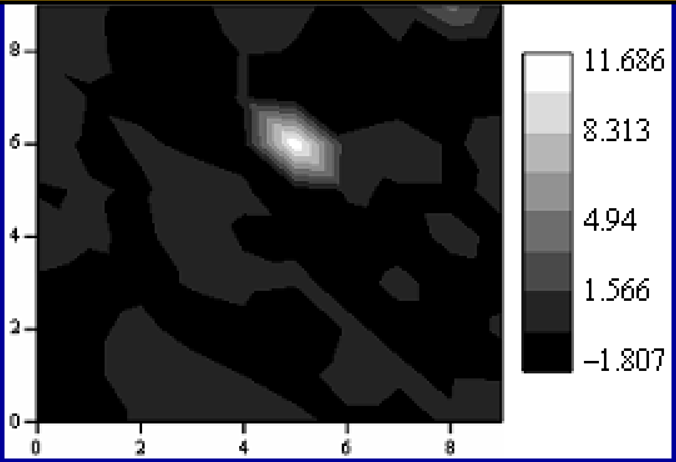
Localization Indices of Oxidation and Sulfidation at 750 °C

Localization Indices of Sulfidation at Different Temperatures

Future Works

- To expand the functionality of the high temperature in-situ electrochemical sensor system with a design that can identify the location localized corrosion

Localized Corrosion Current Distribution



- To investigate the underlying mechanism of the observed electrochemical corrosion noise

Thank You