Quarterly Progress Report

High Temperature Electrochemical Polishing of H2S
from Coal Gasification Process Streams

Grant DE-FG22-94-PC94207

July 1, 1996 - September 30, 1996

by

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Project Objectives

Coal may be used to generate electrical energy by any of several processes, most of which involve combustion or gasification. Combustion in a coal-fired boiler and power generation using a steam-cycle is the conventional conversion method; however total energy conversion efficiencies for this type of process are only slightly over 30%\(^1\). Integration of a gas-cycle in the process (combined cycle) may increase the total conversion efficiency to 40%\(^1\). Conversion processes based on gasification offer efficiencies above 50%\(^1\).

H\(_2\)S is the predominant gaseous contaminant in raw coal gas. Coal depending on the type and area of extraction can contain up to 5 wt% sulfur, which is converted to gaseous H\(_2\)S during gasification. Problems arise due to the corrosive nature of H\(_2\)S on metal components contained in these cycles. Because of this, H\(_2\)S concentrations must be reduced to low levels corresponding to certain power applications. For example, an integrated coal gasification-combined cycle (IGCC) process producing electricity from coal at nearly 50% overall efficiency\(^1\) incorporates gas turbines that cannot tolerate H\(_2\)S levels above 100 ppm. Coal gasification/Molten Carbonate Fuel-Cell (MCFC) systems, achieving conversion efficiencies around 60%\(^2\), function properly only if H\(_2\)S is below 1 ppm.

An advanced process for the separation of hydrogen sulfide (H\(_2\)S) from coal gasification product streams through an electrochemical membrane is being developed using funds from this grant. H\(_2\)S is removed from the syn-gas stream, split into hydrogen, which enriches the exiting syn-gas, and sulfur, which is condensed from an inert sweep gas stream, Figure 1. The process allows removal of H\(_2\)S without cooling the gas stream and with negligible pressure loss through the separator. The process is made economically attractive by the lack of need for a Claus process for sulfur recovery. To this extent the project presents a novel concept for improving utilization of coal for more efficient power generation.

Past experiments using this concept dealt with identifying removal of 1-2% H\(_2\)S from gases containing only H\(_2\)S in N\(_2\)\(^3\), simulated natural gas\(^4,5\), and simulated coal gas\(^6\). Data
obtained from these experiments resulted in extended studies into electrode kinetics and electrode stability in molten melts\textsuperscript{7,8,9}. The most recent experiments evaluated the polishing application (removal of H\textsubscript{2}S below 10 ppm) using the Electrochemical Membrane Separator (EMS). H\textsubscript{2}S removal efficiencies over 90\% were achieved at these stringent conditions of low H\textsubscript{2}S concentrations proving the technologies polishing capabilities.

Other goals include optimization of cell materials capable of improving cell performance. Once cell materials are defined, cell experiments determining maximum removal capabilities and current efficiencies will be conducted.

Also, a model theoretically describing the preferred reduction of H\textsubscript{2}S, the transport of S\textsuperscript{2-}, and the competing transport of CO\textsubscript{2} will be investigated. The model should identify the maximum current efficiency for H\textsubscript{2}S removal, depending on variables such as flow rate, temperature, current application, and the total cell potential.
Introduction

The Electrochemical Membrane Separator (E.M.S.), the focus of experimental work, purges a fuel gas contaminated with H$_2$S. This is done by reducing the most electro-active species in the gas stream. In this case, H$_2$S is reduced by the following:

$$\text{H}_2\text{S} + 2e^- \rightarrow \text{H}_2 + \text{S}^{2-} \quad (1)$$

A membrane which contains sulfide ions in a molten salt electrolyte will act to transport the ions across to the anode. If the membrane is impermeable to H$_2$ diffusion from the cathode side, an inert sweep gas can be used to carry the vaporous oxidized sulfur downstream to be condensed.

$$\text{S}^{2-} \rightarrow \frac{1}{2} \text{S}_2 + 2e^- \quad (2)$$

Processes to remove H$_2$S typically rely on low-to-ambient temperature adsorption, followed by sorbent regeneration and Claus plant treatment for conversion of H$_2$S to a salable by-product, sulfur. Although effective, this type of removal is very process-intensive as well as energy-inefficient due to low temperature operation. Gasification streams generally range from 500°C - 1000°C, requiring cooling before and reheating after process gas sweetening. Although these technologies have proven capable of meeting H$_2$S levels required by MCFC, there are several disadvantages inherent to these processes$^{10,11}$.

Alternative high temperature methods are presently available, but process drawbacks including morphological changes in catalytic beds$^{12}$ or inefficient molten salt sorbent processes$^{13}$ negate savings incurred through energy efficient removal temperatures.

An electrochemical membrane separation system for removing H$_2$S from coal gasification product streams is the subject of this investigation. The high operating temperature, flow-through design, and capability of selective H$_2$S removal and direct production of elemental
sulfur offered by this process provide several advantages over existing and developmental H₂S removal technologies.

Figure 1. Single-Cell View of the Electrochemical Membrane Separator
Quarterly Summary

Utilizing Ni as a cathode material at reduced temperatures (decrease from 650 °C to 580 °C) in full-cell experiments was the primary focus this quarter. A Ni cathode was purchased from ERC and utilized in one full-cell experiments (run 31). The membrane was a fabricated membrane purchased from Zircar Corporation. Table III gives an outline of the membrane materials as well as other components used for experiment 31.

Run 31 served a three-fold purpose: 1) testing the electrochemical membrane separators ability to concentrate CO₂; 2) testing the electrochemical membrane separators ability to remove H₂S; and 3) testing modifications of the experimental apparatus (i.e. Ni cathode performance at 580 °C).

Table III. Experimental Components

<table>
<thead>
<tr>
<th>Run</th>
<th>Temp. °C</th>
<th>Cathode</th>
<th>Anode</th>
<th>Membrane</th>
<th>Housings</th>
<th>Electrolyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>580</td>
<td>Ni</td>
<td>Ni</td>
<td>Fabricated (ZrO₂)</td>
<td>MACOR machineable ceramic</td>
<td>(Li₀.₆₂K₀.₃₈)₂CO₃</td>
</tr>
</tbody>
</table>

CO₂ Concentration

Before addition of H₂S to the cell, evaluation of theoretical CO₂ removal from the process-gas (cathode coal syn-gas) (3):

\[ \text{CO}_2 + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + \text{CO}_3^{2-} \]  \hspace{1cm} (3)

and anode CO₂ evolution (4):
with applied current was the first test conducted on the Electrochemical Membrane Separator (E.M.S.) full-cell run; percentage of CO₂ removal/evolution compared to the theoretical value, based on 2 Faraday's of charge transferred per mole of species reduced or oxidized, determines system permanence. A current step method was performed in order to determine CO₂ removal, CO₂ evolution, as well as the potential profile at varying currents. CO₂ removal data is given in Figure 2 and cell potentials are illustrated in Figure 3, respectively. H₂S addition to the cell occurred once CO₂ transport performance was proven.

Upon addition of H₂S, cathode gases equilibrated by:

\[
\text{H}_2 + \text{CO}_2 \leftrightarrow \text{H}_2\text{O} + \text{CO}
\]  

(5)

via a stainless steel shift reactor before entering the cell housing. Once process gases entered the cell housings the molten-electrolyte - process-gas equilibrium given by (6)

\[
(\text{Li}_{0.68}\text{K}_{0.32})_2\text{CO}_3 + \text{H}_2\text{S} \leftrightarrow (\text{Li}_{0.68}\text{K}_{0.32})_2\text{S} + \text{CO}_2 + \text{H}_2\text{O}
\]  

(6)

creates a conversion of carbonate ions to sulfide ions dependent on the partial pressure of H₂S above the electrolyte.

Upon equilibration of the electrolyte and process-gas species (H₂S inlet ~ H₂S outlet at varying flow rates) current was applied to the cell to test H₂S removal capabilities.
Figure 2. Cathode CO₂ Level vs. Applied Current; Run #31
Figure 5-3: Run #31 Carbonate Transport: Cell Potential vs. Applied Current
Removal of H2S from Very Sour Coal Gas

Run #31

Stoichiometric CO2 removal with current was shown, figure 2; however anodic CO2 production was limited by sweep-gas seals. Potentials for CO2 removal across the range of applied current are illustrated in figure 3.

Once system permanence was established through validating CO2 removal, H2S was sent to the cell. Process gases equilibrated, at a cathode flow of 265 cc/min, to 5.6% CO2, 2.2% CO, 8.3% H2, 6.7% H2O, and 2500 ppm H2S. Gas-phase limiting current estimated at 34.24 mA/cm2 was one-half the membrane limiting current density; electrolyte species were estimated to contain 93.1 mole% (Li0.68K0.32)2CO3 and 6.9 mole% (Li0.68K0.32)2S. H2S outlet versus applied current and %H2S removals are shown in figure 4 & figure 5, with over 90% removals from the cathode outlet evidenced. A potential diagram, internal resistance was calculated at 4 Ω, with applied current is given in Figure 6.

Next, flow rate was increased to 440 cc/min (limiting current density in the gas and membrane equals 34.39 mA/cm2 and 81.77 mA/cm2) followed by 675 cc/min (limiting current density in the gas and membrane equals 34.46 mA/cm2 and 104.75 mA/cm2) maintaining a 2500 ppm H2S outlet. Internal resistance increased to 5 Ω. Once again 90% H2S removals were shown, figure 4 and figure 5, along with reasonable potentials, figure 6, with the excessive internal resistance (5 times greater than the normal value of 1 Ω).
Inlet H$_2$S: 2500 ppm
Temp.: 580 °C

Figure 4. % H$_2$S Removal vs. Applied Current; 2500 ppm Inlet H$_2$S
Inlet H$_2$S: 2500 ppm
Temp.: 580 °C

Figure 5. Outlet H$_2$S vs. Applied Current; 2500 ppm Inlet H$_2$S
Figure 6. Cell Potentials vs. Applied Current; 2500 ppm Inlet H₂S

Inlet H₂S: 2500 ppm
Temp.: 580 °C
Once effective H2S removals were shown at 2500 ppm, inlet gas was adjusted with a new inlet value of 4500 ppm H2S. Gases equilibrated to 12.2% CO2, 14.5% CO, 21.4% H2, and 5.6% H2O creating a calculated electrolyte concentration of 94.4 mole% (Li0.68K0.32)2CO3, 5.6 mole% (Li0.68K0.32)2S; limiting current densities were 50.53 mA/cm² in the gas-phase and 52.3 mA/cm² in the membrane. At these concentrations the cathode flow rate was varied from 130 cc/min to 570 cc/min. 90% removals were shown at varying current in the range of flows, figures 7 & 8. Potentials recorded at different currents, figure 9, were higher than expected but can be explained by the continual loss of electrolyte; internal resistance was around 10 Ω.

Run #31 was eventually shut-down after 408 hours (17 days) due to loss of process-gas seals attributed to the excessive loss of electrolyte.

Post mortem analysis revealed a three-phase change in the cathode from Ni to a combination of Ni3-xS2, NiS (Millerite), and Ni3S2 (Heazlewoodite), Figure 10. 0.03 grams of sulfur was recovered from the anode outlet of the cell; verification occurred by heating the powder above its melting point (130 °C) creating a viscous-garnet liquid.
Figure 7. %H₂S Removal vs. Applied Current; 4500 ppm Inlet H₂S

Inlet H₂S: 4500 ppm
Temp.: 580 °C
Inlet H$_2$S: 4500 ppm
Temp.: 580 °C

Figure 8. Outlet H$_2$S vs. Applied Current; 4500 ppm Inlet H$_2$S
Inlet H$_2$S: 4500 ppm
Temp.: 580 °C

Figure 9. Cell Potentials vs. Applied Current; 4500 ppm Inlet H$_2$S
Figure 10. X-ray Diffraction Pattern for Ni Cathode; Run #31
Electrode Materials

Nickel

The nickel-oxygen-sulfur system phase diagram at 580 °C is shown in figure 11; the predominant stable phase in equilibrium with the coal synthesis gas is Ni$_3$S$_2$, existing between an H$_2$S/H$_2$ ratio of 0.0006 and 0.25. At 650 °C the phase diagram has a small change in these compound windows, figure 12, however the predominant phase remains Ni$_3$S$_2$, stable between an H$_2$S/H$_2$ ratio of 0.002 and 4.0. This compound consists of either nickel or sulfur in solid solution with the high temperature form of tetragonal Ni$_{3-x}$S$_2$; this creates a crystallographic change from hexagonal Heazlewoodite (Ni$_3$S$_2$)\textsuperscript{14}. This non-quenchable phase exists above 556 °C and separates into the low-temperature form of Ni$_3$S$_2$ (Heazlewoodite) upon cooling\textsuperscript{14}. Physical property data is rare for Ni$_{3-x}$S$_2$ and is usually approximated by Ni$_3$S$_2$\textsuperscript{14,15}. As the H$_2$S/H$_2$ ratio of the coal gas stream is lowered, the nickel content in solid solution increases until saturation, at which point a separate nickel phase is formed, figures 11 & 12. A eutectic point for this system is evidenced at 640 °C\textsuperscript{14,16} which is well within the operable range of the E.M.S. system, below which operation should be acceptable by maintaining cathode pore morphology; cell operation must be above the electrolyte melting point of 490 °C.

Analysis, by x-ray diffraction, of cathode materials utilized at 650 °C within the H$_2$S/H$_2$ ratio mentioned above revealed the presence of both Ni$_{3-x}$S$_2$ and Ni$_3$S$_2$. Since the cell was operable above the eutectic temperature a common phenomenon evidenced on post-mortem analysis was the cathode diameter on average decreased 25%; this decreased the active surface area by 43%. Current collectors were also embedded within the surface of the cathode. Cathode materials utilized at 580 °C were also analyzed and showed similar phase changes as at 650 °C; however, electrode morphology did not appear to change.

The anode material was in the range of NiO and showed complete chemical and electrochemical stability in full-cell experiment.
Figure 11. Ni-O-S System Phase Diagram at 580 °C
Figure 12. Ni-O-S System Phase Diagram at 650 °C
Discussion

The goal of full-cell experiments was to validate the removal capabilities of the E.M.S. system while maintaining economically viable current efficiencies (high current efficiencies at high inlet H2S concentrations). H2S current efficiency is calculated by:

\[ \eta_{H2S} = \frac{\% H2S \text{ Removal}_{\text{actual}}}{\% H2S \text{ Removal}_{\text{theoretical}}} \]  

representing the ratio of H2S actually removed compared to the theoretical amount that should be removed at a finite applied current.

In this section the current efficiencies and cell potentials of these experiments are compared to those predicted by the theoretical limiting values. This being the prediction of the theoretical limiting H2S removal performance achievable in the presence of overwhelming levels of H2O and CO2 (on the order of 10^5 higher in concentration than H2S). Predicted current efficiencies and cell potentials were a function of several parameters involved in completing the unit operation including applied current, flow rate, and Nernstian effects. Thermodynamic principles based on standard Gibb's energy and concentration of electro-active species in the gas phase gave the minimum potential requirements in order for cell operation to occur. Upon application of current other factors including electro-kinetics, mass transfer, chemical equilibria, and internal resistance were incorporated into the prediction.

Theoretical predictions, which represent a limiting value, show achievable current efficiencies close to 100 percent for H2S levels on the order of 1000 ppm at 90% removals. At this same removal level with 100 ppm and 10 ppm inlet gas, the current efficiencies dropped, due to aforementioned concentration effects, to 93% and 40% respectively. This solidifies the importance of obtaining close to 100% current efficiencies at sour gas levels compared to polishing applications where the removal, not the current efficiency, is more important.
Predicted cell potentials were consistently in the same range, -0.450 V to -0.550 V, for all concentration levels at 90% removal.

H2S current, removal efficiencies, and cell potentials fluctuated over the duration of each experiment. This was mainly attributed to a variation in electrolyte distribution within the system, H2 permeation, and variable process gas seals. Potentials were IR compensated giving more realistic values.

Experimental error of the collected data (actual values) from the bench-scale apparatus was based on sample collection and analysis equipment not on the changes associated with the aforementioned electrolyte and process seal variabilities; a quantitative value for these variables was not possible. The error is conservatively identified within a 95% confidence interval based on a random sampling distribution of sums and quotients (7) & (8).

\[
\%_{\text{H}_2\text{S Removal}} = \left( \frac{\text{Outlet H}_2\text{S}_{\text{zero current}} - \text{Outlet H}_2\text{S}_{\text{1 applied}}} {\text{Outlet H}_2\text{S}_{\text{zero current}}} \right) \times 100
\]  

Figure 13 illustrates a successful bench-scale experiment at 580 °C utilizing MACOR housings; current efficiency was within 10% of the theoretical maximum value at 90% removals. Ni cathode morphology remained constant throughout the duration of the experiment converting to Ni3S2 without incurring the phase transition associated with Ni3-XS2.

Potentials, shown in figure 14, were higher than those predicted by the model due mainly to a high internal resistance (4 times greater than the standard value of 1 ohm) dampening ionic mobility. The compensated potentials are also given, showing an increase in potential with %H2S removal; this was again attributed to increasing H2 permeation through the membrane.

A yellow solid, 0.03 grams of sulfur, was collected from the anode outlet tube. The calculated amount based on applied current, current efficiency, and time was 1 gram. The reason for the low sulfur yield was attributed to losses through incomplete condensation of the vapor on the inside of the
Inlet H₂S: 2500 ppm
Temp.: 580 °C
Cathode Flow: 675 cc/min

Figure 13. Comparison of Theoretical and Actual Values; % H₂S Removal vs Current Efficiency for Run #31
Figure 14. Cell Potentials vs %H₂S Removal; Theoretical vs Actual Values for Run #31
anode outlet tube (some particulates escaped through the outlet tube). Other losses were
associated with faulty process gas seals. Nevertheless, this was the first positive sign at the
anode side of the E.M.S system of sulfur liberation (2) taking precedence over the competing
parasitic reaction (4).

\[
S^{2-} \rightarrow \frac{1}{2}S_2 + 2e^- \tag{2}
\]

\[
CO_3^{2-} \rightarrow CO_2 + \frac{1}{2}O_2 + 2e^- \tag{4}
\]

Since \(H_2S\) is the lone source of sulfur entering the cell, reaction (2) validates sulfur liberation at
the anode, as well as reaction (6),

\[
(Li_{0.62}K_{0.38})_2CO_3 + H_2S \leftrightarrow (Li_{0.62}K_{0.38})_2S + CO_2 + H_2O \tag{6}
\]

providing the necessary ionic pathway for sulfide transport.

**Past vs. Present**

Past experimentation on the E.M.S. system at varying levels of inlet \(H_2S\) has
demonstrated high removal capabilities, but at relatively low current efficiencies. Figure 15
represents one of the best results obtained from previous bench-scale experiments.

Removals and current efficiencies were increased ~20% when operating the system at
580 °C, with Ni electrodes, at sour gas concentrations. Comparison with the sour gas
experiment, illustrated in Figure 15, revealed higher current efficiencies although electrode &
membrane materials differed. Improvements in both areas have drastically improved not only
removal results but assembly and effective long-term operation of the bench-scale apparatus.
Inlet H$_2$S: 13000 ppm
Temp.: 650 °C
Cathode Flow: 75 cc/min

Figure 15. %H$_2$S Removal and Current Efficiency Collected by Weaver$^{17}$ Compared to the Theoretical Model Prediction
Conclusion

The Fossil Energy Advanced Research Program requires high temperature separations to remove environmental contaminants from post-combustion flue gases as well as pre-combustion process gases. This project is aimed at the latter: the removal of hydrogen sulfide from coal gas at gasifier temperatures. This development would enable a simplification of the entire gasification scheme by permitting a one-step removal of hydrogen sulfide and production of elemental sulfur. Energy savings accrue due to the high temperature processing.

The DOE programs relating to gasification for power production have as their goal the more efficient, clean paths toward affordable energy from coal. Gas clean-up accounts for nearly one-third of the cost of this conversion. Simplification and economization will benefit the entire effort.

Project Output

Current experiments are based on improving selective removal from initial H2S concentrations ranging from contaminant levels to very sour levels. High flow rate effects, membrane stability and selectivity, and electrode morphology characterizes present studies, with recent results showing over 90% H2S removal with applied current.

Contaminant Level Removals

Two experiments have demonstrated the polishing application of the E.M.S. system. In the first, outlet H2S levels were reduced from 10 ppm to ~1 ppm or 90% removal. The current efficiency at this removal level was 12.6% which compared favorably to the theoretical model prediction of 30.8% current efficiency at 90% removal. H2S current and removal efficiencies are illustrated in figure 16. Potentials at 90% removals were ~ -0.012 V (the theoretical value is -0.521 V, figure 17). The discrepancy in actual vs predicted potentials can be explained by H2
H2S Current Efficiency (%)  

100, IL 200 25 50 1  

H2S Removal (%)  

Inlet H2S: 14 ppm  
Temp.: 650 °C  
Cathode Flow: 215 cc/min

Figure 16. Comparison of Theoretical and Actual Values; %H2S Removal vs Current Efficiency
Total Cell Potential (V)

-0.5, -0.25

I I

Actual Values

Theoretical Value

H₂S Removal (%)

0 25 50 75 100

Inlet H₂S: 14 ppm
Temp.: 650 ºC
Cathode Flow: 215 cc/min

Figure 17. Cell Potentials vs %H₂S Removal; Theoretical vs Actual Values
cross-over, detailed earlier, associated with electrolyte loss from MACOR degradation. The Ni cathode also remained chemically stable (no conversion to Ni$_3$S$_2$ or the eutectic Ni$_{3-x}$S$_2$) at these removal levels.

In the second, polishing of H$_2$S from a contaminant gas was accomplished utilizing a purchased zirconia membrane. Over 80% removals occurred at varying flow rates. Electrodes donated from ERC remained stable throughout the duration of the experiment; no morphology change associated with the phase transition to Ni$_3$S$_2$ occurred due to the low levels of H$_2$S in the cathode gas. Bench-scale current efficiencies (50% at 80% removals) agreed well with the theoretical predictions (68% at 80% removals) in a similar relationship to those of run 21 (~20% below the theoretical maximum value). However, fluctuation occurred over the experimental run, due in part to a change in flow rate and electrolyte loss associated with the MACOR housings (IR varied from 1 to 3 ohms). Figure 18 and figure 19 illustrate the removals of H$_2$S from the cathode gas. Figure 18 gives a representative proximity of the theoretical values to bench-scale data at a cathode flow of 375 cc/min. Actual potentials were much less than those predicted, illustrated in figure 19, due to H$_2$ cross-over.

**H$_2$S Removals From Very Sour Coal Gas**

Successful application of the E.M.S. technology to sour coal gas is shown in figure 20. The H$_2$S current and removal efficiencies demonstrate the actual bench-scale values agreement with the model predictions; current efficiencies were within 10% of the maximum theoretical values. Applied current exceeded the stoichiometric value at 90% H$_2$S removal (from 1700 ppm to 141 ppm) by 45 mA. Potentials remained low (~0.100 V below theoretical value shown in figure 21, representing compensated and uncompensated values) which is economically beneficial at this level of H$_2$S removal; MACOR degradation created a deficiency of electrolyte allowing a pathway for H$_2$ cross-over.
Figure 18. Comparison of Theoretical and Actual Values; %H₂S Removal vs Current Efficiency

Inlet H₂S: 25 ppm
Temp.: 650 °C
Cathode Flow: 375 cc/min
Inlet H₂S: 25 ppm  
Temp.: 650 °C  
Cathode Flow: 375 cc/min

Figure 19. Cell Potentials vs %H₂S Removal; Theoretical vs Actual Values
Figure 20. Comparison of Theoretical and Actual Values; %H₂S Removal vs Current Efficiency

Inlet H₂S: 1630 ppm
Temp.: 580 ºC
Cathode Flow: 560 cc/min
Total Cell Potential (V)

-0.2

Actual Compensated Value
Actual Raw Value
Theoretical Val

H₂S Removal (%)

Inlet H₂S: 1630 ppm
Temp.: 580 °C
Cathode Flow: 560 cc/min

Figure 5.8. Cell Potentials vs %H₂S Removal; Theoretical vs Actual Values
Since the cell was operated at 580 °C, 70 °C below polishing operation temperature, the Ni cathode converted to the predicted compound, Ni$_3$S$_2$; no evidence of the eutectic phase Ni$_{3-x}$S$_2$ was identified since the cathode morphology remained constant and current efficiencies were realistic for scale-up application.

**Next Quarter Goals**

A continual problem with the E.M.S. system is an appropriate cathode material with chemical and electrochemical stability in the high temperature corrosive environment. At high levels of H$_2$S, the Ni cathode converts to a molten Ni$_{S_y}$ creating adverse effects mentioned previously. A review of the literature$^{21}$ revealed that maintaining a temperature below 635 °C, usual experiments are performed at 650 °C, prevents the liquid Ni$_{S_y}$ from forming. Next quarters experiments will be performed at 600 °C with the E.R.C. Ni electrodes at the anode and the cathode. Co electrodes will continue to be investigated as well; however, persistent oxidation of the material during binder-burn-out has created adverse reactions schemes upon applications of current exposing permanent damage to E.M.S. system.

Stainless steel housing materials will also be the focus of future work since a less exotic material, other than MACOR, is necessary for eventual scale-up.
References