REMOTE DETECTION OF INTERNAL PIPELINE CORROSION USING FLUIDIZED SENSORS

STATUS REPORT – PROJECT QUARTER 1

SwRI® Project 10926 / NETL Project 42267

Prepared for

U.S. Department of Energy
National Energy Technology Laboratory

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EXECUTIVE SUMMARY

According to the Department of Transportation Office of Pipeline Safety (OPS), internal corrosion caused about 15 percent of all gas transmission pipeline reportable incidents over the last several years, leading to an average of $3 million in annual property damage and several fatalities. As a further complication, a significant portion of the pipeline system is unpiggable. Internal corrosion direct assessment (ICDA) can be a viable option for such lines, but has uncertainties with respect to the location and extent of possible water hold up. The overall objective of the proposed project is to enable remote interrogation of possible internal corrosion of pipelines. This will be accomplished though the establishment a distributed wireless sensor network inside the pipe using miniaturized sensor packages introduced into the gas stream. The project is divided into four main tasks related to (1) wireless data transmission, (2) corrosion sensor development, (3) sensor system motion and delivery, and (4) consideration of other pipeline operations issues.

Work this quarter has primarily been focused on some aspects of wireless data transmission and corrosion sensor identification and development. The results obtained have clearly demonstrated that wireless data transmission within a pipeline is technologically feasible. Several potential corrosion sensors have been identified and the interdigitated galvanic couple sensor and the MAS probe both show significant promise for use in the proposed sensor concept.

Work in the next quarter will be aimed at:

- Exploring the effect of pipeline operations on wireless data transmission
- Evaluating small scale electrical resistance probes for corrosion measurements and exploring miniaturization and modifications to both the galvanic couple and MAS probe sensor systems.
- Fluid dynamics modeling will be used to refine the initial calculations and explore other conditions for fluidized sensor motion and delivery
- Examining possible energy harvesting from the corrosion reaction and gas flow

BACKGROUND

According to the Department of Transportation Office of Pipeline Safety (OPS), internal corrosion caused about 15 percent of all gas transmission pipeline reportable incidents over the last several years, leading to an average of $3 million in annual property damage and several fatalities. As a further complication, a significant portion of the pipeline system is unpiggable. Internal corrosion direct assessment (ICDA) can be a viable option for such lines, but has uncertainties with respect to the location and extent of the internal corrosion, requiring extensive digs. The overall objective of the proposed project is to develop an independent and complementary technology that will enable remote interrogation of the internal corrosion of pipelines by establishing a distributed wireless sensor network inside the pipe using miniaturized sensor packages introduced into the gas stream (Figure 1).

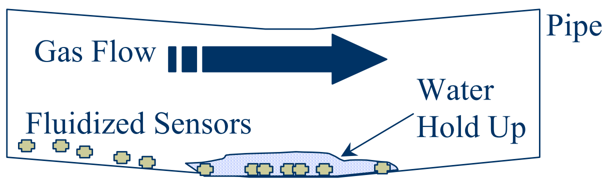

Figure 1: Schematic diagram of proposed sensor concept.

WORK ACCOMPLISHED THIS QUARTER

The overall approach for this project is divided into four main tasks:

- Wireless data transmission and acquisition
- Corrosion sensor identification and development
- Sensor motion and delivery
- Safety and other pipeline operations issues

Efforts this quarter were primarily aimed at the first two areas and are discussed below.

Wireless Data Transmission and Acquisition

The main goals of this task are to determine whether wireless transmission within a pipeline is technologically feasible, what influence operating conditions may have on such transmissions, what data transmission distances might be achievable, and ultimately how to extract the data from the sensor network and use it to make decisions regarding pipeline integrity. Initial tests were conducted using short pipe test loops of 20 to 80 foot lengths and pipe diameters of 18, 6, and 3 inches (Figure 2). Initial efforts clearly demonstrated that wireless data transmission inside the pipeline was feasible. Furthermore, the signal strength observed inside the pipeline in non-line-of-sight situations was greater than that noted for line-of-sight transmissions in the air (Figure 3). These results are extremely encouraging and demonstrate that the pipeline can act as a signal wave guide. Current efforts are now aimed at setting up an 80 foot pipe loop to conduct tests to explore what effects pipeline operational conditions (e.g., pressure) might have on data transmission.

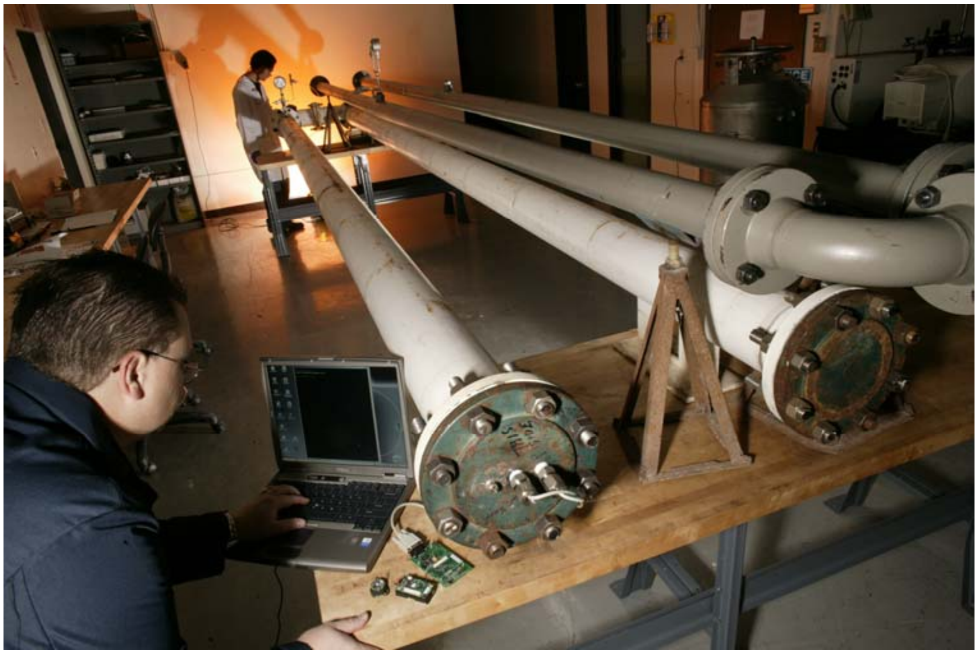

Figure 2: Non-line-of-sight pipeline wireless data transmission test setup.

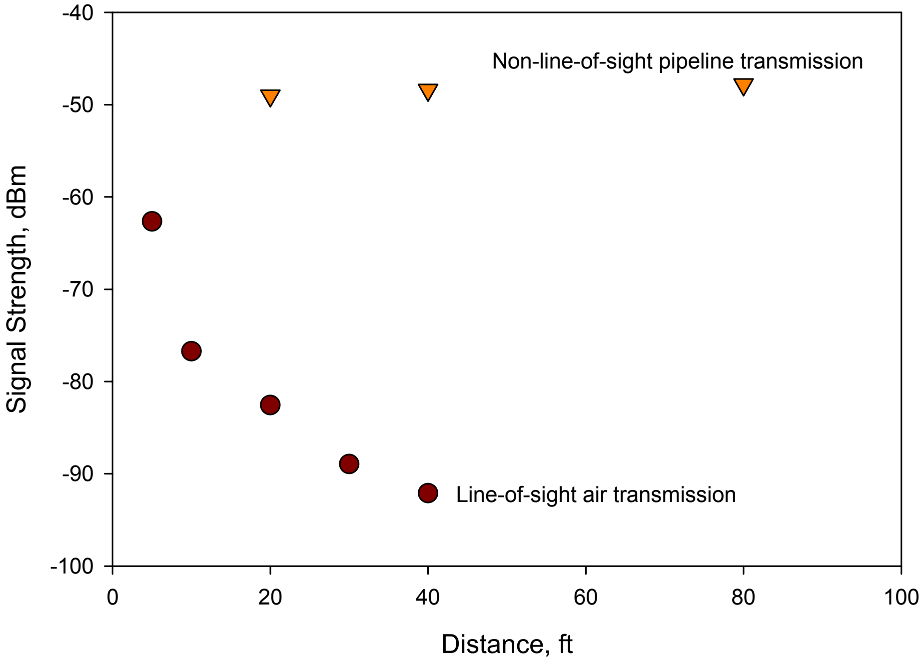

Figure 3: Wireless data transmission results comparing the performance of non-line-of-sight internal pipeline communications to line-of-sight communications in air.

Corrosion Sensor Identification and Development

The main objective of this task is to identify corrosion sensors that can accurately and reliably indicate if water accumulation has taken place and if the accumulated water possesses a significant corrosion risk. To accomplish this, the chosen sensor must be able to distinguish between accumulated water and the accumulation of other less corrosive electrolytes (e.g., glycol) as well as be able to quantify different levels of environmental corrosivity or aggressiveness. Initial efforts have explored the possible use of an interdigitated carbon-silver galvanic couple thin film sensor (Figure 4) and the SwRI developed multielectrode array sensor (MAS) probe constructed from carbon steel (Figure 5).

Figure 4: Planar view of thin film interdigitated galvanic couple sensor. This sensor is currently composed of conductive carbon (black lines) and silver laid out on Mylar.

Figure 5: End view of several different versions of the SwRI developed MAS probe.

These sensors were evaluated under ambient temperature and pressure conditions in a glass vessel. The galvanic couple sensor was evaluated by measuring the DC resistance between the elements, the DC current flow between elements, the potential difference between the elements, and by using electrochemical impedance spectroscopy to determine the AC impedance between the elements. Each of these measurements was compared to the corrosion rate of carbon steel measured using linear polarization resistance in the same environments. The environments examined included deionized water, glycol, and combinations of the two containing moderate concentrations of sodium chloride or sodium bicarbonate. Figures 6 – 9 illustrate some of the key results obtained. In examining the different possible interrogation modes, the sensor DC current (Figure 8) and resistance (Figure 9) measurements appear to offer the best signal fidelity and correlation with the actual carbon steel corrosion rate.

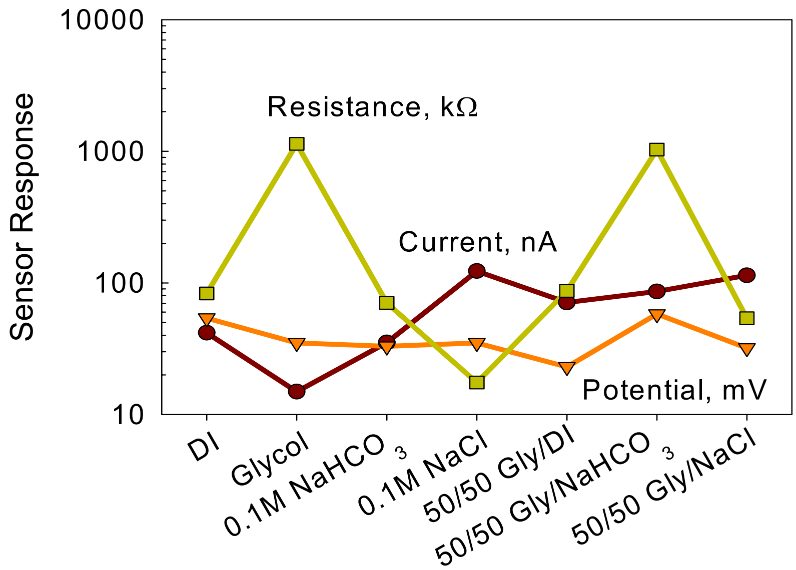

Figure 6: Interdigitated sensor response in different environments.

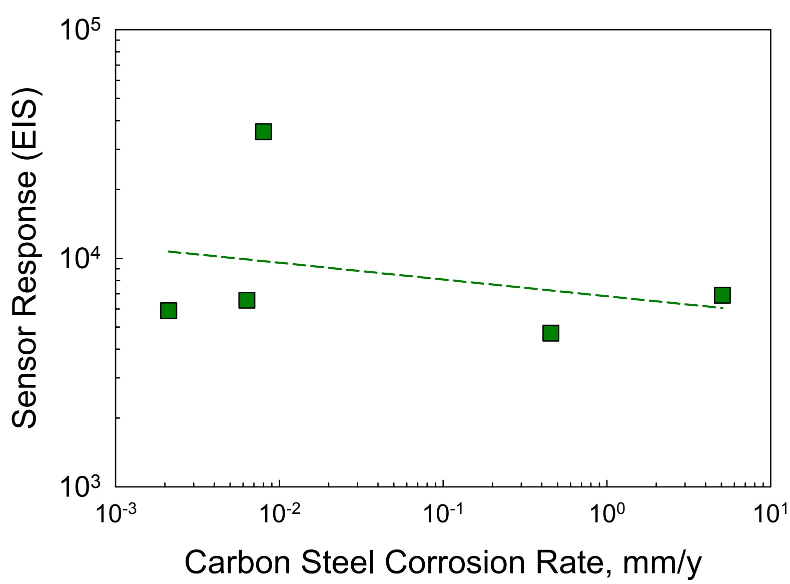

Figure 7: Relationship between interdigitated sensor response using EIS (impedance modulus at 100 Hz) and carbon steel corrosion rate using LPR.

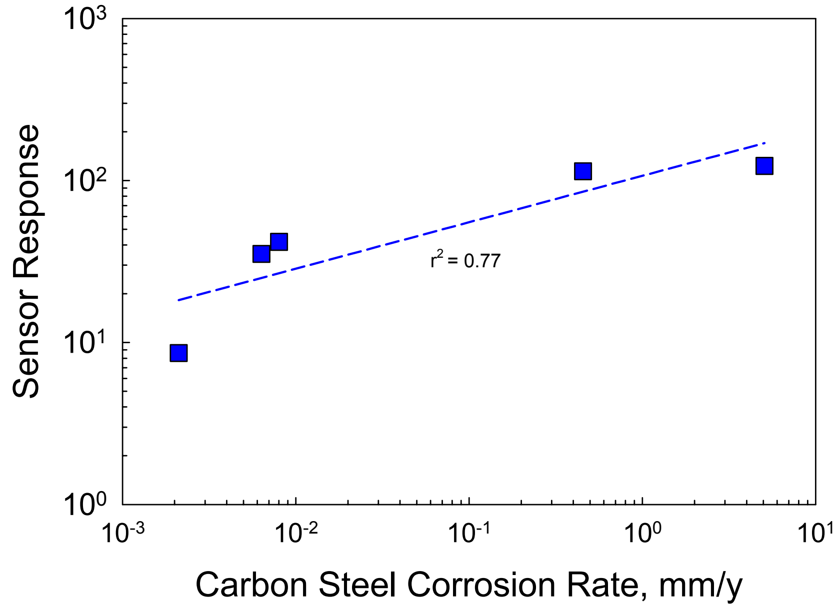

Figure 8: Relationship between interdigitated sensor response using DC current and carbon steel corrosion rate.

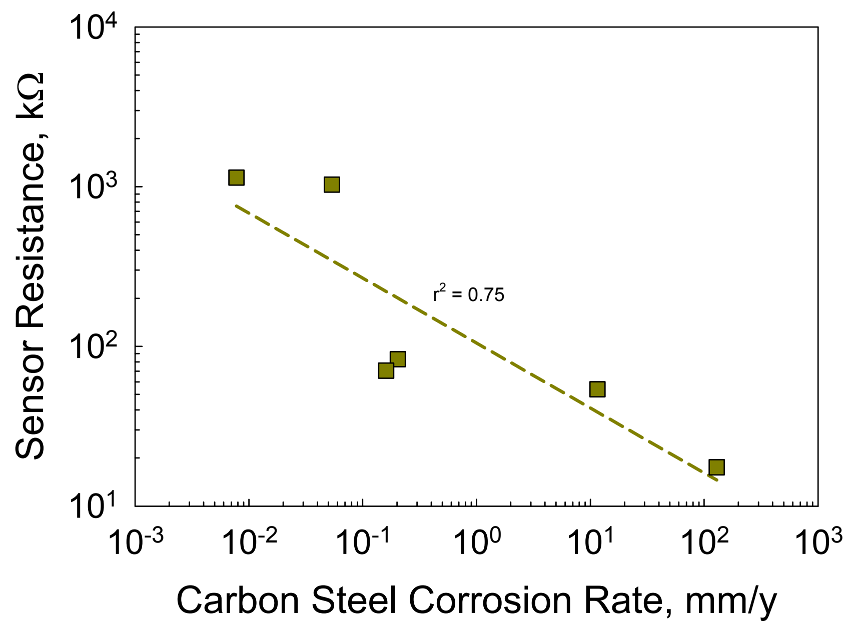

Figure 9: Relationship between interdigitated sensor response using DC resistance and carbon steel corrosion rate.

Based on these results it appears that this approach holds some promise in providing an accurate and reliable indication of possible corrosion. Because the materials used in making this thin film sensor were conductive carbon and silver, however, some of the scatter in the data may be attributed to degradation processes that will not be encountered by the steel pipeline. Current efforts are aimed at designing and fabricating a modified version of this sensor (Figure 10) in which iron or steel will be used as one of the materials in the couple. It is felt that this will provide more reliable indications of possible corrosion.

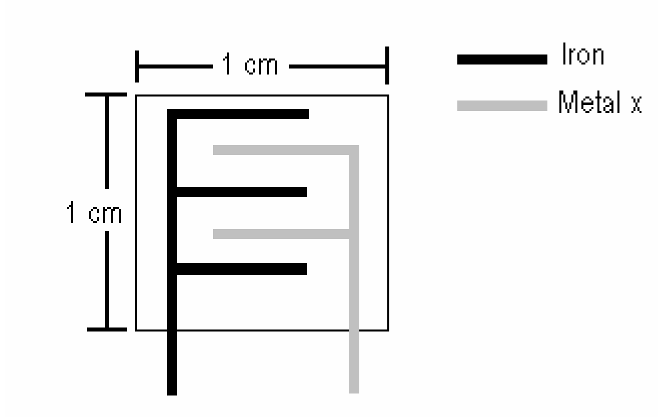

Figure 10: Proposed design of second generation interdigitated galvanic couple sensor.

Despite the encouraging results obtained using the interdigitated galvanic couple sensor, it cannot provide an actual measure of steel corrosion rate, especially if localized corrosion is involved. Because of this, a carbon steel MAS probe was evaluated under identical conditions (Figure 11). The results indicate a clear relationship and excellent correlation between the corrosion rates measured using the MAS probe to that obtained using LPR. The primary constraint in using the MAS probe for the present application is its physical size. This constrain arises because the MAS probe was originally developed to monitor for localized corrosion in chemical process streams as a stationary device. Presently, methods to fabricate a miniaturized version (Figure 12) are underway.

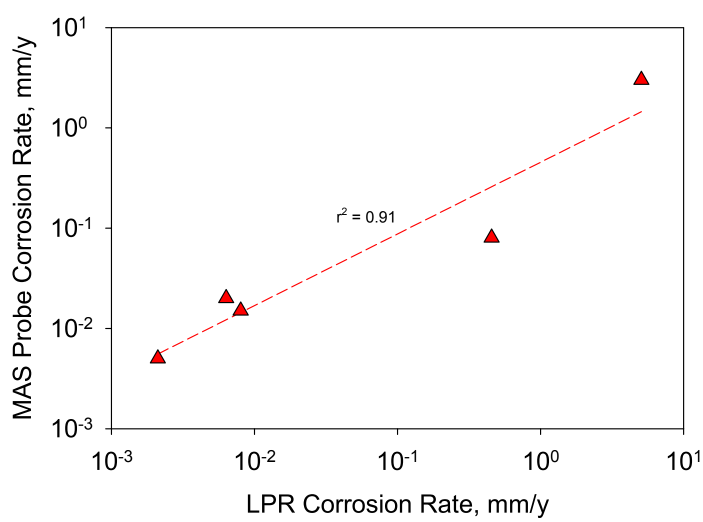

Figure 11: Comparison of corrosion rates determined using the MAS probe to those obtained using LPR measurements.

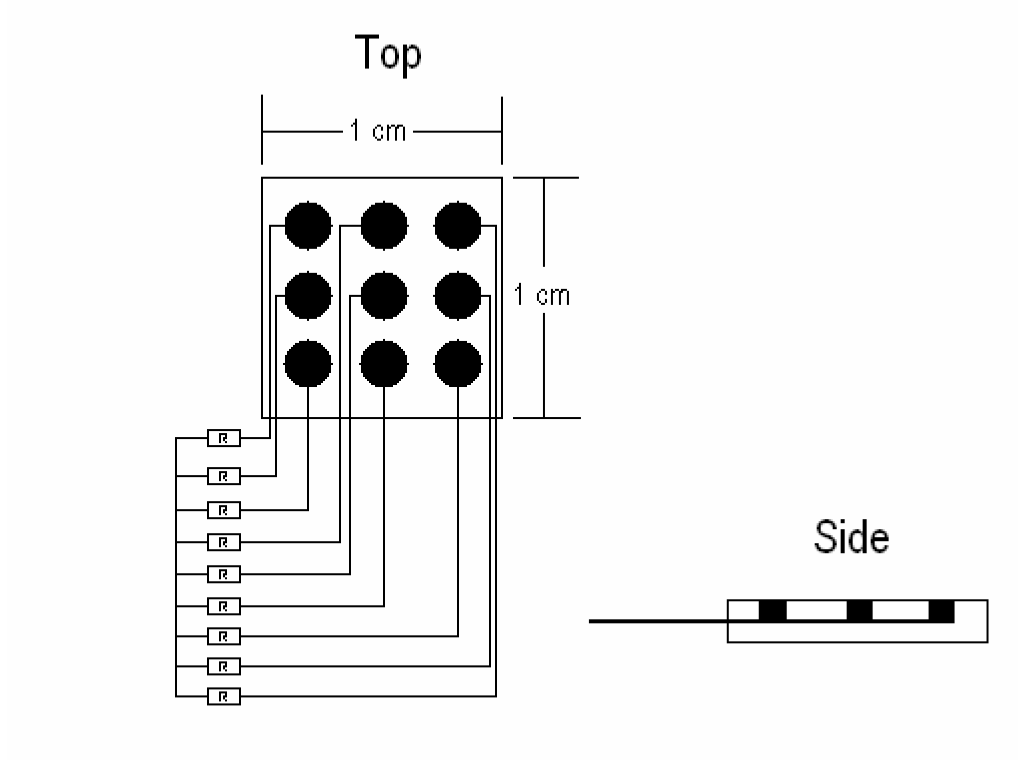

Figure 12: Conceptual configuration for miniaturized MAS probe.

PLANNED ACTIVITIES FOR NEXT QUARTER

Activities in each of the four primary tasks of this project are planned for the next quarter. These include:

Wireless Data Transmission and Acquisition

- The effect of pipeline operation pressures (up to a few hundred psi) on wireless transmission signal and hardware will be examined
- The present 80 foot pipe loop will be modified to enable examination of the effects of gas flow on wireless transmission

Corrosion Sensor Identification and Development

- The next generation interdigitated galvanic couple sensor design will be finalized and fabrication initiated
- The miniaturized MAS probe design will be finalized and fabrication initiated. Associated electronics will also be designed.
- Small-scale electrical resistance probes will be evaluated to determine the viability of this approach for use in the fluidized sensors
- The potential to use microelectromechanical systems (MEMS) fabrication approaches to construct ultra small electrical resistance and LPR probes will be

explored and potential fabricators will be contacted to determine cost and schedule information

Sensor Motion and Delivery

- Fluid dynamics modeling of fluidized sensor motion and delivery to locations of possible water hold up will be initiated with emphasis on determining what depth of liquid will result in stalling sensor motion

Safety and Other Pipeline Operations Issues

- Because the current sensor design relies on batteries for power which may limit the lifetime of the sensor system, a limited effort to explore possible energy harvesting from the corrosion process itself will be conducted. The possibility of energy harvesting from gas flow will also be considered.

FINANCIAL STATUS

The current financial summary for the project is outlined in Table 1. The project is currently on-budget and on-schedule.

Table 1: Project financial status summary.

Project Year	Total Funding Level (including all co-funding)	Funds Expended to Date	Balance
Year 1	$280,000	$41,625	$238,375
Year 2	$265,329	$0	$265,329
Total	**$545,329**	**$41,625**	**$503,704**

SUMMARY AND CONCLUSIONS

The overall objective of the proposed project is to enable remote interrogation of possible internal corrosion of pipelines by establishing a distributed wireless sensor network inside the pipe using miniaturized sensor packages introduced into the gas stream. To accomplish this, the project is divided into four main tasks related to wireless data transmission, corrosion sensor development, sensor system motion and delivery, and consideration of other pipeline operations issues.

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- Fluid dynamics modeling will be used to refine the initial calculations and explore other conditions for fluidized sensor motion and delivery
- A limited effort to explore possible energy harvesting from the corrosion reaction and gas flow will be explored