NPRE 432: Laboratory 8 - Corrosion

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1 Abstract

Corrosion is a mechanism that affects any metallic material exposed to an electrolyte solution. In nuclear engineering, fluoride salt-cooled high-temperatures need to account for the high corrosion rate of all structural members caused by the impurities and dissolved fission products in the fluoride salt. This laboratory investigated the rate of corrosion using $CuSO_4$, Fe, and Al as reference electrodes in an electrolytic cell using tap water as the solution. The $CuSO_4$ was compared against Cu, Sn, Fe, Al, Zn, and Mg while the Fe and Al were compared against Cu, Mg, Zn, and Sn. The results from this experiment indicated that $CuSO_4$ was the most noble of the materials measured followed by Cu, Sn, Fe, Al, Zn, and Mg. Comparing the voltage differences between $CuSO_4$ and Fe as the reference electrodes, the voltage differences measured with Fe as the reference electrode were 0.5026 V higher than the voltage differences measured with $CuSO_4$ as the reference electrode. Similarly, the voltage differences measured with Al as the reference electrode were 0.0.4823 V higher than the voltage differences measured with $CuSO_4$ as the reference electrode. Next, salt was added to the tap water to measure the effect additional electrolytes on current. The currents measured using the $3\%_{wt}$ saline solution were roughly an order of magnitude higher than the currents measured using the tap water alone. The increased current means the corrosion rate is roughly an order of magnitude higher in the saline solution. The increased corrosion rate in saline environments requires additional engineering considerations to counteract.

2   Results

During this laboratory, the students measured the voltage difference and current between a reference material and an electrode. First, the voltage across a $CuSO_4$ reference electrode was connected to various anodes – both electrodes were placed in a beaker of tap water. The results of these measurements are tabulated below in Table 1.

Table 1: Reduction Potentials from $CuSO_4$.

Anode	Voltage [V]
CuSO4	0 (Ref.)
Cu	-0.145
Sn	-0.286
Fe	-0.3975
Al	-0.6715
Zn	-1.2135
Mg	-1.505

After measuring the voltage difference between the $CuSO_4$ reference and electrodes of differing materials, the students changed the reference electrodes made of Fe or Al. Then, the voltage difference and current between the reference and electrodes of differing materials were measured in tap water and a 3% saline solution (NaCl). These measurements are tabulated below in Table 2.

Table 2: Reduction Potentials from Fe and Al.

Reference	Electrode	Solution			
		Water		Saline	
		Voltage [V]	Current [mA]	Voltage [V]	Current [mA]
Fe	Cu*	0.33	0.41	0.38	2.28
	Mg	-1.03	-2.63	-0.85	-67.2
	Zn	-0.605	-1.93	-0.578	-10.69
	Sn*	0.166	0.01	0.57	0.17
Al	Cu*	0.455	0.36	0.49	4.42
	Mg	-1.125	-0.86	-0.888	-8.9
	Zn	-1.181	-0.822	-0.509	-3.84
	Sn*	0.631	0.105	0.56	1.176

In the "Electrode" column, no * means the electrode is corroding. Converesely, an electrode with a * means the reference material is corroding.

3 Analysis of Results and Points for Discussion

To conduct this experiment, the students split into four groups and conducted individual reference voltage and current measurements. First, each group filled a 600 ml beaker with 500 ml of water, placed the beaker on top of a stir station, and placed a stir bar in the water. Then, each group placed a reference electrode made of copper-copper sulphate in the electrode support. Another anode was placed in the remaining electrode support made of Cu, Sn, Fe, Al, Zn, or Mg – each group conducted three measurements on different materials that resulted in two measurements for each electrode material. Once the electrodes were fixated, the negative terminal of a voltmeter was connected to the reference electrode and the the positive terminal was connected to the other electrode. Then, the voltage was measured in volts and recorded for each material the group tested.

After using $CuSO_4$ as the reference electrode, two groups swapped the reference electrode for Fe and the other two for Al. Then, the voltmeter was connected in the same manner as the $CuSO_4$ reference electrode. The current [mA] and the voltage [V] of both reference electrodes were measured against Cu, Mg, Zn, and Sn. After measuring the voltage and current in water, 15 g of salt (NaCl) was added to the water and the currents and voltages were measured and recorded again. All of these results have been aforetabulated in Sec. 2. Finally, the beakers, stir platform, stir bar, and all electrodes were cleaned in the lab sink and put away. There were no discrepancies from the standard method presented in [1].

After using different reference electrodes, the $CuSO_4$ electrode was the most "noble" electrode tested. The term noble refers to how likely a material is to corrode when placed in an electrolytic cell with another material – more noble materials corrode less than ignoble materials. In this experiment, the negative terminal of the voltmeter was connected to the reference cell. Therefore, if the measured voltage is negative, the reference cell is more noble than the non-reference cell. Conversely, if the measured voltage is positive, the non-reference cell is more noble than the reference cell.

For the Fe reference cell, the Cu and Sn electrodes were more noble than the Fe reference meaning the Fe will corrode and not the Cu or Sn. Compared to the $CuSO_4$ reference cell, which was more noble than all tested materials, Fe had a voltage difference of -0.3975 V. Therefore, the measurements using Fe as the reference cell should be roughly 0.3975 V higher than the measurements using $CuSO_4$ as the reference cell. The expected result is somewhat observed with the mean difference in voltages being 0.5026 V – meaning the voltages measured with Fe as the reference were 0.5026 V higher than using $CuSO_4$ as the reference. The higher measured voltages are expected, however, the discrepancy in the values indicates not enough data points were taken.

For the Al reference cell, the Cu and Sn electrodes were once again more noble than the Al reference. With $CuSO_4$ as the reference cell, the voltage difference for Al was -0.6715 V. However, the the voltages measured with Al as the reference were 0.4823 V higher than using $CuSO_4$ as the reference. The expected results are the measured voltage differences using Al as the reference would be 0.6715 V higher than using $CuSO_4$ as a reference. However, this discrepancy could be explained by the lack of data. Using Fe and Al as the reference electrode, all voltages were higher than when $CuSO_4$ was used as the reference voltage, which is expected from the $CuSO_4$ voltage measurements.

After testing how voltage varied with tap water for various electrodes, salt was added to the beaker to make a saline solution of $3\%_{wt}$ NaCl. By adding salt, the solution gains electrolytes. The additional electrolytes cause a higher current to flow through the solution, in theory, increasing the current between cells. The increase in current is explained through an investigation of the circuit – the circuit is two metal electrodes connected by metal wires through the voltmeter on one end and a solution on the other end.

Metals are the best conductors, therefore, the circuit part with the lowest conductivity is the solution – the solution is the rate-limiting step for corrosion.

From the experiment, the addition of salt increased the current by roughly an order of magnitude for all trials. The current increasing is expected as the salinity makes the conductivity of the water higher. It is known that the electrolytic current is directly proportional to corrosion rate. Therefore, the increase in salinity is accompanied by a proportional increase in corrosion. A higher corrosion rate in more saline environments has implication on aquatic designs. Any structure made in fresh water, analogous to the tap water in this experiment, will have one-tenth of the corrosion as a structure made in salt water, analogous to the saline solution in this experiment. Additional engineering concerns need to be made in more saline environments to counteract the increased corrosion.

References

[1]   *Lab 8: Corrosion.* University of Illinois at Urbana-Champaign. 15 pp.