# Connecting Educators with Inter-Disciplinary Inquiry-Based Science and Students with STEM Careers with Real-World Experiences

**Suzanne Lunsford, Ph.D.**
**Professor of Chemistry**
**Department of Chemistry**
**Wright State University**
**Dayton, OH 45435, USA**

**Lei Zhai, Ph.D.**
**Associate Professor of Chemistry**
**University of Central Florida**
**Nanoscience Technology Center**
**Orlando, FL 32826**

**Justin Lee**
**Department of Chemistry**
**Wright State University**
**Dayton, OH 45435, USA**

**Dolores Dodson**
**Department of Chemistry**
**Wright State University**
**Dayton, OH 45435, USA**

**ABSTRACT:**
Our professional development workshops have provided participating teachers (in-service and pre-service) with interdisciplinary experiences in earth and environmental science that have built their content into real-world problem based research initiatives (STEM, Science Technology, Engineering and Mathematics). One of our real-world issues has been the detection of phenol since it has been a concern in the real-world coal mining industry. Coal tars are a complex of variable mixtures of phenols. Phenol and phenol derivative compounds are widely used in the production of polymers, drugs, dyes, explosives, pesticides, stabilizers and antioxidants. These phenolic compounds are discharged into the environment and can represent a serious hazard, mainly by the contamination of superficial and underground waters. The toxic effect of phenol can cause comas, convulsions, cyanosis, liver damage, kidney damage, lung damage and death.
The mining industry for coal is an alternative source of energy and used in thermoelectric power plants. However, the pollutant phenol that can be found in coal has high need to be detected and is an important aspect to keep an eye on due to these harmful chemicals such as phenol discharging into the environment. Our inquiry-based labs have engaged our in-service and pre-service students by visiting a mine and learning the positive and negative aspects of mining and the importance of water quality. Thus, this inquiry-based module will illustrate the use of an electrochemistry modified carbon nanotube poly-3-hexylthiophene electrode to detect such harmful chemicals as phenol by unique electrochemistry techniques such as Differential Pulse Voltammetry (DPV).

**INTRODUCTION:** Water is one of the most important nutrients for a healthy human and organic pollutants such as phenol in water are listed as priority pollutants according to the US EPA. The use of electrochemical techniques such as DPV for monitoring phenol in aqueous solution with the use of multi-walled carbon nanotubes with poly-3-hexythiophene (P3HT) compared to bare carbon electrode as a sensor. The selectivity of the carbon nanotube CNT-P3HT electrode to detect phenol in basic conditions will be shown. The advantages of this environmental sensor studied were introduced to our in-service and pre-service teachers to enhance their understanding of real-world analysis and challenges that may be encountered in sensor development. The students gained the understanding of how to use DPV electrochemistry software and how small pulses of constant amplitude are superimposed on a linear potential ramp applied to the working electrode. The potentials are applied just before the end of the drop and this DPV technique can detect organic chemicals such as phenol in the low $10^{-8}$M range with the optimum modified working electrode.

## EXPERIMENTAL

*Safety and Hazards*

All solution preparations were carried out under the fume hood. Phenol is harmful upon contact with tissue or if digested. Sodium hydroxide is harmful upon contact with tissue or if digested. Sulfuric acid heat evolves when mixing with water and precaution should be taken. All waste was disposed in the proper waste containers with labels. Protective garment, goggles and gloves were worn at all times. All MSDS information can be found at www.sigmaaldrich.com for all products.

*Reagent and Chemicals*

Sulfuric acid (A.C.S. reagent), sodium dihydrogen phosphate monohydrate and phenol (certified) were obtained from Fisher Scientific. The poly-3-hexylthiophene was synthesized and multiwalled carbon nanotubes (MWCNT) were purchased from Nano Lab (diameter 10-20 nm; length 5-20 µm with a purity of 95%. The typical procedure is 20 mg MWCNT and 20 mg poly-3-hexylthiophene were mixed in 20 mL of tetrahydrofuran and ultrasonicated for 1 hour. The suspension was drop casted on the bare carbon electrodes to make the MWCNT-P3HT films.

*Apparatus/Procedure*

A polished carbon electrode (1.6 mm) with the carbon nanotube poly-3-hexylthiophene was deposited onto the working electrode. A three-electrode single compartment cell was utilized for the voltammetry studies with the platinum foil as the auxiliary and the reference was Ag/AgCl/3M NaCl (MF-2074, BAS). Bioanalytical Systems Epsilon potentiostat-galvanostat instrument was utilized to carry out by cyclic voltammetry and by differential pulse voltammetry studies.

## RESULTS/DISCUSSION:

The electrochemical oxidation of phenol will be detected by Differential Pulse Voltammetry (DPV) in this lab (basic conditions) with a modified CNT-P3HT working electrode (carbon) and compared to the bare carbon electrode. In the past, there have been studies shown use of platinum working electrode and a carbon working electrode to detect phenol but there were problems with adsorption of phenol on the platinum electrode surface and carbon electrode surface. Additionally, It has been reported in the literature that even a Boron Doped Diamond electrode was not proven useful in the detection of phenol. Therefore, a modified carbon electrode has been found to be better than most working electrodes in the literature for detection of phenol in aqueous solution but no investigations have occurred with the use of a modified carbon electrode to detect phenol with a CNT-P3HT electrode. Therefore, this lab required our students to investigate the detection of phenol by DPV with the CNT-P3HT electrode in acidic and basic conditions. Figure 1., displays the detection of phenol at a CNT-P3HT electrode compared to the bare carbon electrode to detect phenol in basic conditions. The drain off of the contaminant phenol can require detection under basic conditions (pH of approximately 10) thus there was an analysis of $5X10^{-4}$ M phenol with the CNT-P3HT electrode with enhanced electrocatalytic activity compared to the bare carbon electrode with minimum response, Figure 1.

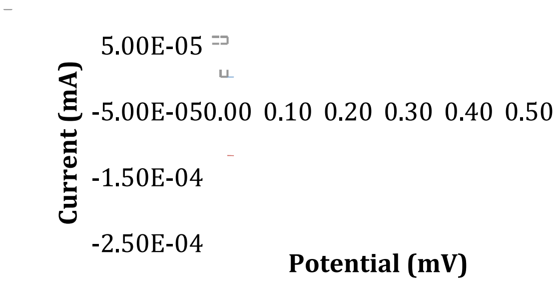


Figure 1. DPV of bare C (--) versus CNT-P3HT electrode (--) to detect 5X10$^{-4}$ M phenol in buffer (basic conditions pH=10).

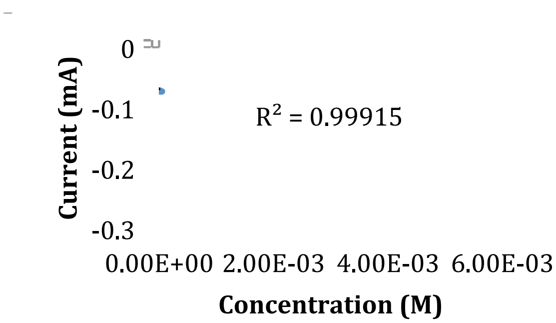


Figure 2. Current (mA) versus Concentration (M) of phenol detection with CNT-P3HT electrode (correlation coefficient of 0.99915).

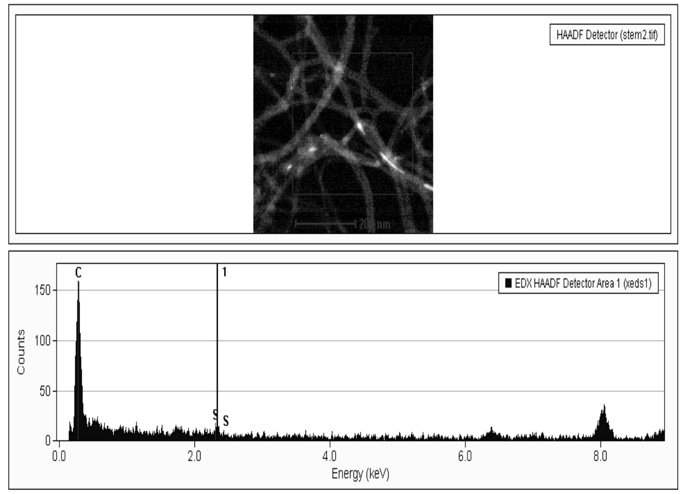


Figure 3. Scanning Electron Microscope (SEM)-Energy Dispersive X-Ray Analysis (EDX) of CNT-P3HT electrode material.

Figure 1. illustrates the better electrocatalytic activity of the CNT-P3HT electrode response by DPV to detect phenol with the more enhanced oxidation peak than the bare carbon electrode with the extremely small oxidation peak. Figure 2. Illustrates the linear response of the CNT-P3HT electrode to detect phenol at various concentrations with a correlation coefficient $R^2$ of 0.99915 when plotted current versus concentration of phenol by DPV technique making it amendable for electroanalysis. Figure 3., was taken at UCF by Dr. Lei Zhai research group and shared with our students to learn about the technology of SEM-EDX and how it verifies the material was made of CNT-poly-3-hexythiophene verified by the EDX showing peaks for C and S.

## CONCLUSION:

CNT-P3HT has been a novel electrode to detect phenol in the $5X10^{-7}$ M and these electrodes can be expanded into more inquiry-based modules related to common neurotransmitter detection in the future as well due to the selectivity of the modified electrode for the hydroxyl group on phenol. The importance of water quality and the correlation with the aspects encountered in the mining industry to detect phenol has developed students interest due to the real-world based problems to resolve in creating a sensor for toxic chemicals. Our hope for sharing this novel experiment is to encourage other faculty to collaborate with industry and academia at other institutions to build a strong problem-based experience for our undergraduate and graduate students.


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