

**Fabrication and Testing of Polyaniline/ Graphite composite
based Enzymatic Bio Fuel Cell**

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FINAL YEAR PROJECT REPORT



Under The Guidance Of

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Designation: Assistant Professor

DECLARATION

We declare that we carried out the work reported in here in the Department of Mechanical Engineering, University of Petroleum and Energy Studies, under the supervision of Mr. Anil Babu Sankuru and Mr. Diwakar Kashyap. We solemnly declare that to the best of our knowledge, no part of this report has been submitted here or elsewhere in a previous application for award of a degree. All sources of knowledge used and cited have been fully acknowledged.

Student's Signature/s and Date




Name/s of Students and SAP ID

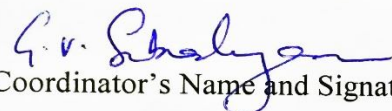
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APPROVAL

This is to certify that the project titled “**Fabrication and Testing of Polyaniline/Graphite composite based Enzymatic Bio Fuel Cell**”, carried out by Geetansha Sood and Samarth Tripathi has been read and approved for meeting part of the requirements and regulations governing the award of the Bachelor of Technology with specialization in Material Sciences and Nanotechnology of University of Petroleum and Energy Studies, India.


Supervisor/s' Name and Signature (SANIL BABU)

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17/04/15
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Associate HOD/HOD's Name and Signature

17/04/15
DATE

ACKNOWLEDGEMENT

It has been a great honor and privilege to take up this project titled **“Fabrication and Testing of Polyaniline/Graphite composite based Enzymatic Bio Fuel Cell”**.

We would like to take this opportunity to express our humble gratitude to Dr. Sanket Goel, Dr. JK Pandey, Dr. Garimella, Mr. Diwakar Kashyap, Mr. Anil Babu Sankuru whose invaluable guidance helped us understand the project better. Their constant guidance and willingness to share his vast knowledge made us understand this project and its manifestations in great depths and helped us to complete the assigned tasks.

Although there may be many who remain unacknowledged in this humble note of gratitude, there are none who remain unappreciated.

Thank you all

Geetansha Sood
Samarth Tripathi



ABSTRACT

A fuel cell is an electrochemical device that manages the flow of electrons and positive ions (protons or alkali metal cations such as Li^+ or Na^+) in a redox reaction such that the electrons move through an external circuit performing electrochemical work. A bio fuel cell is the combination of two technologies: fuel cells and biotechnology. Similar to conventional fuel cells, biofuel cells consist of an anode and a cathode separated by a barrier that is selective for the passage of positively charged ions; they require the addition of fuel to generate power. Unlike conventional fuel cells, which usually use precious metals as catalysts, biofuel cells utilize enzymatic catalysts (as in Enzymatic Bio Fuel Cells).

In our experiment we have synthesized a Polyaniline/ Graphite composite based Enzymatic Bio Fuel Cell and immobilized the enzymes laccase and glucose oxidase (GOx) over it.

Our major aim was to be able to fabricate a device which can be able to carry out suitable electrochemical reactions on the anode and cathode and can be utilized in applications like implantable and portable devices.

We conducted characterizations including Fourier Transform Infrared Spectroscopy, Chronoamperometry, Open Circuit Potential Analysis and Electrical Impedance Spectroscopy on our specimen and were able to conclude that the device is working with a potential of -0.09V .

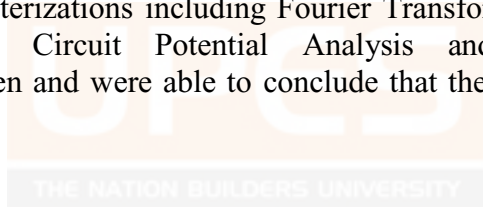


Table of Contents

Declaration.....	i
Acknowledgement.....	ii
Abstract.....	iv
List of figures.....	vi
Chapter 1: Introduction.....	1
Chapter 2: Literature Review.....	2
2.1 Biofuel Cells.....	2
2.2 Enzymatic Biofuel Cells.....	2
2.3 Recent developments in enzymatic biofuel cells.....	3
2.4 Challenges in developing effective enzymatic biofuel cells.....	4
2.5 Graphite /Poly aniline based composite.....	4
Chapter 3: Experimental Techniques/ Procedures.....	5
3.1 Materials.....	5
3.2 Procedure.....	6
3.3 Vacuum filtration.....	7
3.4 Preparation of solutions for electrochemical testing.....	7
3.5 Immobilizing the enzyme on the samples.....	8
3.6 Attaching electrode onto the pellets.....	9
3.7 Electrochemical testing.....	10
3.8 Half Cell Testing.....	10
Chapter 4: Results and Discussions.....	11
4.1 Contact angle measurement.....	11
4.2 Fourier Transform Infrared spectroscopy.....	12
4.3 Chronoamperometry.....	13
4.4 Electrochemical Impedance.....	15
4.5 Open circuit potential.....	18
Chapter 5: Conclusion.....	20
Chapter 6: References.....	21

LIST OF FIGURES

<u>Fig no.</u>	<u>Title</u>	<u>Page no.</u>
1.	Schematic illustration of an enzymatic biofuel cell	3
2.	Schematic of Vacuum Filtration of the samples	7
3.	Schematic of electrochemical testing	10
4.	Schematic of a surface drop analyser	11
5.	FTIR spectra of Graphite-Polyaniline composite	12
6.	Chronoamperometry of electrode Glucose Oxidase	14
7.	Chronoamperometry of electrode containing Laccase	14
8.	EIS of the electrode containing Glucose oxidase	16
9.	EIS of the electrode containing Laccase	17
10.	Open circuit potential of the anode	18
11.	Open circuit potential of the cathode	19

LIST OF TABLES

Table 1: Comparison of Fuel Cells	1
Table 2: Interpretation of the FTIR peak	13

CHAPTER – 1

Introduction

A fuel cell is typically a battery that generates electricity from an electrochemical reaction. Both batteries and fuel cells convert chemical energy into electrical energy. However, a battery holds a closed store of energy within it and once this is depleted the battery must be discarded, or recharged by using an external supply of electricity to drive the electrochemical reaction in the reverse direction.

On the other hand, a fuel cell uses an external supply of chemical energy and can run as long as it is supplied with a source of hydrogen and a source of oxygen (usually air). The source of hydrogen is the fuel and this gives the fuel cell its name.

Different types of Fuel Cell include:

1. Proton Exchange Membrane Fuel cell(PEMFC)
2. Phosphoric- acid Fuel Cell (PAFC)
3. Solid Oxide Fuel Cell (SOFC)
4. Molten Carbonate fuel Cell (MCFC)
5. Alkaline Fuel Cell (AFC)
6. Biofuel Cell (BFC)
 - Microbial Fuel Cells (MFCs)
 - **Enzymatic Bio Fuel Cell (EBFC)**
7. Direct Methanol Fuel Cell (DMFC)

Comparison of Fuel Cells

Fuel Cell	Temperature (°C)	Application
Alkaline (AFC)	70 – 90	Space
Phosphoric Acid (PAFC)	150-210	Commercially available
Solid Polymer (PEMFC)	70-90	Automotive application
Molten Carbonate (MCFC)	550-650	Power generation
Solid Oxide (SOFC)	1000-1100	Power generation
Direct Methanol (DMFC)	70-90	Under Development

Table 1: Comparison of Fuel Cells

Enzymatic biofuel cells possess several advantages including energy conversion due to renewable catalysts, flexibility of fuels (including renewables), and the ability to work at room temperature. However, these devices remain limited by short lifetimes, low power densities and inefficient oxidation of fuels.

Recent research in biofuel cell technology have addressed these deficiencies and address methods to increase lifetime and environmental stability.

CHAPTER – 2

Literature Review

2.1 Biofuel Cells

A biofuel cell is a fuel cell that works in a considerably different way from a conventional fuel cell. The term fuel cell is used because the fundamental working is same, but the prefix “bio” indicates that there are some compounds in the fuel cell that are related to living organisms. Thus, a biofuel cell uses a biological fuel and its reactions involve microbial or enzymatic activity to create energy.

2.2 Enzymatic Biofuel Cells

Enzymatic Biofuel Cell takes advantage of naturally catalysed catalysts to enhance the Oxidation/Reduction reaction rate inside the cell. The Natural catalysts are the Enzymes.

The biofuel cells can be classified into two categories based on the functions of the biocatalysts (enzymes),

1. **Product type.** In this type the enzymes are not involved in direct energy generation. The energy generation is conducted by a conventional fuel cell. Enzymes generate the fuel substrate for fuel cell by a biocatalytic transformation or metabolic process.
2. **Direct energy production type.** In this type enzymes are directly involved in the bioreactions for energy production. Enzymes participate in the electron transfer chain between the fuel and the anode.

On the anode, enzymes oxidise organic matters and produce electrons, and on the cathode, enzymes act as catalysts for oxidant reduction and accept electrons.

The performance of the fuel cell is primarily dependant on the enzyme activity. One of the main issues for this type of fuel cells is to establish efficient electron transfer between enzymes and electrode supports.

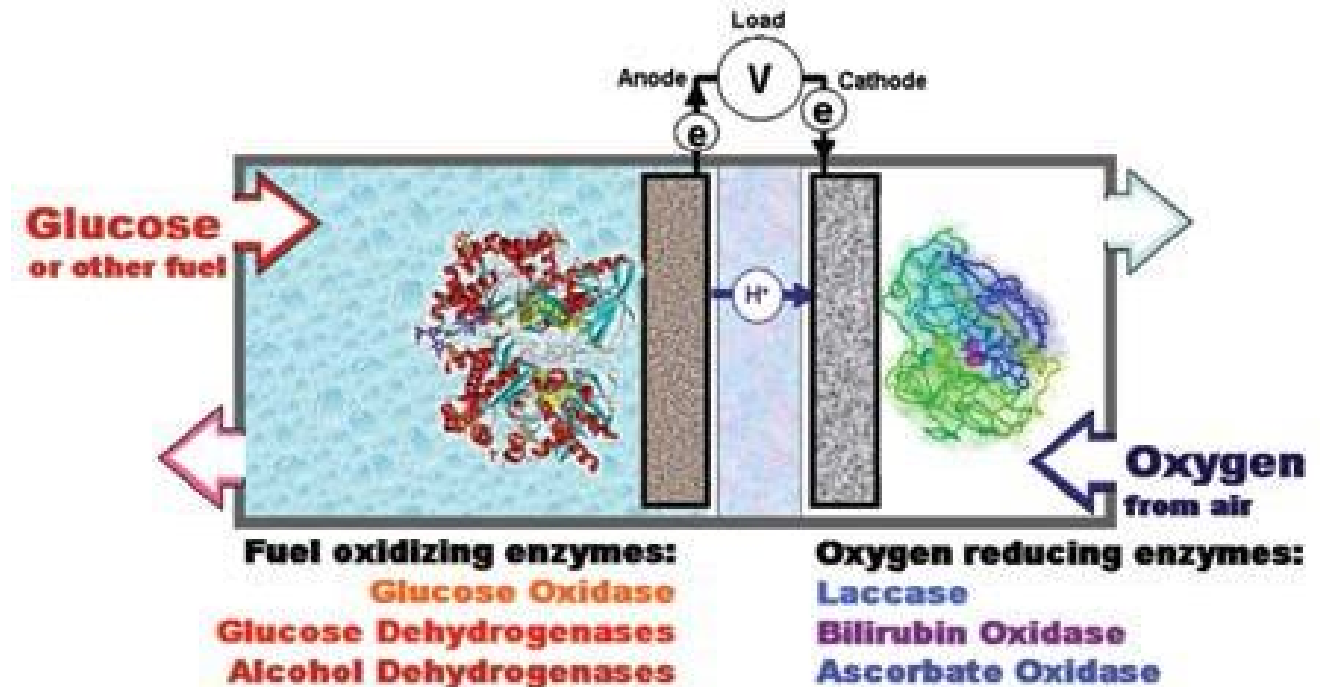


Fig. 1. Schematic illustration of an enzymatic biofuel cell consisting of an anode, catalysed by oxidases. The cathode featuring an oxidoreductase that uses molecular oxygen as the ultimate electron acceptor and catalyzes reduction to water in neutral or slightly acidic media.

4.8 Recent developments in enzymatic biofuel cells

One of the most essential developments in biofuel cells has been the production of biocathodes and bioanodes that use direct electron transfer (DET) instead of mediated electron transfer (MET). The significance of DET is that the electrons are transferred from the catalyst (enzyme) directly to the electrode and challenges associated with the use of mediators are overcome.

Other than this, there has been an increase in the active lifetime of the immobilized enzymes considering enzymes are proteins that typically have short lifetimes (8 h to 2 days) in buffer solution, although their active lifetimes can be extended to 7–20 days by immobilization on electrode surfaces via entrapment, chemical bonding, and crosslinking. Recently, active lifetimes have even been improved to beyond 1 year through encapsulation in micellar polymers (Nafion). These polymers enable physical confining of the enzyme and do not let it denature by providing a biocompatible hydrophobic nest and buffered pH microchemical environment.

4.8 Challenges in developing effective enzymatic biofuel cells

Fuel cells require porous anode and cathode structures that support fuel transport to the catalyst reaction sites.

Enzymatic fuel cells are not different from this except that, if they are to be able to compete against primary batteries as a power source, they will need anodes that maximize power density. This requirement demands a solution to three key issues:

- 1- Biofuel cell anodes should be three-dimensional, as opposed to biosensors which are less sensitive to this requirement. The need for surface area, which implies smaller pores that increase the reactive surface area and thus the current generated, and the need for larger pores, which generally supports the mass transport of liquid phase fuel should be optimized.
- 2- The need for successful immobilization of multienzyme systems that can completely oxidize the fuel to carbon dioxide. Current enzymatic biofuel cells have low efficiency, as only a single type of enzyme is employed and can only partially oxidize the fuel. This is in direct contrast to living cells that can completely oxidize biofuels (e.g. ethanol, lactate and glucose) to carbon dioxide and water.
- 3- Finally, the anode must support efficient charge transfer mechanisms, whether it be direct or mediated, and balance electron transfer with proton transfer.

4.8 Graphite /Poly aniline based composite

The use of intrinsically conducting polymers (ICPs) for a wide range of applications has been researched upon. When ICPs are combined with other conducting materials, some unique properties can be observed.

The use of ICPs, especially polyaniline (PANi) and polypyrrole (Ppy), and carbon black (CB) as conductive additives in the thermoplastics industry are limited because of their undesirable properties at elevated temperatures. However, the carbon black-ICP composites, have shown enhanced properties at higher temperatures.

Graphite has been used as a conductive filler in the matrix of insulating polymers to render conductive polymers. Some recent research has focused on using compositions of graphite and ICPs for use as both anodes and cathodes in rechargeable batteries. The inclusion of Ppy into the graphite electrode material provides for more particle-to-particle contact due to the ICP providing a conducting backbone between the graphite particles. The composites that used a combination of PANi, graphite and acetylene black for cathodes in dry rechargeable batteries also show improved efficiency.

CHAPTER – 3

EXPERIMENTAL TECHNIQUES/PROCEDURES

3.1 Materials required for fabricating the graphite and polyaniline composite

- Graphite fine powder (mesh size)
- 0.5M Ammonium Persulphate (0.5L)
- 1M HCL solution (2L)
- Aniline

1) HCL procured had molarity 11.36 which was diluted with water to a molarity of 1 by the following method.

$$M_1 * V_1 = M_2 * V_2$$

$$11.36 * V_1 = 1 * 2$$

$$V_1 = 176\text{ml}$$



2) Ammonium Persulphate

$$M = (\text{Weight} * 1000) / (\text{Molecular weight} * \text{Volume in ml})$$

$$0.5 = (\text{Weight} * 1000) / (228.19 * 500)$$

$$\text{Weight} = 57.04\text{gm}$$

Ammonium Persulphate of molarity 0.1M is also required in the experiment

$$M_1 * V_1 = M_2 * V_2$$

$$0.5 * V_1 = 0.1 * 100$$

$$V_1 = 20\text{ml}$$

Now taking this 20ml Ammonium Persulphate a solution of 100 ml is prepared by diluting it in 80ml of water.

Let this be called as **solution A**.

3) Another 100ml solution is prepared by taking 10ml of Aniline and 90ml of HCL.
Let this be called as **solution B**

3.2 Procedure

Preparation of sample 1

- In a beaker 2gm Graphite and 20ml of 1M HCL is mixed and sonicated for 5mins in an Ultrasonic bath (LabMan Ultrasonicator) at room temperature.
- In the same beaker pour 10ml of solution B and sonicate it for 5mins.
- Then slowly put 10ml of solution A and while sonicating the above solution.
- Thus **sample 1** (10ml) is prepared.

Preparation of sample 2

- In a beaker 2gm Graphite and 20ml of 1M HCL is mixed and sonicated for 5mins in an Ultrasonic bath (LabMan Ultrasonicator) at room temperature.
- In the same beaker pour 20ml of solution B and sonicate it for 5mins.
- Then slowly put 20ml of solution A and while sonicating the above solution.
- Thus **sample 2** (20ml) is prepared.

Preparation of sample 3

- In a beaker 2gm Graphite and 20ml of 1M HCL is mixed and sonicated for 5mins in an Ultrasonic bath (LabMan Ultrasonicator) at room temperature.
- In the same beaker pour 30ml of solution B and sonicate it for 5mins.
- Then slowly put 30ml of solution A and while sonicating the above solution.
- Thus **sample 3** (30ml) is prepared.

Preparation of sample 4

- In a beaker 2gm Graphite and 20ml of 1M HCL is mixed and sonicated for 5mins in an Ultrasonic bath (LabMan Ultrasonicator) at room temperature.
- In the same beaker pour 40ml of solution B and sonicate it for 5mins.
- Then slowly put 40ml of solution A and while sonicating the above solution.
- Thus **sample 4** (40ml) is prepared.

Preparation of sample 5

- In a beaker 2gm Graphite and 20ml of 1M HCL is mixed and sonicated for 5mins in an Ultrasonic bath (LabMan Ultrasonicator) at room temperature.
- In the same beaker pour 50ml of solution B and sonicate it for 5mins.
- Then slowly put 50ml of solution A and while sonicating the above solution.
- Thus **sample 5** (50ml) is prepared.

3.3 Vacuum filtration of all the above samples

Vacuum filtration is used to segregate the prepared composite from the solvent. Continuous rinsing of the composite dissolved in the solvent is done with methanol and water to remove the impurities from the sample. All the organic impurities are dissolved in Methanol and all the water soluble impurities is dissolved and washed out with water. The unpolymerized Aniline is removed by Methanol and the Ammonium Persulphate is removed by water.



Fig. 2. Schematic of Vacuum Filtration of the samples

3.4 Preparation of solutions for electrochemical testing

Solution 1

Glucose $C_6H_{12}O_6$

$$M = (\text{Weight} * 1000) / (\text{Molecular weight} * \text{Volume in ml})$$

$$0.1 = (\text{Weight} * 1000) / (180.16 * 500)$$

$$\text{Weight} = 9.008 \text{ gm}$$

Solution 2

NaH₂PO₄

$$M = (\text{Weight} * 1000) / (\text{Molecular weight} * \text{Volume in ml})$$

$$4 = (\text{Weight} * 1000) / (137.99 * 100)$$

$$\text{Weight} = 13.8\text{gm}$$

Phosphate buffer (mono and di basic) (Solution 3 and 4)*

Solution 3*

Na₂HPO₄

$$M = (\text{Weight} * 1000) / (\text{Molecular weight} * \text{Volume in ml})$$

$$4 = (\text{Weight} * 1000) / (141.96 * 300)$$

$$\text{Weight} = 42.58\text{gm}$$

Solution 4*

Sodium Citrate

$$M = (\text{Weight} * 1000) / (\text{Molecular weight} * \text{Volume in ml})$$

$$4 = (\text{Weight} * 1000) / (294.10 * 300)$$

$$\text{Weight} = 88.2\text{gm}$$

Solution 5

7.45gms KCl in 100gm of Water

3.5 Immobilizing the enzyme on the samples

Immobilizing enzymes refers to enzymes physically confined or localized in a certain defined region of space with retention of their catalytic activities, and which can be used repeatedly and continuously.

The major components of an immobilized enzyme system are the enzyme, the matrix and the mode of attachment.

Enzymes attachment is done by interactions like reversible physical adsorption and ionic linkages and also by stable covalent bonds.

The lifetime of enzymes in solution can be increased from a few hours to 7-20 days by entrapment in hydrogels and binding them to the surface of electrodes.

Few microliters of Gox was pipetted out on one pellet and few microliters of laccase on the other pellet until they are absorbed completely. Repeat the process 3-4 times for proper absorption of the enzymes onto the pellet. Dry the pellets at room temperature for some time.

3.6 Attaching electrode onto the pellets

Materials required

- 1) Conductive carbon paste
- 2) 3cm copper wire
- 3) 3cm platinum wire
- 4) Pellet 1- (Gox + Graphite + Aniline) 40ml
- 5) Pellet 2- (Laccase + Glucose) 40ml

Steps

- 1) Take conductive carbon paste and apply on the side of the pellet where the enzymes are not present.
- 2) On pellet 1 attach a copper wire using a clip for support.
- 3) On pellet attach a Platinum wire in the same manner.
- 4) Keep it for 12 hours to solidify.
- 5) Dip both the pellets in a 5% solution of Nafion in ethanol. This is done in so that the enzyme is captured and does not wash out when it is dipped in the electrolyte solution.

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3.7 Electrochemical testing

Anode testing

- 1) Working electrode (Anode) : Glucose Oxidase
- 2) Phosphate Buffer Solution (pH – 7.0, 0.1M) + Glucose 1mM.
- 3) Reference electrode – Ag/AgCl (KCl, 1.0M)
- 4) Counter electrode – Platinum wire

Cathode testing

- 1) Working electrode (Cathode) : Laccase
- 2) Phosphate Buffer Solution (pH – 5.0, 0.1M) + Air saturated.
- 3) Reference electrode – Ag/AgCl
- 4) Counter electrode – Platinum wire

3.8 Half Cell Testing

- 1) In a beaker take Phosphate Buffer Solution ($\text{NaH}_2\text{PO}_4 + \text{Na}_2\text{HPO}_4$) along with Glucose as electrolyte.
- 2) pH should be maintained at 7 because the activity of the enzymes used is maximum at this pH.
- 3) Connect the working electrode, counter electrode and reference electrode to the sample and note the readings for OPC, reduction potential and current.
- 4) Now measure the readings for the cathode as well by connecting the working electrode to the cathode.



Fig.3. Schematic of electrochemical testing

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Contact angle measurement

Wetting properties are of great importance in industries during oil recovery, coatings, quenching and lubrication. The angle of contact between the fluid and the solid material determines whether the surface is hydrophilic, hydrophobic or super-hydrophobic. Hydrophilicity and hydrophobicity depends on the angle of contact. If the angle is $\ll 90^\circ$, the surface is hydrophilic and if the angle of contact is $\gg 90^\circ$ the surface is hydrophobic in nature.

Wetting properties of our sample was studied to find out the nature of the electrode prepared in this project using a surface drop analyser. The contact angle was found to be 56.3° . This proves that the surface is hydrophilic in nature and will not segregate the electrolyte when it comes in contact with the electrode which is also known as apparent repulsion of hydrophobic materials.

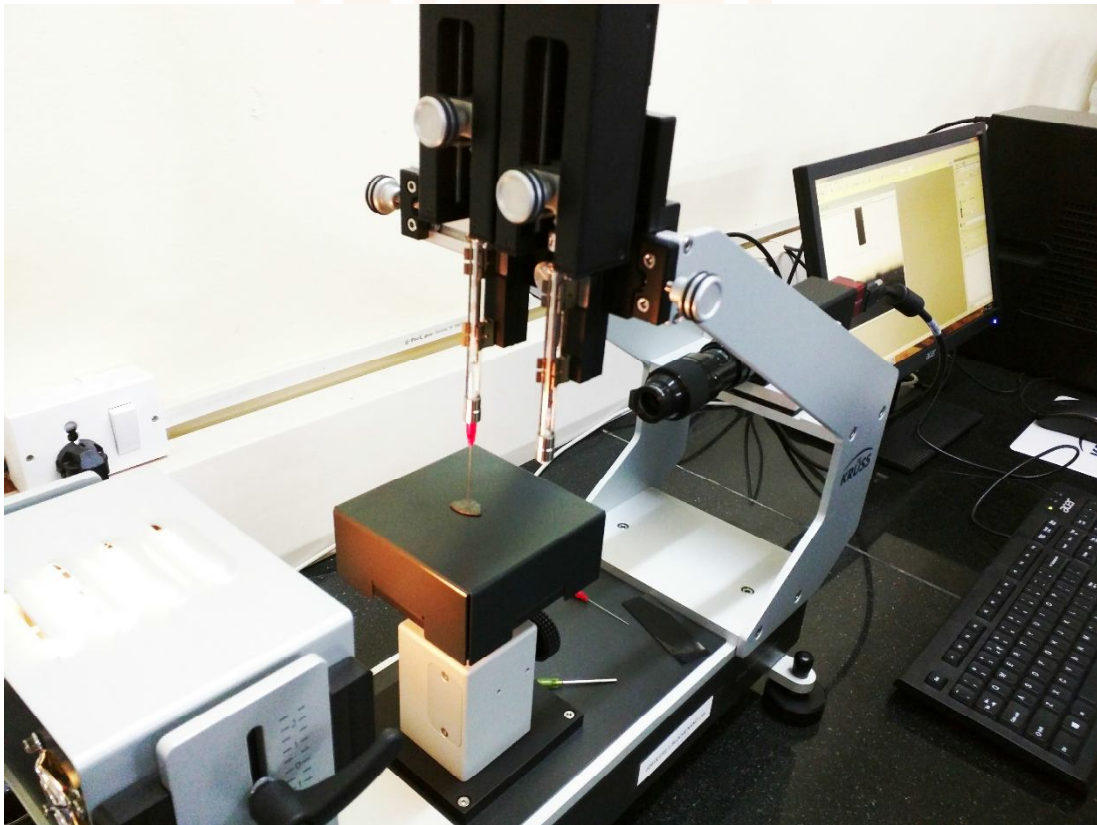


Fig.4 Schematic of a surface drop analyser

4.2 Fourier Transform Infrared spectroscopy

A spectrometer is an optical instrument that is used to measure the properties of light over a specific portion of the electromagnetic spectrum. FT-IR stands for Fourier Transform Infrared. In this method of spectroscopy the infrared radiations are passed through the sample. Some of the radiation is absorbed by the sample and some is transmitted. FTIR obtains an infrared spectra by first collecting an interferogram of a sample signal using an interferometer, then performs a Fourier Transform on the interferogram to obtain the spectrum. The resulting spectrum is like a fingerprint of that molecule. No two unique molecules can produce the same infrared spectrum.

In conducting polymers, in this case Polyaniline, the incident infrared radiation vibrates the bonds of the molecules and also the free carriers present in the electronic structure. The FTIR of sample was taken using PerkinElmer spectrum version 10.03.09 and is given below.

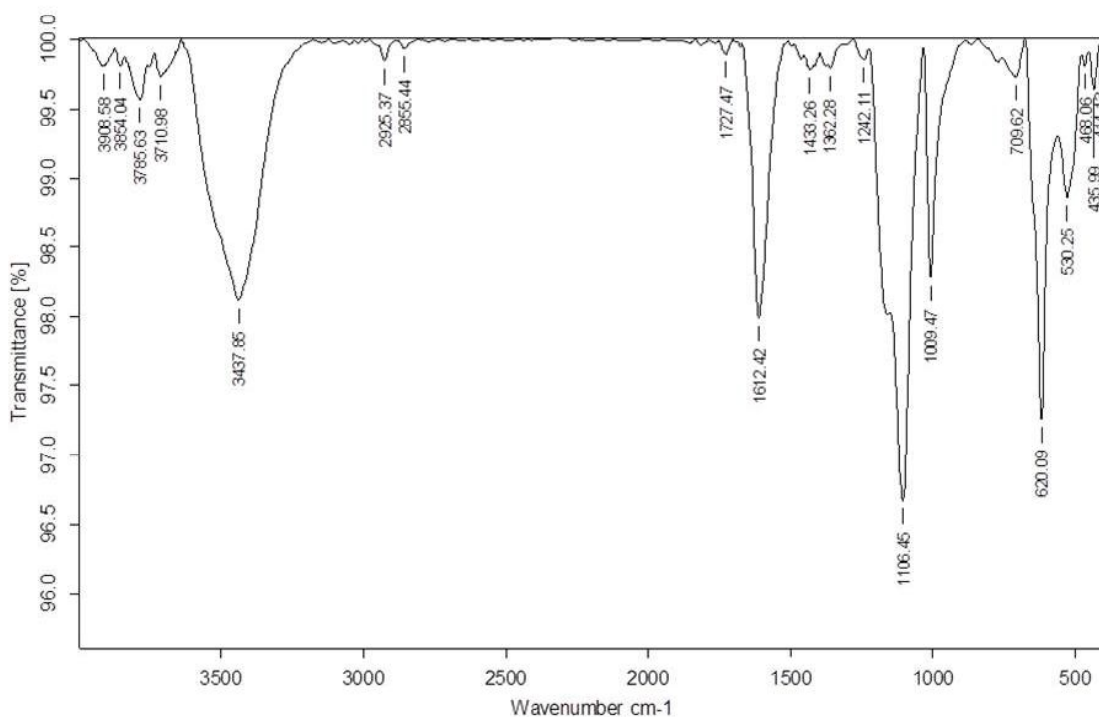


Fig. 5. FTIR spectra of Graphite-Polyaniline composite

The FTIR spectra of the sample containing Graphite and Polyaniline can be interpreted using the Table 2.

<u>Peaks</u>	<u>Range (cm-1)</u>	<u>Group and class</u>	<u>Assignment and Remarks</u>
620.09	680-620	C-O-H in alcohols	C-O-H bending
709.62	710-590	C-S in sulphides	C-S stretch
1009.47	1030-950	Carbon ring in cyclic compounds	Ring breathing mode
1106.45	1120-1030	C-NH ₂ in primary aliphatic amines	C-N stretch
1242.11	1280-1180	C-N in aromatic amines	C-N stretch
1362.28	1375-1350	NO ₂ in aliphatic nitro compounds	NO ₂ sym stretch
1433.26	1440-1400	OH in carboxylic acids	In plane OH bending
1612.42	1612-1590	Benzene ring in aromatic compounds	Ring stretch; sharp peak
	1650-1580	NH ₂ in primary amines	NH ₂ deformation
1727.47	1740-1720	C=O in aldehydes	C=O stretch
2925.37	2990-2850	-CH ₃ and -CH ₂ in aliphatic compounds	CH antisym and sym stretching
3437.85	3520-3320	NH ₂ in aromatic amines, primary amines	N-H stretch

Table 2. Interpretation of the FTIR peaks

The peak corresponding to 3437.85 hints the presence of NH₂ in aromatic amines which is due to the N-H stretch in the molecule. The peaks corresponding to 709.62 and 1433.26 show that there are small traces of sulphides which may be due to some unreacted ammonium persulphate. Overall this proves that the prepared sample consists polyaniline and graphite in it.

4.3 Chronoamperometry

Chronoamperometry is a technique in which change in current with time at a constant voltage is observed. The voltage of the working electrode is stepped and this generates high charging current which decreases exponentially with time. Chronoamperometry is favoured over other amperometry techniques as it produces better signal to noise ratio.

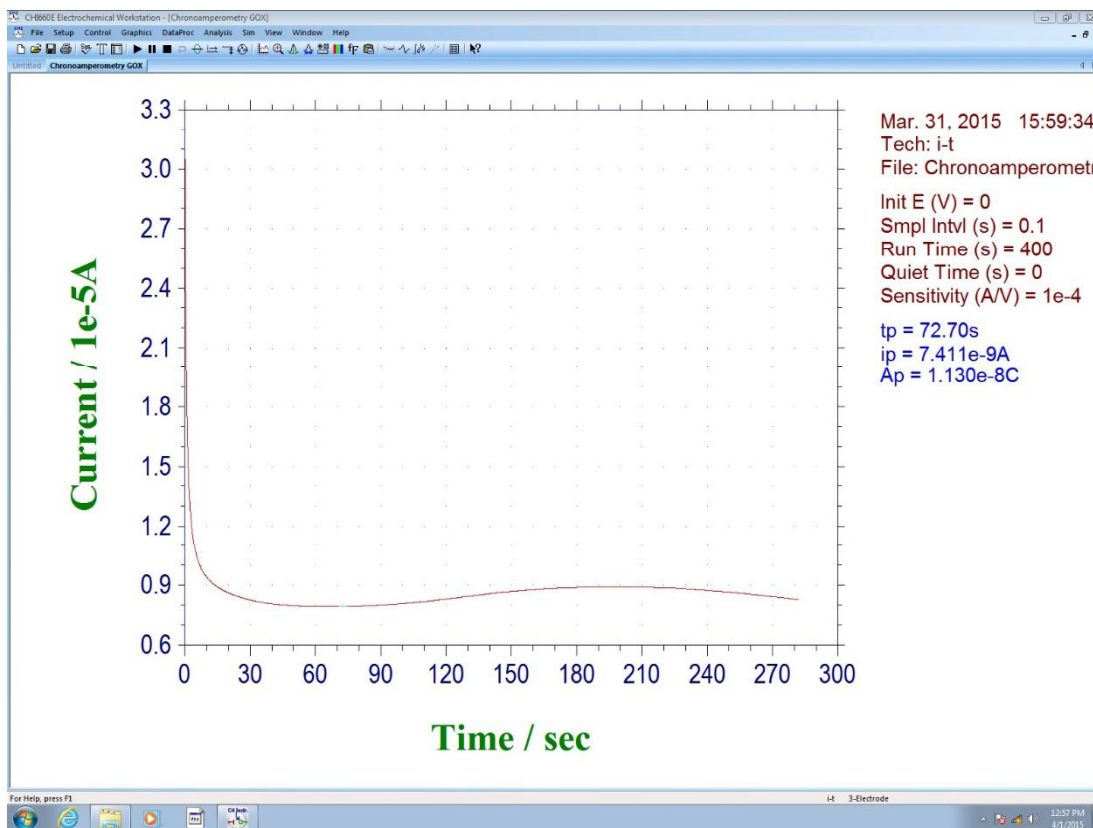


Fig. 6. Chronoamperometry of electrode containing Glucose Oxidase

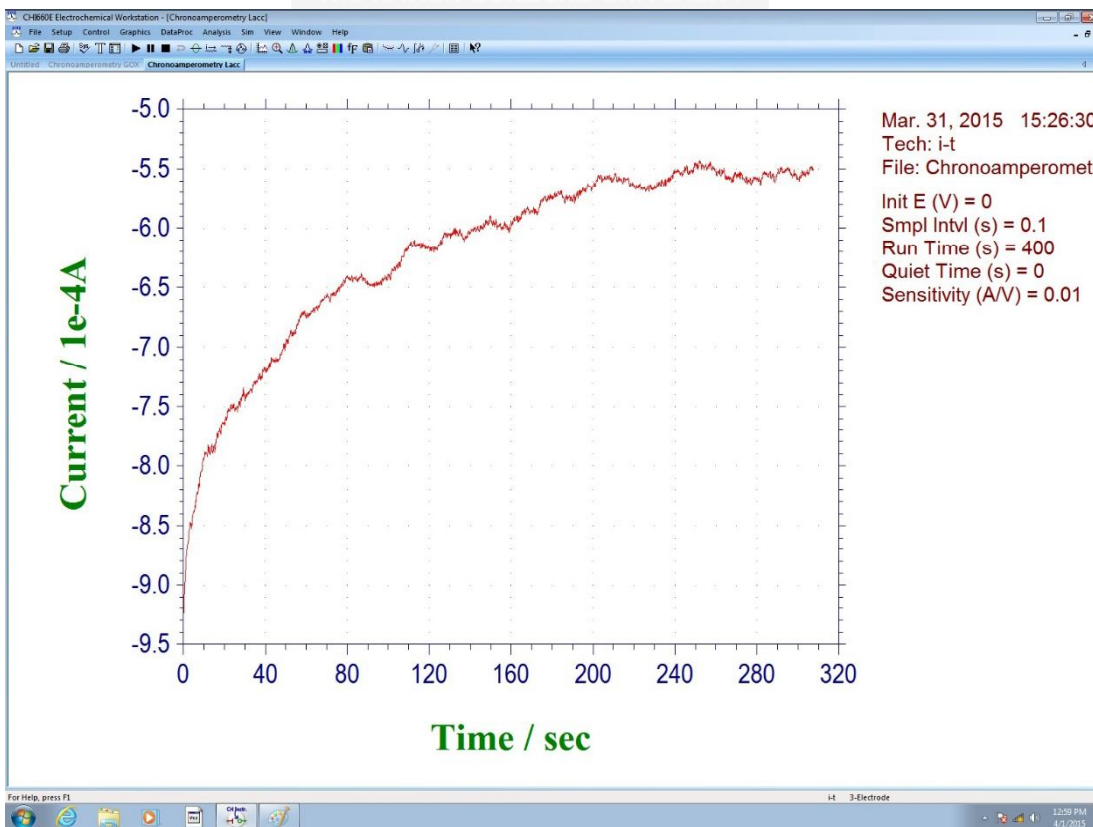


Fig. 7. Chronoamperometry of electrode containing Laccase

The two graphs show the effect of oxygen in the electrolyte solution. In case of electrode containing Glucose Oxidase enzyme, which acts as an anode, decay of current can be observed with time which is due to the decrease in oxygen content in the electrolyte since the electrolyte is not air saturated. Observing the graph from the fig. , we see that the current doesn't decrease with time, in fact it actually increases with time which shows that the effect of oxygen in the electrolyte has no effect on the current at constant voltage.

4.4 Electrochemical Impedance

The concept of resistance is very common and known to almost all of us. The parameters related to the impedance of electrochemical species are electrolyte resistance, double layer capacitance, polarization resistance, charge transfer resistance and diffusion. Materials with coatings usually have very high impedance.

In electrochemical impedance spectroscopy the range of frequency is usually taken between 100 KHz to 1 mHz. A very small AC is applied to observe the current response in enzymatic biofuel cells. The amplitude is taken between 5 to 10mV. A large overpotential is thus not created and the system works undisturbed. The enzymatic biofuel cell electrode is connected to a 3-electrode mode which contain a working electrode, reference electrode and a counter electrode to complete the circuit. In three- electrode mode individual impedance of the anode or cathode is studied. If the impedance of the cathode is to be measured, cathode is connected as the working electrode. If anode is to be measured, connect anode as the working electrode. Impedance spectra is more often than not collected at the potential of the Open Circuit Voltage or by applying different potentials depending on the testing conditions and the system under study.

Electrochemical Impedance spectroscopy is used to determine the resistance offered by the individual components with the help of equivalent circuit models. This model and the impedance characteristics observed can be helped to optimize the design and other aspects of the enzymatic biofuel cells to obtain higher output from the cells.

The graph shown below is for the impedance of the anode which increases as the alternating current is increased. This curve is due to the various resistances offered by the electrolyte, electrode, diffusion and polarization.

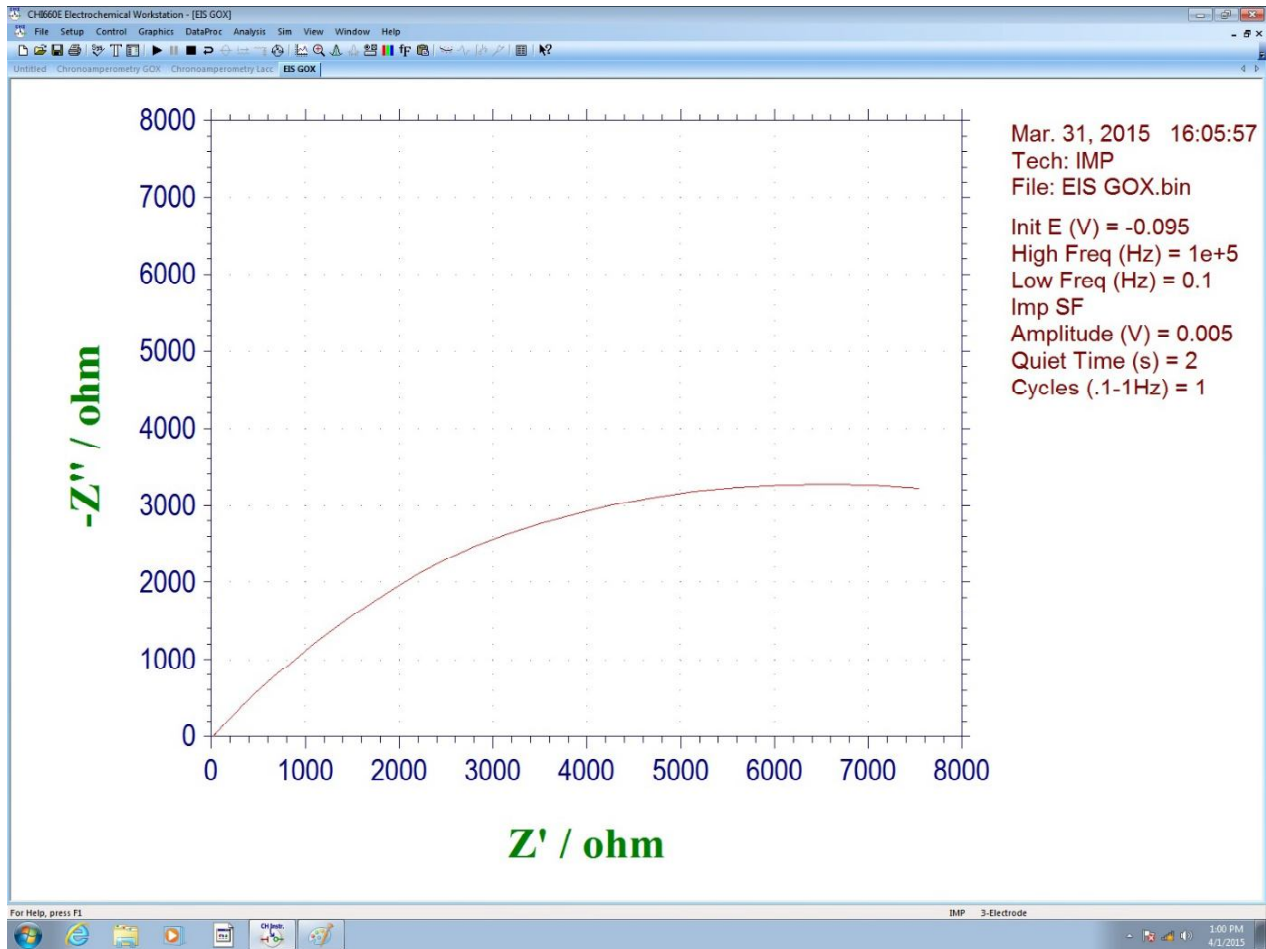


Fig. 8. EIS of the electrode containing Glucose oxidase.

The graph given below with laccase enzyme shows the Nyquist plot which includes a semicircular arc intersecting the real axis (Z') at almost two places. The intercept closest to the origin of gives the value of resistance offered by the solution ($R\Omega$) and the intercept farthest from the origin gives the total resistance value ($R\Omega+R_{CT}$). Although, the equivalent circuit for a smooth coating on the electrode would only include resistance and simple capacitance.

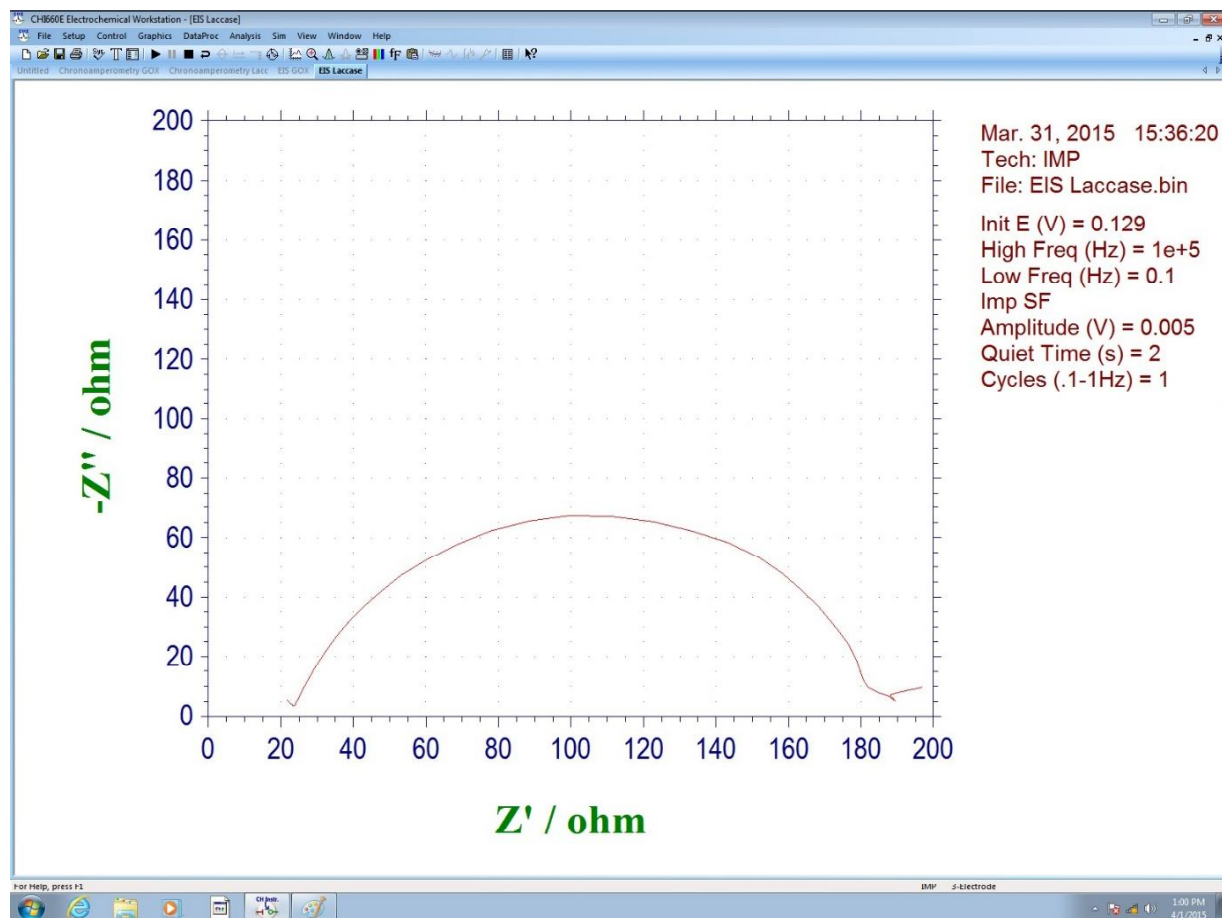


Fig. 9. EIS of the electrode containing Laccase. The graph clearly shows the Niquist plot.

4.5 Open circuit potential

When no current or potential is being applied to the electrode, the difference in potential of the working electrode relative to the reference electrode is known as the open circuit potential. There is no external current between the terminals of the cell. The OCP measurements were made at room temperature with taking anode as the working electrode first and then taking cathode as the working electrode. Three electrode system was used for the calculation of the OCP.

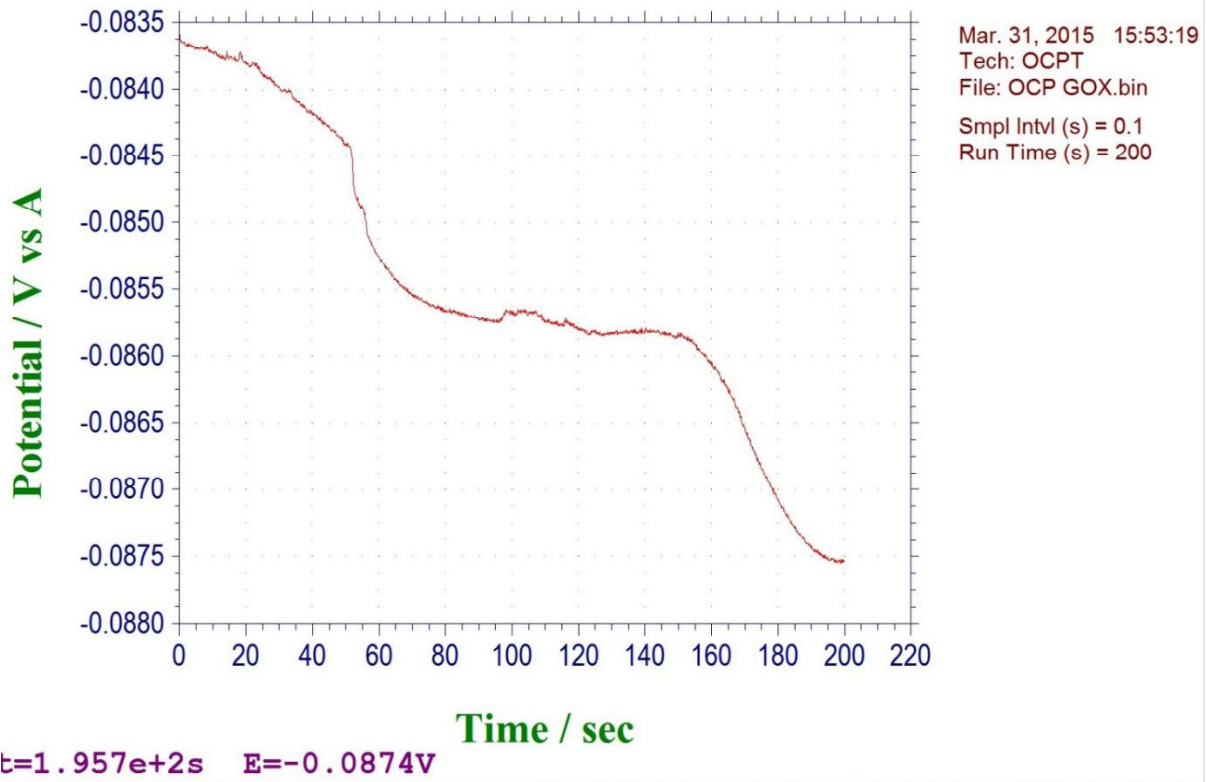
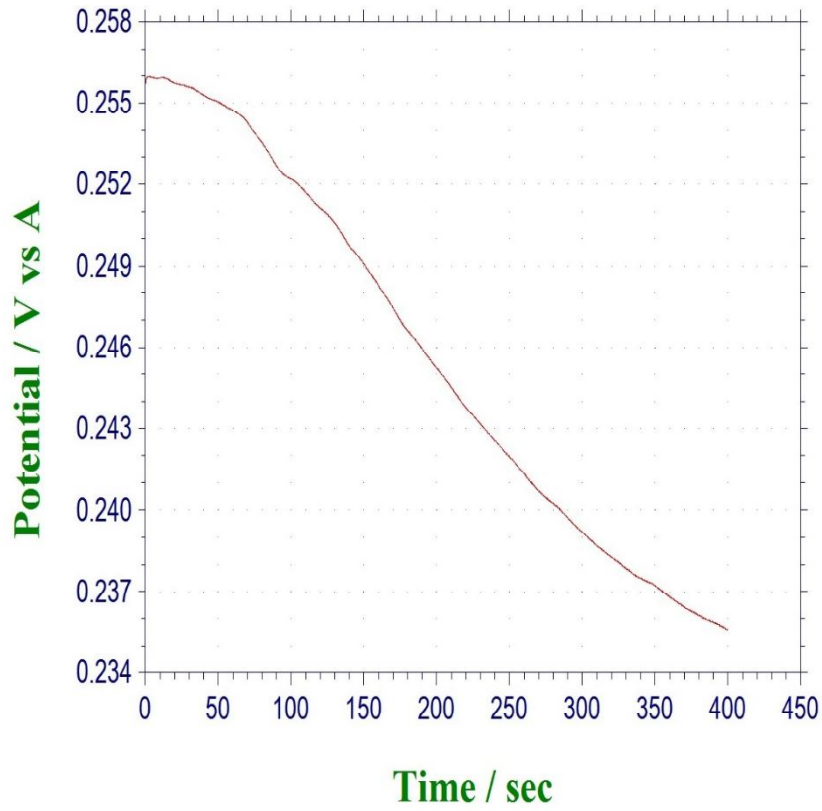


Fig. 10. Open circuit potential of the anode

The open circuit voltage of the electrode with Glucose Oxidase (anode) was found to be around -0.0876V and that of the electrode containing Laccase (cathode) was around +0.235V.



Mar. 31, 2015 15:07:55
Tech: OCPT
File: OCP Laccase.bin
Smpl Intvl (s) = 0.1
Run Time (s) = 400

Fig. 11. Open circuit potential of the cathode

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CHAPTER 5

CONCLUSION

Development of enzymatic biofuel cells was achieved 10 years ago. Since then rigorous research work is going on in developing enzymatic biofuel cells to make them more efficient and increase the life of the cells. Different type of electrode materials are being discovered to make them bio compatible. These biocompatible electrodes can be used in implantable devices and can help replace the currently used lithium-iodide batteries which have a life time of around 10 years. After the life time of these cells are over, they have to be replaced by new batteries which is a very costly process and needs special care during the process so that the devices do not disturb the functioning of the body. In this project graphite and polyaniline composite electrode was synthesised in the lab which was tested to explore new areas of enzymatic biofuel cells. The electrode prepared was tested using FT-IR which showed that the synthesis was successful, although there were some sulphides present as impurities, further optimising and taking special care during the synthesis process can help eliminate such impurities. The enzymes used in this project were Glucose Oxidase and Laccase which is an oxido-reductase enzyme. These enzymes were used to catalyse the oxidation and reduction reactions carried out at the anode and cathode. The fuel cell was found to be working.

Due to their vast applications enzymatic biofuel cells can revolutionize the implantable devices and other electronic devices in future. The best part about these cells is that they are environment friendly and use nothing but the enzymes that are produced in our body. The product of the reactions going on inside the enzymatic biofuel cell is water.

The main challenges that are being faced right now are producing higher power density between the electrodes and enzymes, long term stability of these bio fuel cells. Enzymatic biofuel cells will replace conventional batteries of their high activity from enzymes and the miniaturisation capabilities. The same technology can be used to model the biosensors.

CHAPTER 6

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