UNIVERSITI PUTRA MALAYSIA

FABRICATION OF ELECTROCHEMICAL SENSOR BASED ON MULTIWALLED CARBON NANOTUBES/GOLD NANOPARTICLES FOR VOLTAMMETRIC DETECTION OF AMOXICILLIN AND THIAMPHENICOL RESIDUES IN BOVINE MILK

ALIYU MUHAMMAD

FS 2016 64

FABRICATION OF ELECTROCHEMICAL SENSOR BASED ON MULTI-WALLED CARBON NANOTUBES/GOLD NANOPARTICLES FOR VOLTAMMETRIC DETECTION OF AMOXICILLIN AND THIAMPHENICOL RESIDUES IN BOVINE MILK

By

ALIYU MUHAMMAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

October 2016

DEDICATION

This thesis is dedicated to my late father (Alhaji Muhammad Garba Nagari Nakowa) and the entire Muslim Ummah**.**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

FABRICATION OF ELECTROCHEMICAL SENSOR BASED ON MULTI-WALLED CARBON NANOTUBES/GOLD NANOPARTICLES FOR VOLTAMMETRIC DETECTION OF AMOXICILLIN AND THIAMPHENICOL RESIDUES IN BOVINE MILK

By

ALIYU MUHAMMAD

October 2016

Chairman : Professor Nor Azah Yusof, PhD
Faculty : Science

Antibiotic residues in milk are of great concern to health regulatory agencies, milk consumers and dairy farmers due largely to their effects ranging from allergic reactions, antibiotic resistance and ability to interfere with the technological properties of milk used for manufacturing fermented products. The conventional methods used in detecting these residues suffered some limitations of being expensive, time consuming and lack the capacity for point of care analysis.

A bulk scale synthesis of nanocomposites containing gold nanoparticles (AuNPs) and multi-walled carbon nanotubes (MWCNTs) using ethylenediamine (en) as a cross linker between MWCNTs and AuNPs is presented here. The amine groups in en were used as growth point for the AuNPs synthesis through electrostatic attraction between the amine group (NH_4^+) and $AuCl_4^-$ while sodium citrate acts as a reducing agent. The results showed that the size and distribution of AuNPs on the surface of the MWCNTs is greatly affected by the amount of $HAuCl_4$. Morphology of the synthesized nanocomposites was characterized by Field Emission Scanning Electron Microscopy and Transmission Electron Microscopy while the elemental composition and crystallography of the composites were investigated by Energy Dispersive X-ray, X-ray Diffraction, Ultraviolet Visible, Thermal Gravimetric Analysis and Raman spectroscopic techniques. The nanocomposite was used to modify a screen printed electrode. Electrochemical characterization of the electrode revealed that the nanocomposites have increased its electro-active surface area and conductivity. The fabricated sensor was applied for the voltammetric detection of amoxicillin in Bovine milk samples by adsorptive stripping voltammetry (AdSV). The result shows that the synthesized nanocomposites had induced a remarkable synergetic effect towards electro-oxidation of amoxicillin. Under optimized experimental conditions, (0.1 M phosphate buffer of pH 7.0, accumulation potential -0.4 V, accumulation time 180 s.) AdsV measurements of amoxicillin showed a wide linear dynamic range within the

concentration range of 0.2-30 µM. Two linear calibration ranges from 0.2-10 µM and 10-30 µM were observed with equations of I_{pa} (µA) = 2.88 C (µM) + 1.2017; r = 0.9939 and I_{pa} (µA) = 0.88 C (µM) + 22.97; r = 0.9973 respectively. The limit of detection (LOD) and limit of quantification (LOQ) were calculated as 0.015 µM and 0.149 µM, respectively. Differential pulse voltammetric technique (DPV) was employed for thiamphenicol detection. The result shows that the synthesized nanocomposites also induced a remarkable synergetic effect for the oxidation of thiamphenicol. Under optimized experimental conditions, (0.1 M citrate buffer of pH 6.0, accumulation potential -0.7 V, accumulation time 150 s). DPV measurements of thiamphenicol shows a wide linear dynamic range within the concentration range of 0.1-30 µM. Two linear ranges were recorded from 0.1- 10 µM and 10-30 µM with equations of I_{pa} (µA) = 0.9888 C (µM) + 1.2563; r = 0.9939 and I_{pa} (µA) = 0.216 C (µM) + 7.36; r= 0.9973 with LOD and LOQ of 0.003 µM and 0.01.0 µM respectively. The fabricated sensor was applied for determination of amoxicillin and thiamphenicol in Bovine milk with satisfactory recovery results which compared favorably with HPLC standard method. This suggests its applicability as an alternative means of detecting amoxicillin and thiamphenicol in Bovine milk samples for environmental monitoring and quality control processes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah.

FABRIKASI PENDERIA ELEKTROKIMIA BERASASKAN TIUB NANO KARBON PELBAGAI DINDING /NANOPARTIKEL EMAS UNTUB PENGESANAN VOLTAMMETRI SISA AMOXICILLIN DAN THIAMPHENICOL DIDALAM SUSU LEMBU

Oleh

ALIYU MUHAMMAD

Oktober 2016

Pengerusi : Profesor Nor Azah Yusof, PhD
Fakulti : Sains

Sisa antibiotik dalam susu adalah suatu kebimbangan kepada agensi-agensi kawal selia kesihatan, pengguna susu dan penternak tenusu dan sebahagian besarnya adalah disebabkan oleh kesan yang terdiri daripada reaksi alahan, rintangan antibiotik dan kesan terhadap teknologi susu digunakan untuk mengeluarkan produk-produk ditapai. Kaedah konvensional yang digunakan dalam mengesan sisa-sisa ini mempunyai beberapa kelemahan seperti mahal, memakan masa dan tidak boleh digunakan untuk analisis POC (Point of Care). Sintesis untuk nanokomposit mengandungi partikel nano emas (AuNPs) dan tiub nano karbon pelbagai berdinding (MWCNTs) menggunakan ethylenediamine (en) sebagai pemaut kacukan antara MWCNTs dan AuNPs adalah dibentangkan di sini. Kumpulan-kumpulan amina dalam en telah digunakan sebagai titik pertumbuhan untuk sintesis AuNPs melalui tarikan elektrostatik antara kumpulan amina (NH_4^+) dan $AuCl_4^-$ manakala natrium sitrat digunakan sebagai agen penurunan. Hasil kajian menunjukkan bahawa saiz dan tebaran AuNPs pada permukaan MWCNTs sangat dipengaruhi oleh kandungan $HAuCl_4$. Morfologi nanokomposit yang disintesis dicirikan oleh *Field Emission Scanning Electron Microscopy* (FESEM) dan *Transmission Electron Microscopy* (TEM) manakala komposisi unsur dan kristalografi bagi komposit telah dikaji menggunakan *X-ray Diffraction* (XRD), *UV-Visible*, *Thermal Gravimetric* (TG) dan Raman. Nanokomposit digunakan untuk mengubahsuai elektrod skrin dicetak. Pencirian elektrokimia elektrod mendedahkan bahawa nanokomposit telah meningkatkan luas permukaan dan kekonduksian elektro-aktif. Penderia yang direka telah digunakan untuk pengesanan amoxicillin dalam sampel susu lembu dengan menggunakan *Adsorptive Stripping Voltammetry* (AdSV). Hasil kajian menunjukkan bahawa nanokomposit disintesis telah didorong kesan sinergi yang luar biasa ke arah elektro-pengoksidaan amoxicillin. Di bawah keadaan kajian dioptimumkan, (0.1 M penimbal fosfat pH 7.0, pengumpulan berpotensi -0.4 V, masa pengumpulan 180 s), AdsV amoxicillin menunjukkan julat dinamik linear yang luas dalam julat kepekatan 0.2-30 mikroMolar. Dua penentukuran linear antara

0.2-10 µM dan 10-30 µM diperhatikan dengan persamaan Ipa (A) = 2.88 C (µM) + 1.2017; r = 0.9939 dan Ipa (A) = 0.88 C (µM) + 22.97; r = 0.9973 masing-masing. Had pengesanan (LOD) dan had kuantifikasi (LOQ) dikira sebagai 0.015 µM dan 0,149 µM, masing-masing. Teknik *Different Pulse Voltammetry* (DPV) telah digunakan untuk mengesan thiamphenicol. Hasil kajian menunjukkan bahawa nanokomposits disintesis juga menyebabkan kesan sinergi yang luar biasa untuk pengoksidaan thiamphenicol. Di bawah keadaan optimum, (0.1 M sitrat penampan pH 6.0, pengumpulan berpotensi -0.7 V, masa pengumpulan 150 s), ukuran DPV daripada thiamphenicol menunjukkan julat dinamik linear yang luas dalam julat kepekatan 0.1-30 µM. Dua julat linear direkodkan daripada 0.1- 10 µM dan 10-30 µM dengan persamaan Ipa (A) = 0.9888 C (µM) + 1,2563; r = 0.9939 dan Ipa (A) = 0.216 C (µM) + 7.36; r = 0,9973 dengan masing-masing LOD dan LOQ daripada 0.003 µM dan 0.01.0 µM. Penderia direka telah digunakan untuk menentukan amoxicillin dan thiamphenicol dalam susu lembu dengan hasil pemulihan memuaskan yang baik berbanding dengan kaedah piawai HPLC. Ini menunjukkan kesesuaiannya sebagai satu alternatif untuk mengesan amoxicillin dan thiamphenicol dalam sampel susu lembu untuk pemantauan alam sekitar dan proses kawalan kualiti.

ACKNOWLEDGEMENTS

Let me start by expressing my deep sense of appreciation to my supervisory team chaired by Professor Dr. Nor Azah Yusof supported by Dr. Reza Hajian and Dr. Jaafar Bin Abdullah. The guidance and support received from the team is enormous and largely rewarding, the humility and open-mindedness of members of the supervisory team throughout my studentship will forever be remembered. I therefore say a big thanks and God bless.

The enabling environment provided by Universiti Putra Malaysia and its staff deserve to be mentioned and appreciated. In particular, I am indebted to all the staff of Universiti Putra Malaysia in the Department of Chemistry, Institute of Advanced Technology, School of Graduate Studies and Sultan Abdussamad Library.

This work may not have been possible without the prayers, support and encouragement from my beloved parents May Allah (S.W.T) reward them abundantly. Word cannot be enough to express my appreciation to my beloved wife Maryam D and my daughters Nusaiba and Hafsat Aliyu for their prayers and encouragement. A warm appreciation to my supporting and wonderful brothers and sisters; Hassan and Hussaini Muhammad, Rabi, Hauwau, Maryam, Zainab, Hasiya Saratu and Khadiza Muhammad to mention but a few for their assistance.

The support received from my laboratory mates and sensor research group members with whom I traveled with, in this long journey is highly appreciated. My friends and well-wishers in Universiti Putra Malaysia are numerous but I would like to specifically mention and appreciate the contributions of Dr. Muhammad Gidado Liman, Dr. Saifullahi Bullo, Hajiya Hannatu Abubakar Sani, Malam Danlami Umar Zuru, Malam Suleiman Fowotade, Malam Suleiman Salihu, Malam Faruk Sani, Malam Aminu Musa Yar adua, Ibrahim Birma Bwatanglang, Malam Yahaya Kaka, Malam Abubakar Umar Birnin-Yauri, Boshra, Hazani, Fuzi, Nur Hidayah Azeman, (miss) Nafiseh Shams (Mrs), Nur Hidayah Yusof (miss) and Syamimi Suleiman (miss). To all of them and the countless others which time and space could not allow me to mention. I am grateful and pray for your success in this life and the next to come.

My profound gratitude goes to the management of Kebbi State University of Science and Technology, Aliero for sponsoring my study.

I certify that a Thesis Examination Committee has met on 19 October 2016 to conduct the final examination of Aliyu Muhammad on his thesis entitled "Fabrication of Electrochemical Sensor Based on Multi-Walled Carbon Nanotubes/Gold Nanoparticles for Voltammetric Detection of Amoxicillin and Thiamphenicol Residues in Bovine Milk" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Tan Kar Ban, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Zulkarnain bin Zainal, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Tan Yen Ping, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Werasak Surareungchai, PhD
Associate Professor
University of Technology Thonburi
Thailand
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 27 December 2016

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Nor Azah Yusof, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Reza Hajian, PhD
Assistant Professor
Institute of Advanced Technology
Universiti Putra Malaysia
(Member)

Jaafar Abdullahi, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: _____ Date: _____

Name and Matric No: Aliyu Muhammad

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Professor Dr. Nor Azah Yusof

Signature: _____
Name of Member of Supervisory Committee: Assistant Professor Dr. Reza Hajian

Signature: _____
Name of Member of Supervisory Committee: Dr. Jaafar Abdullahi

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AdSV	Adsorptive Stripping Voltammetry
Amox	Amoxicillin
ASV	Anodic Stripping Voltammetry
CE	Counter Electrode
CGME	Control Growth Mercury Electrode
CME	Chemically Modified Electrode
CNTs	Carbon Nanotubes
CSV	Carthodic Stripping Voltammetry
CV	Cyclic Voltammetry
DPV	Differential Pulse Voltammetry
EDX	Energy Dispersive X ray
EIS	Electrochemical Impedance Spectroscopy
En	Ethylediamine
FESEM	Field Emission Scanned Electron Microscopy
HPLC	Higher Performance Liquid Chromatography
LOD	Limit of Detection
LOQ	Limit of Quantification
MWCNT	Multi-Walled Carbon Nanotunes
NPs	Nanoparticles
RE	Reference Electrode
SPE	Screen Printed Electrode
SPR	Surface Plasmon Resonance
SWCNTs	Single Walled Carbon Nanotubes
TAP	Thiamphenicol

TEM	Transmission Electron Microscopy
UV-Vis	Ultraviolet Visible
WE	Working Electrode
WIGE	Wax Impregnated Graphite Electrode
XRD	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Over the years, different brands of antibiotics have been synthesized for antibacterial purposes, which played major roles in the field of medicine for the treatment of diseases. Antibiotics have been used to treat wide variety of infectious diseases caused by bacteria in both human and animals which results in saving lives and money. The discovery of these drugs has revolutionized the medical sector in terms of health care delivery, thereby making a turning-point in human history. Unfortunately, the use of these medically and economically benign drugs has been abused by the same beneficiaries (i.e human being) through misapplication in veterinary practice. Antibiotics are used for the treatment of bacterial infections and as feed additives in veterinary practice, remnant of these drugs can be found in edible products of animal origin, which are linked to the emergence of allergic reactions, antibiotic resistance and other related health issues (Aerts et al., 1995; Reeves, 2011).

The use of antibiotics in animal production has increased to the extent that about 80 % of all animals produced for food purposes received medication at one point of their life or the other. It is presumed that in the near future nearly all animals in the world that are meant for food production will have received a veterinary drug for one purpose or the other (Lee et al., 2001). The use of these veterinary drugs has attracted serious public attention due largely to their continuous residue in animal tissues.

The primary concern of the public regarding drugs residues in food products of animal origin is the potential of the residues to pose health threats and economic lost. This public awareness and concern have made it crucial that marketed products of veterinary origin should be free of antibiotic residues (Irum et al., 2014).

Quality management in food analysis is designed to ensure that reliable food items are supplied to consumers. Therefore, the primary goal of national and international regulatory frameworks for the use of veterinary drugs in food producing animals is to ensure that authorized products are used in a manner that will not lead to non-compliance residues. To achieve this, government agencies and international bodies have established standard guidelines and regulations that food producers and trade partners need to meet safeguard and adhere, in order to ensure food safety. However, analytical methods are required to rapidly and accurately detect, quantify and confirm that antibiotic residues in food have met the regulatory standards and to remove products that do not comply with these safety standards from circulation. (Reeves, 2011).

1.2 Antibiotics

Antibiotics are drugs of natural or synthetic origin that have the capacity to kill or inhibit the growth of microorganisms. They are known to have the potentials of slowing down or totally eradicating the multiplication of bacteria (Kümmerer, 2009). Antibiotics have been used in the veterinary industry for decades, being used for prophylactic purpose to prevent diseases, therapeutic purpose to treat diseases and also serves as feed additives to improve growth, breeding performance and enhance milk or meet production (Dasenaki & Thomaidis, 2015; Stolker et al., 2007; Barton, 2000; Lee et al., 2001). Antibiotics are administered to animals by different methods namely; through injections (intramuscular, intravenous, or subcutaneous), orally, topically, via intra-mammary or intra-uterine infusion (Kantiani et al., 2009). The use of these drugs in food producing animals is of concern since they tend to leave antibiotic residues that can be found in different concentration in products of animal origin. Presence of these residues above the maximum residue limit (MRL) accepted by standard health regulatory agencies is of concern since they get into human system through the food chain, thereby posing potential health hazards (Dayan, 1993).

1.2.1 Antibiotic residue in products of animal origin

An antibiotic residue is either a parent compound or its metabolites that deposit or accumulate within the organ, tissue, cells or edible products (e.g. milk, meat, egg) of animal resulting from its use for therapeutic, prophylactic or as feed additive (Lee et al.,2001). Depending on the time-span between administration of the antibiotic and the collection of the animal product (i.e. withdrawal time, which is the time between the administration of the drug and the time its concentration is supposed to be depleted to tolerable limit), drug residues may be present in these products, because farmers are eager to get money they most often collect products from these animals after drug administration without observing the withdrawal period (Cow et al., 2010).

Another factor which led to the presence of residue in animal products is the route of administration of the drugs, sometimes farmers tend to administer drugs to animals contrary to specification (i.e. off label usage) (Stolker et al., 2007; van der Kreek, 1984), for instance, a drug meant to be administered through the vein (intravenous) is administered through the muscles (intramuscular) because intravenous involved some technicalities which required a veterinary expert. But farmers administer the drug through the muscles in order to avoid professional expenses of the veterinary expert so, as to avoid spending more money if they are to employ the services of an expert, the time taken for a drug administered through the vein to break down to lower concentration is less compared to the one administered through the muscle. So this practice can leads to antibiotic residues.

Physical condition of the animal is also a factor that can lead to drug residue in animal products (Aerts, et al., 1995), owing to the diminishing rate at which living organism eat and drink water whenever the organism is disease-ridden (Stuttgen, 2011). So, even if the drugs were administered according to specification, and the withdrawal time is observed there may still be residues since metabolism in the animal's body will

be minimal resulting from lower feeding habit which automatically affect the rate at which the drug is broken down. Present of these antibiotic residues in product of animal origin is of concern because they poses health hazards and economic loses to milk users (Novais et al., 2010; Adrian et al., 2009).

1.2.2 Amoxicillin

Amoxicillin (Amox) (2S,5R,6R)-6{[(2R)-2-amino-2-(4-hydroxylphenyl)-acetyl]amino}-3,3-dimethyl-7-oxo-4-thia-1-azabicyclo[3.2.0]heptane-2-carboxylic acid), with a molecular formula of $C_{16}H_{19}N_3O_5S$ and Molecular weight of 365 g/mol, is quite soluble in water, methanol, and slightly soluble in ethanol (Ahmed, et al., 2011), it belongs to the β-lactam group of antibiotics and like all other members of this group, Amox structure (Fig. 1.1) contains a β-lactam ring which is responsible for its anti-bacterial property but differs from other members of the group by the side-chain which account for the major differences in their chemical and pharmacological properties (Akhond et al., 2015). Amox is the only phenolic penicillin β- lactam antibiotic (Ojani et al., 2012). It has higher ability of getting absorbed via oral administration, it is quickly distributed through the body and is resistance to acid produced in the stomach (Kantiani et al., 2010). It is used to treat bacterial infections caused by susceptible micro-organisms It is the drug of choice within the class, because it is better absorbed following oral administration, and it acts by inhibiting the cross-linkage between the linear peptidoglycan polymer chains that makes up the bacterial cell wall (Irum et al., 2014; Ahmed et al., 2011; Uslu & Biryol, 1999).

In both clinical and veterinary practice, amox is used to treat many types of infections caused by bacteria such as acute exacerbations of chronic bronchitis, pneumonia, gonorrhea, skin and urinary tract infections (Dhoka & Gawande, 2010).

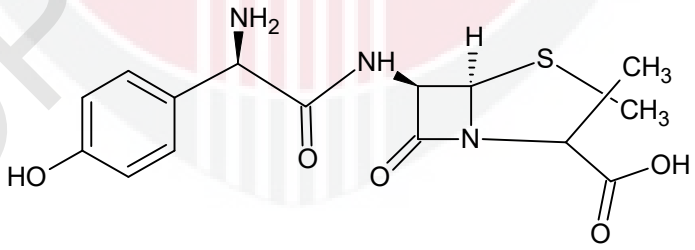

Figure 1.1 : Chemical structure of Amox.

1.2.3 Thiamphenicol

Thiamphenicol (TAP) [D-threo-2,2-dichloro-N-β-hydroxy-a-(hydroxymethyl)-p-(methyl-sulphonyl)-phenethyl acetamide], with a molecular formular of $C_{12}H_{15}Cl_2NO_5S$ and molecular weight of 356 g/mol is an analogue of chloramphenicol in which the nitro group on the benzene ring is replaced with a methyl sulfonic group (Kowalski, 2007; Chen et al.,2006) (Fig.1. 2).

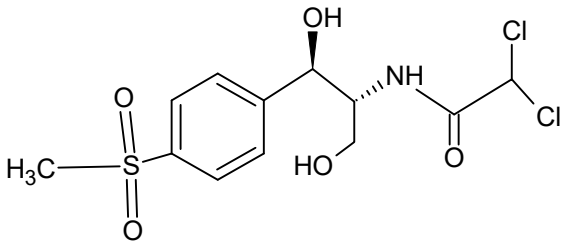

Figure 1.2 : Chemical Structure of Thiamphenicol

It is a broad-spectrum bacteriostatic antibiotic, active against both Gram-positive and Gram-negative pathogens (Hajra et al., 2006). At a sub-cellular level, TAP inhibits the protein synthesis joining the ribosomes and thus preventing the binding of the amino acid with peptidyl transferase (Kowalski, 2007).

TAP has been used for therapeutic purpose in both clinical and veterinary practice (Shinohara, et al., 2009). In human being, it is used for the treatment of sexually transmitted infections and pelvic inflammatory diseases while in livestock it is used in the treatment of wide range of respiratory and alimentary tract infections of bacterial origin (Kowalski, 2007).

1.3 Electrochemical techniques

Electrochemical techniques are powerful and wide range analytical techniques which are based on electrical properties of analytes in electrochemical cell. The technique offers a higher degree of sensitivity, accuracy, precision as well as a wider linear dynamic range, with relatively low-cost instrumentation (Özkan et al., 2003). These techniques make measurements based on the conductive property of the electrodes that makes up the electrochemical cell. Electrochemical measurements are two-dimensional, with the potential being related to qualitative properties and the current related to quantitative properties (Özkan et al., 2003). The techniques have the advantage of simplicity, fastness with ability to carrying out experiments with less-expensive equipment. They are capable of detecting analytes at a very low concentrations, they are selective making it possible to determine a specific analyte even in the presence of some common interfering species due to their high selectivity (Alizadeh et al., 2012).

1.4 Problem statement

The use of antibiotics for the treatment and prevention of diseases as well as growth enhancement in food producing animals have proved to be a great achievement in the field of veterinary practice, because it saved money and increased profit of dairy farmers. Amox is one of the most commonly use antibiotic, it is usually the drug of choice within the β-Lactam class because it is better absorbed following oral administration (Ahmed et al., 2011; Ojani et al., 2012), it is widely used in veterinary practice for the treatment and prevention of respiratory, gastrointestinal, urinary and

skin bacterial infections due to its pharmacological and pharmacokinetic properties, it is also approved for use in lactating dairy cows by intra-mammary infusion (Irum et al., 2014).

TAP is another antibiotic used for the treatment of bacterial infections, it is active against both Gram-positive and Gram-negative pathogens and specifically effective against anaerobic organisms(Kowalski, 2007). TAP is used in place of chloramphenicol which had been linked to aplastic anemia due to the presence of nitro group in its structure which have been replaced in TAP by a methylsulphonyl group (Kowalski, 2007). The use of these drugs also come with a price since not all the drugs administered or given to animals are completely metabolized, they end-up leaving residues that can be found in products of animal origin. The presence of these residues above the maximum residue limit (MRL) in product of veterinary origin is of concern because they poses health hazards to consumers ranging from allergic reactions to the development of mechanisms of antibiotic resistance (Kantiani et al., 2009). They also create economic losses by the inhibitory effect they produced in the fermentation processes in production of cultured milk products such as cheese and yoghurt (Conzuelo et al., 2014).

The conventional methods used for the detection of these antibiotics in products of animal origin, though they have the advantage of accuracy, suffered the disadvantages of being time consuming, expensive and large size which hinder their application for on-site monitoring/analysis (Alizadeh et al., 2012). Some of the methods also present the necessity for large amount of high purity organic solvents, long equilibration and derivatization treatment (Rezaei and Damiri, 2009; Ojani et al., 2012).

Electrochemical techniques have emerged as alternative ways of detecting antibiotics in real samples, due to their exceptional properties which include; simplicity, sensitivity, selectivity, fastness, low cost instrumentation and portability that makes them suitable for on-site/point of care application (Cosofret et al., 1995; Ojani et al., 2012).

Previous works have reported high detection limit of these drugs i.e amoxicillin in different real samples (Uslu and Biryol, 1999; Santos, et al., 2008; Ojani et al., 2012). Therefore, devising an electrochemical method of higher sensitivity, selectivity with lower detection limit for the detection of these antibiotics (i.e. Amox and TAP) whose residues are associated with different problems to the user of milk of veterinary origin is research-worthy.

Although, substantial reports are available on the decoration of carbon nanotubes with gold nanoparticles but the use of refluxing method to construct a nanohybrid based on multi-walled carbon nanotubes and gold nanoparticles with ethylenediamine as a cross linker and its use in fabrication of electrochemical sensor for the detection of amoxicillin and thiamphenicol residues in bovine milk is not reported.

1.5 Objectives of the study

This work is aimed at developing a simple and sensitive electrochemical sensor for voltammetric detection of antibiotics in bovine milk. The detection and selectivity of the proposed sensor is based on the incorporation of multi-walled carbon nanotubes and gold nanoparticles to form nanocomposites having synergetic properties capable of enhancing the electrochemical performance of the proposed sensor towards detection of the said antibiotics in Bovine milk.

The main objective of this work is to develop an electrochemical sensor based on multi-walled nanotubes and gold nanoparticles for the detection of antibiotic residues in Bovine milk. To achieve this set objective, the following specific objectives are outlined:

i. To prepare and characterize nanocomposites based on multi-walled carbon nanotubes and gold nanoparticles via electroless deposition process.
ii. To apply the synthesized and characterized nanocomposites in fabricating electrochemical sensor and evaluate the electrochemical performance of the fabricated sensor by CV and EIS techniques and further test the electrochemical behavior of the analytes (Amox and TAP) towards the fabricated sensor.
iii. To optimize variable experimental conditions for improving the sensing capability of the fabricated sensors towards the detection of the said analytes.
iv. To apply the fabricated sensor under optimized experimental conditions for real sample analysis.
v. To validate the results obtained from the proposed method by High Performance Liquid Chromatographic technique.

REFERENCES

Abdelhalim, M. A. K., & M. Mady, M. (2012). Physical Properties of Different Gold Nanoparticles: Ultraviolet-Visible and Fluorescence Measurements. *Journal of Nanomedicine & Nanotechnology*, *03*(3), 1–5. doi:10.4172/2157-7439.1000133

Abo El-Maali, N. (2004). Voltammetric analysis of drugs. *Bioelectrochemistry*, *64*, 99–107. doi:10.1016/j.bioelechem.2004.03.003

Adrian, J., Font, H., Diserens, J. M., Sánchez-Baeza, F., & Marco, M. P. (2009). Generation of broad specificity antibodies for sulfonamide antibiotics and development of an enzyme-linked immunosorbent assay (ELISA) for the analysis of milk samples. *Journal of Agricultural and Food Chemistry*, *57*, 385–394. doi:10.1021/jf8027655

Aerts, M. M. L., Hogenboom, A. C., & Brinkman, U. A T. (1995). Analytical strategies for the screening of veterinary drugs and their residues in edible products. *Journal of Chromatography B: Biomedical Applications*, *667*, 1–40. doi:10.1016/0378-4347(95)00021-A

Afkhami, A., Khoshsafar, H., Bagheri, H., & Madrakian, T. (2014). Construction of a carbon ionic liquid paste electrode based on multi-walled carbon nanotubes-synthesized Schiff base composite for trace electrochemical detection of cadmium. *Materials Science and Engineering C*, *35*, 8–14. doi:10.1016/j.msec.2013.10.025

Afkhami, A., Soltani-Felehgari, F., & Madrakian, T. (2013). Gold nanoparticles modified carbon paste electrode as an efficient electrochemical sensor for rapid and sensitive determination of cefixime in urine and pharmaceutical samples. *Electrochimica Acta*, *103*, 125–133. doi:10.1016/j.electacta.2013.04.064

Ahammad, A. J. S., Lee, J.-J., & Rahman, M. A. (2009). Electrochemical Sensors Based on Carbon Nanotubes. *Sensors*, *9*, 2289–2319. doi:10.3390/s90402289

Ahmadzadeh Tofighy, M., & Mohammadi, T. (2012). Nitrate removal from water using functionalized carbon nanotube sheets. *Chemical Engineering Research and Design*, *90*(11), 1815–1822. doi:10.1016/j.cherd.2012.04.001

Ahmed, M., Babu, S., & Shetty, S. (2011). Development and validation of Amoxicillin by RP-HPLC method in bulk drug and pharmaceutical dosage forms. *International Journal of Chem. Tech Research*, *3*(3), 1037–1041. Retrieved from http://scholar.google.com/scholar.

Ajayan P. M. Aneix, J. M. P, Coustel, N. Coq, B. Brotons, V. Kumbhar, P. S. Dutartre, R. Geneste, P. Bernier, P. . (1994). Application of Carbon Nanotubes as Supports in Heterogeneous Catalysis. *Journal of the American Chemical Society*, *116*(17), 7935–7936.

Ajayan, P. M., & Zhou, O. Z. (2001). Applications of Carbon Nanotubes. *Most*, *425*, 391–425. doi:10.1007/978-1-61779-052-2_15

Akhond, M., Absalan, G., & Ershadifar, H. (2015). Highly sensitive colorimetric determination of amoxicillin in pharmaceutical formulations based on induced aggregation of gold nanoparticles. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *143*, 223–229. doi:10.1016/j.saa.2015.01.071

Alizadeh, T., Ganjali, M. R., Zare, M., & Norouzi, P. (2012). Selective determination of chloramphenicol at trace level in milk samples by the electrode modified with molecularly imprinted polymer. *Food Chemistry*, *130*(4), 1108–1114. doi:10.1016/j.foodchem.2011.08.016

Arduini, F., Zanardi, C., Cinti, S., Terzi, F., Moscone, D., Palleschi, G., & Seeber, R. (2015). Effective electrochemical sensor based on screen-printed electrodes modified with a carbon black-Au nanoparticles composite. *Sensors and Actuators B: Chemical*, *212*, 536–543. doi:10.1016/j.snb.2015.02.051

Bagheri, H., Afkhami, A., Panahi, Y., Khoshsafar, H., & Shirzadmehr, A. (2014). Facile stripping voltammetric determination of haloperidol using a high performance magnetite/carbon nanotube paste electrode in pharmaceutical and biological samples. *Materials Science and Engineering: C*, *37*, 264–270. doi:10.1016/j.msec.2014.01.023

Bao, Y., Shen, G., Liu, H., & Li, Y. (2013). Fabrication of gold nanoparticles through autoreduction of chloroaurate ions by thermo- and pH-responsive amino acid-based star-shaped copolymers. *Polymer (United Kingdom)*, *54*(2), 652–660. doi:10.1016/j.polymer.2012.12.040

Barton, M. D. (2000). Antibiotic use in animal feed and its impact on human healt. *Nutrition Research Reviews*, *13*, 279–299. doi:10.1079/095442200108729106

Bobrowski, A., Królicka, A., Maczuga, M., & Zarębski, J. (2014). A novel screen-printed electrode modified with lead film for adsorptive stripping voltammetric determination of cobalt and nickel. *Sensors and Actuators, B: Chemical*, *191*, 291–297. doi:10.1016/j.snb.2013.10.006

Borowiec, J., Wang, R., Zhu, L., & Zhang, J. (2013). Synthesis of nitrogen-doped graphene nanosheets decorated with gold nanoparticles as an improved sensor for electrochemical determination of chloramphenicol. *Electrochimica Acta*, *99*, 138–144. doi:10.1016/j.electacta.2013.03.092

Brahman, P. K., Dar, R. A., & Pitre, K. S. (2013). Conducting polymer film based electrochemical sensor for the determination of amoxicillin in micellar media. *Sensors and Actuators B: Chemical*, *176*, 307–314. doi:10.1016/j.snb.2012.09.007

Britto, P. J., Santhanam, K. S. V, & Ajayan, P. M. (1996). Carbon nanotube electrode for oxidation of dopamine. *Bioelectrochemistry and Bioenergetics*, *41*, 121–125. doi:10.1016/0302-4598(96)05078-7

Britto, P. J., Santhanam, K. S. V, Rubio, A., Alonso, J. A, & Ajayan, P. M. (1999). Improved Charge Transfer at Carbon Nanotube Electrodes. *Advanced Materials*, *11*(2), 154–157. doi:10.1002/(SICI)1521-4095(199902)11:2<154::AID-ADMA154>3.0.CO;2-B

Brooks, M. A., Hackman, M. R., & Mazzo, D. J. (1981). Determination of Amoxicillin by HPLC with Amperometric detection. *J. Chromatography*, *10*(210), 531 – 535.

Buck, R. P., & Lindner, E. (1998). Studies of Potential Generation Across Membrane Sensors at Interfaces and through Bulk. *Accounts of Chemical Research*, *31*(5), 257–266. doi:10.1021/ar9700623

Chen, J., & Lu, G. (2007). Carbon Nanotube-Nanoparticle Hybrid Structures, 611–635.

Chen, X., Yang, B., Ni, L., & Wang, G. (2006). Simultaneous analysis of thiamphenicol and its prodrug thiamphenicol glycinate in human plasma and urine by high performance liquid chromatography: Application to pharmacokinetic study. *Journal of Pharmaceutical and Biomedical Analysis*, *41*, 943–949. doi:10.1016/j.jpba.2006.01.038

Conzuelo, F., Ruiz-Valdepe??as Montiel, V., Campuzano, S., Gamella, M., Torrente-Rodruguez, R. M., Reviejo, a. J., & Pingarruun, J. M. (2014). Rapid screening of multiple antibiotic residues in milk using disposable amperometric magnetosensors. *Analytica Chimica Acta*, *820*, 32–38. doi:10.1016/j.aca.2014.03.005

Cosofret, V. V., Erdosy, M., Johnson, T. a., Buck, R. P., Ash, R. B., & Neuman, M. R. (1995). Microfabricated Sensor Arrays Sensitive to pH and K+ for Ionic Distribution Measurements in the Beating Heart. *Analytical Chemistry*. doi:10.1021/ac00106a001

Cow, A. D., Cow, A. D., Cow, C. D., Enduro, O., Laboratories, N., Health, A., & Health, P. A. (2010). What are the withholding periods for antibiotics used for mastitis treatment ? Withholding periods, 1–2.

Dago, À., Navarro, J., Ariño, C., Díaz-Cruz, J. M., & Esteban, M. (2015). Carbon nanotubes and graphene modified screen-printed carbon electrodes as sensitive sensors for the determination of phytochelatins in plants using liquid chromatography with amperometric detection. *Journal of Chromatography A*, *1409*, 210–217. doi:10.1016/j.chroma.2015.07.057

Damian, C. M., Garea, S. A., Vasile, E., & Iovu, H. (2012). Covalent and non-covalent functionalized MWCNTs for improved thermo-mechanical properties of epoxy composites. *Composites Part B: Engineering*, *43*(8), 3507–3515. doi:10.1016/j.compositesb.2011.11.052

Dasenaki, M. E., & Thomaidis, N. S. (2015). Multi-residue determination of 115 veterinary drugs and pharmaceutical residues in milk powder, butter, fish tissue and eggs using liquid chromatography-tandem mass spectrometry. *Analytica Chimica Acta*, *880*, 103–21. doi:10.1016/j.aca.2015.04.013

Dayan, A. D. (1993). Allergy to antimicrobial residues in food: assessment of the risk to man. *Veterinary Microbiology*, *35*, 213–26. doi:10.1016/0378-1135(93)90146-X

Deng, P., Xu, Z., Zeng, R., & Ding, C. (2015). Electrochemical behavior and voltammetric determination of vanillin based on an acetylene black paste electrode modified with graphene-polyvinylpyrrolidone composite film. *Food Chemistry*, *180*, 156–63. doi:10.1016/j.foodchem.2015.02.035

Dhall, S., & Jaggi, N. (2015). Room temperature hydrogen gas sensing properties of Pt sputtered F-MWCNTs/SnO2 network. *Sensors and Actuators, B: Chemical*, *210*, 742–747. doi:10.1016/j.snb.2015.01.031

Doak, J., Gupta, R. K., Manivannan, K., Ghosh, K., & Kahol, P. K. (2010). Effect of particle size distributions on absorbance spectra of gold nanoparticles. *Physica E: Low-Dimensional Systems and Nanostructures*, *42*(March), 1605–1609. doi:10.1016/j.physe.2010.01.004

Doyen, M., Goole, J., Bartik, K., & Bruylants, G. (2016). Amino acid induced fractal aggregation of gold nanoparticles: Why and how. *Journal of Colloid and Interface Science*, *464*, 60–166. doi:10.1016/j.jcis.2015.11.017

Du, P., Liu, S., Wu, P., & Cai, C. (2007). Preparation and characterization of room temperature ionic liquid/single-walled carbon nanotube nanocomposites and their application to the direct electrochemistry of heme-containing proteins/enzymes. *Electrochimica Acta*, *52*, 6534–6547. doi:10.1016/j.electacta.2007.04.092

Ellis, A. V., Vijayamohanan, K., Goswami, R., Chakrapani, N., Ramanathan, L. S., Ajayan, P. M., & Ramanath, G. (2003). Hydrophobic anchoring of monolayer-protected gold nanoclusters to carbon nanotubes. *Nano Letters*, *3*, 279–282. doi:10.1021/nl025824o

Elouarzaki, K., Mandoc, L.-R. P., Gorgy, K., Holzinger, M., Amarandei, C.-A., Ungureanu, E.-M., & Cosnier, S. (2015). Synthesis and electrochemical characterization of original "TEMPO" functionalized multiwall carbon nanotube materials: Application to iron (II) detection. *Electrochemistry Communications*, *60*, 131–134. doi:10.1016/j.elecom.2015.08.024

Freitas, T. A, Mattos, A. B., Silva, B. V. M., & Dutra, R. F. (2014). Amino-functionalization of carbon nanotubes by using a factorial design: human cardiac troponin T immunosensing application. *BioMed Research International*, *2014*, 929786. doi:10.1155/2014/929786

Gan, T., Shi, Z., Sun, J., & Liu, Y. (2014). Simple and novel electrochemical sensor for the determination of tetracycline based on iron/zinc cations-exchanged montmorillonite catalyst. *Talanta*, *121*, 187–193. doi:10.1016/j.talanta.2014.01.002

Georgakilas, V., Gournis, D., Tzitzios, V., Pasquato, L., Guldi, D. M., & Prato, M. (2007a). Decorating carbon nanotubes with metal or semiconductor nanoparticles. *Journal of Materials Chemistry*, *17*, 2679. doi:10.1039/b700857k

Georgakilas, V., Gournis, D., Tzitzios, V., Pasquato, L., Guldi, D. M., & Prato, M. (2007b). Decorating carbon nanotubes with metal or semiconductor nanoparticles. *Journal of Materials Chemistry*, *17*, 2679. doi:10.1039/b700857k

Ghadimi, H., Tehrani, R. M. A, Ali, A. S. M., Mohamed, N., & Ab Ghani, S. (2013). Sensitive voltammetric determination of paracetamol by poly (4-vinylpyridine)/multiwalled carbon nanotubes modified glassy carbon electrode. *Analytica Chimica Acta*, *765*, 70–76. doi:10.1016/j.aca.2012.12.039

Ghodselahi, T., Aghababaie, N., Mobasheri, H., & Salimi, K. Z. (2015). Applied Surface Science Fabrication and characterization and biosensor application of gold nanoparticles on the carbon nanotubes. *Applied Surface Science*, *355*, 1175–1179. doi:10.1016/j.apsusc.2015.07.092

Gong, K., Dong, Y., Xiong, S., Chen, Y., & Mao, L. (2004). Novel electrochemical method for sensitive determination of homocysteine with carbon nanotube-based electrodes. *Biosensors and Bioelectronics*, *20*, 253–259. doi:10.1016/j.bios.2004.01.014

Gong, K. P., Yan, Y. M., Zhang, M. N., Su, L., Xiong, S. X., & Mao, L. Q. (2005). Electrochemistry and electroanalytical applications of carbon nanotubes: A review. *Analytical Sciences*, *21*(December), 1383–1393. doi:10.2116/analsci.21.1383

Goornavar V.A B., Jeffers, R. . C. B. S. . R. G. T. . B. (2014). Utilization of highly purified single wall carbon nanotubes dispersed in polymer thin films for an improved performance of an electrochemical glucose sensor. *Materials Science and Engineering C*, *40*, 299–307. doi:10.1016/j.msec.2014.04.009

Goulart, L. A., de Moraes, F. C., & Mascaro, L. H. (2016). Influence of the different carbon nanotubes on the development of electrochemical sensors for bisphenol A. *Materials Science and Engineering: C*, *58*, 768–773. doi:10.1016/j.msec.2015.09.073

Gowda, J. I., & Nandibewoor, S. T. (2014). Electrochemical behavior of paclitaxel and its determination at glassy carbon electrode. *Asian Journal of Pharmaceutical Sciences*, *9*(1), 42–49. doi:10.1016/j.ajps.2013.11.007

Gregory G. Wildgoose, Craig E. Bank, R. G. C. (2006). Metal Nanoparticles and Related Materials Supported on Carbon Nanotubes: Methods and Applications. *Small*, *2*(2), 182–193.

Guo, Y., Guo, S., Fang, Y., & Dong, S. (2010). Gold nanoparticle/carbon nanotube hybrids as an enhanced material for sensitive amperometric determination of tryptophan. *Electrochimica Acta*, *55*(12), 3927–3931. doi:10.1016/j.electacta.2010.02.024

Gupta, V. K., Jain, R., Radhapyari, K., Jadon, N., & Agarwal, S. (2011). Voltammetric techniques for the assay of pharmaceuticals-A review. *Analytical Biochemistry*, *408*, 179–196. doi:10.1016/j.ab.2010.09.027

Gustavo A. Rivas, Nancy F. Ferreyra, M. D. R. (2009). *Nanotechnology Science and Technology Series Carbon Nanotubes : a New alternative for Electrochemical Sensors*. *New York* (p. 69).

Habibi, B., & Jahanbakhshi, M. (2014). Silver nanoparticles/multi walled carbon nanotubes nanocomposite modified electrode: Voltammetric determination of clonazepam. *Electrochimica Acta*, *118*, 10–17. doi:10.1016/j.electacta.2013.11.169

Hajian, R., Mehrayin, Z., Mohagheghian, M., Zafari, M., Hosseini, P., & Shams, N. (2015). Fabrication of an electrochemical sensor based on carbon nanotubes modified with gold nanoparticles for determination of valrubicin as a chemotherapy drug: Valrubicin-DNA interaction. *Materials Science and Engineering: C*, *49*, 769–775. doi:10.1016/j.msec.2015.01.072

Hajra, S., Karmakar, A., Maji, T., & Medda, A. K. (2006). Stereoselective syntheses of (-)-chloramphenicol and (+)-thiamphenicol. *Tetrahedron*, *62*, 8959–8965. doi:10.1016/j.tet.2006.07.014

Han, M., Jung, D., & Lee, G. S. (2014). Palladium-nanoparticle-coated carbon nanotube gas sensor. *Chemical Physics Letters*, *610-611*, 261–266. doi:10.1016/j.cplett.2014.07.053

Hanrahan, G., Patil, D., & Wang, J. (2004). Electrochemical sensors for environmental monitoring: design, development and applications. *Journal of Environmental Monitoring*, 657–664. Retrieved from http://pubs.rsc.org/en/content/articlehtml/2004/em/b403975k

Hatamie, A., Echresh, A., Zargar, B., Nur, O., & Willander, M. (2015). Fabrication and characterization of highly-ordered Zinc Oxide nanorods on gold/glass electrode, and its application as a voltammetric sensor. *Electrochimica Acta*, *174*, 1261–1267. doi:10.1016/j.electacta.2015.06.083

Hayat, A., & Marty, J. L. (2014). Disposable screen printed electrochemical sensors: Tools for environmental monitoring. *Sensors (Switzerland)*, *14*, 10432–10453. doi:10.3390/s140610432

Hou, X., Wang, L., Wang, X., & Li, Z. (2011). Coating multiwalled carbon nanotubes with gold nanoparticles derived from gold salt precursors. *Diamond and Related Materials*, *20*(10), 1329–1332. doi:10.1016/j.diamond.2011.09.003

Huang, Y. Y., & Terentjev, E. M. (2012). Dispersion of carbon nanotubes: Mixing, sonication, stabilization, and composite properties. *Polymers*, *4*, 275–295. doi:10.3390/polym4010275

Hulanicki, A., Glab, S., & Ingman, F. (1991). Chemical sensors: definitions and classification. *Pure and Applied Chemistry*. doi:10.1351/pac199163091247

Iijima, S. (1991). Helical microtubules of graphitic carbon. *Letters to Nature*. doi:10.1038/354056a0

Irum, A., Saeed, H., Shafaqat, A., Farid, M., Parveen, R., Maqbool, U., & Ahmad, R. (2014). Estimation of amoxicillin residues in commercial meat and milk samples. *Journal of Microbiology, Biotechnology and Food Sciences*, *4*, 48–50. doi:10.15414/jmbfs.2014.4.1.48-50

Islam, M. R., Bach, L. G., Nga, T. T., & Lim, K. T. (2013). Covalent ligation of gold coated iron nanoparticles to the multi-walled carbon nanotubes employing click chemistry. *Journal of Alloys and Compounds*, *561*, 201–205. doi:10.1016/j.jallcom.2013.01.176

Jiang, Z., Li, G., & Zhang, M. (2016). Electrochemical sensor based on electro-polymerization of β-cyclodextrin and reduced-graphene oxide on glassy carbon electrode for determination of gatifloxacin. *Sensors and Actuators B: Chemical*, *228*, 59–65. doi:10.1016/j.snb.2016.01.013

Kannan, P., Yoon, C., Yi, S., Yong, S., & Kim, D. (2015). Shape-controlled synthesis of gold e nickel bimetallic nanoparticles and their electrocatalytic properties. *Materials Chemistry and Physics*, *156*, 1–8. doi:10.1016/j.matchemphys.2015.02.010

Kantiani, L., Farré, M., Barceló, D., & Barceló, D. (2009). Analytical methodologies for the detection of β-lactam antibiotics in milk and feed samples. *TrAC - Trends in Analytical Chemistry*, *28*(6), 729–744. doi:10.1016/j.trac.2009.04.005

Kantiani, L., Farre, M., Freixiedas, J. M. G. I., & Barcelo, D. (2010). Development and validation of a pressurised liquid extraction liquid chromatography-electrospray-tandem mass spectrometry method for ??-lactams and sulfonamides in animal feed. *Journal of Chromatography A*, *1217*, 4247–4254. doi:10.1016/j.chroma.2010.04.029

Kongkanand, A., Vinodgopal, K., Kuwabata, S., & Kamat, P. V. (2006). Highly dispersed Pt catalysts on single-walled carbon nanotubes and their role in methanol oxidation. *The Journal of Physical Chemistry. B*, *110*, 16185–8. doi:10.1021/jp064054s

Kowalski, P. (2007). Capillary electrophoretic determination of thiamphenicol in turkeys serum and its pharmacokinetic application. *Journal of Pharmaceutical and Biomedical Analysis*, *43*, 222–227. doi:10.1016/j.jpba.2006.06.005

Kumar, V., & Yadav, S. K. (2009). Plant-mediated synthesis of silver and gold nanoparticles and their applications. *Journal of Chemical Technology and Biotechnology*, *84*(August 2008), 151–157. doi:10.1002/jctb.2023

Kümmerer, K. (2009). Antibiotics in the aquatic environment – A review – Part I. *Chemosphere*, *75*(4), 417–434. doi:10.1016/j.chemosphere.2008.11.086

Kushikawa, R. T., Silva, M. R., Angelo, A. C. D., & Teixeira, M. F. S. (2016). Construction of an electrochemical sensing platform based on platinum nanoparticles supported on carbon for tetracycline determination. *Sensors and Actuators B: Chemical*, *228*, 207–213. doi:10.1016/j.snb.2016.01.009

Kutner, W., Wang, J., L´Her, M., & Buck, R. P. (1998). Analytical Aspects of Chemically Modified Electrodes: Calssification, Critical Evaluation and Recommentadations. *Pure and Applied Chemistry*, *70*(6), 1301–1318.

Lawal, A. T. (2016). Synthesis and utilization of carbon nanotubes for fabrication of electrochemical biosensors. *Materials Research Bulletin*, *73*, 308–350. doi:10.1016/j.materresbull.2015.08.037

Lee, M.H. Lee, H.J. Ryu, P. D. (2001). Public Health Risks: Chemical and Antibiotic Residues.

Li, C. Z., Karadeniz, H., Canavar, E., & Erdem, A. (2012). Electrochemical sensing of label free DNA hybridization related to breast cancer 1 gene at disposable sensor platforms modified with single walled carbon nanotubes. *Electrochimica Acta*, *82*, 137–142. doi:10.1016/j.electacta.2012.05.057

Li, J., Cassell, A, Delzeit, L., Han, J., & Meyyappan, M. (2002). Novel three-dimensional electrodes: Electrochemical properties of carbon nanotube ensembles. *Journal of Physical Chemistry B*, *106*, 9299–9305. doi:10.1021/jp021201n

Li, M., Li, Y. T., Li, D. W., & Long, Y. T. (2012). Recent developments and applications of screen-printed electrodes in environmental assays-A review. *Analytica Chimica Acta*, *734*, 31–44. doi:10.1016/j.aca.2012.05.018

Li, N., Xu, Q., Zhou, M., Xia, W., Chen, X., Bron, M., … Muhler, M. (2010). Ethylenediamine-anchored gold nanoparticles on multi-walled carbon nanotubes: Synthesis and characterization. *Electrochemistry Communications*, *12*(7), 939–943. doi:10.1016/j.elecom.2010.04.026

Lian, W., Liu, S., Yu, J., Li, J., Cui, M., Xu, W., & Huang, J. (2013). Electrochemical sensor using neomycin-imprinted film as recognition element based on chitosan-silver nanoparticles/graphene-multiwalled carbon nanotubes composites modified electrode. *Biosensors and Bioelectronics*, *44*, 70–76. doi:10.1016/j.bios.2013.01.002

Liang, S., Li, G., & Tian, R. (2016). Multi-walled carbon nanotubes functionalized with a ultrahigh fraction of carboxyl and hydroxyl groups by ultrasound-assisted oxidation. *Journal of Materials Science*, *51*(7), 3513–3524. doi:10.1007/s10853-015-9671-z

Lin, T. C., & Huang, B. R. (2012). Palladium nanoparticles modified carbon nanotube/nickel composite rods (Pd/CNT/Ni) for hydrogen sensing. *Sensors and Actuators, B: Chemical*, *162*(1), 108–113. doi:10.1016/j.snb.2011.12.044

Liu, S. Y., Xie, J., Pan, Q., Wu, C. Y., Cao, G. S., Zhu, T. J., & Zhao, X. B. (2012). Graphene anchored with nanocrystal Fe 2O 3 with improved electrochemical Li-storage properties. *International Journal of Electrochemical Science*, *7*, 354–362.

Liu, Y., Yin, F., Long, Y., Zhang, Z., & Yao, S. (2003). Study of the immobilization of alcohol dehydrogenase on Au-colloid modified gold electrode by piezoelectric quartz crystal sensor, cyclic voltammetry, and electrochemical impedance techniques. *Journal of Colloid and Interface Science*, *258*, 75–81. doi:10.1016/S0021-9797(02)00083-8

Livshits, P., Inberg, a., Shacham-Diamand, Y., Malka, D., Fleger, Y., & Zalevsky, Z. (2012). Precipitation of gold nanoparticles on insulating surfaces for metallic ultra-thin film electroless deposition assistance. *Applied Surface Science*, *258*(19), 7503–7506. doi:10.1016/j.apsusc.2012.04.072

M. Dhoka, V. Gawande, P. J. (2010). High Performance Liquid Chromatographic Method for Determination of Amoxicillin Trihydrate and Bromhexine Hydrochloride in Oral Dosage Forms. *Journal of Pharmacy and Pharmaceutical Science*, *2*, 129–133.

Martínez-Paredes, G., González-García, M. B., & Costa-García, A. (2009). In situ electrochemical generation of gold nanostructured screen-printed carbon electrodes. Application to the detection of lead underpotential deposition. *Electrochimica Acta*, *54*, 4801–4808. doi:10.1016/j.electacta.2009.03.085

Moors, M., & Massart, D. L. (1991). Evaluation of solid-phase extraction of basic drugs from human milk. *Journal of Pharmaceutical and Biomedical Analysis\n*, *9*(2), 129–139. Retrieved from http://137.187.144.24/endnote_pdfs/rm-011712.pdf

Murray, R.A., Ewing, A.G., Durst, R. A. (1987). Chemically Modified Electrodes: Molecular Design for Electroanalysis. *EAnalytical Chemistry*, *58*(5), 379–390.

Murugesan, S., Myers, K., & Subramanian, V. R. (2011). Amino-functionalized and acid treated multi-walled carbon nanotubes as supports for electrochemical oxidation of formic acid. *Applied Catalysis B: Environmental*, *103*(3-4), 266–274. doi:10.1016/j.apcatb.2010.07.038

Musameh, M., Wang, J., Merkoci, A., & Lin, Y. (2002). Low-potential stable NADH detection at carbon-nanotube-modified glassy carbon electrodes. *Electrochemistry Communications*, *4*, 743–746. doi:10.1016/S1388-2481(02)00451-4

Muthukumar, T., Sudhakumari, Sambandam, B., Aravinthan, A., Sastry, T. P., & Kim, J.-H. (2016). Green synthesis of gold nanoparticles and their enhanced synergistic antitumor activity using HepG2 and MCF7 cells and its antibacterial effects. *Process Biochemistry*. doi:10.1016/j.procbio.2015.12.017

Neghmouche, N. S., & Lanez, T. (2013). International Journal of Chemical Studies Calculation of Diffusion Coefficients and Layer Thickness for Oxidation the Ferrocene using Voltammetry Technique. *International Journal of Chemical Studies*, *1*(1), 28–32.

Ng, C. M., & Manickam, S. (2013). Improved functionalization and recovery of carboxylated carbon nanotubes using the acoustic cavitation approach. *Chemical Physics Letters*, *557*, 97–101. doi:10.1016/j.cplett.2012.11.095

Nigović, B., Sadiković, M., & Jurić, S. (2016). Electrochemical sensing of mesalazine and its N-acetylated metabolite in biological samples using functionalized carbon nanotubes. *Talanta*, *147*, 50–58. doi:10.1016/j.talanta.2015.09.036

Novais, Â., Comas, I., Baquero, F., Cantón, R., Coque, T. M., Moya, A., … Galán, J.-C. (2010). Evolutionary Trajectories of Beta-Lactamase CTX-M-1 Cluster Enzymes: Predicting Antibiotic Resistance. *PLoS Pathogens*, *6*(1), e1000735. doi:10.1371/journal.ppat.1000735

Ojani, R., Raoof, J.-B., & Zamani, S. (2012). A novel voltammetric sensor for amoxicillin based on nickel–curcumin complex modified carbon paste electrode. *Bioelectrochemistry*, *85*, 44–49. doi:10.1016/j.bioelechem.2011.11.010

Özkan, S. A., Uslu, B., & Aboul-Enein, H. Y. (2003). Analysis of Pharmaceuticals and Biological Fluids Using Modern Electroanalytical Techniques. *Critical Reviews in Analytical Chemistry*, *33*(November), 155–181. doi:10.1080/713609162

Padigi, S. K., Reddy, R. K. K., & Prasad, S. (2007). Carbon nanotube based aliphatic hydrocarbon sensor. *Biosensors and Bioelectronics*, *22*(February 2006), 829–837. doi:10.1016/j.bios.2006.02.023

Parkash, O., Yean, C. Y., & Shueb, R. H. (2014). Screen printed carbon electrode based electrochemical immunosensor for the detection of dengue NS1 antigen. *Diagnostics*, *4*, 165–180. doi:10.3390/diagnostics4040165

Pellegrino, T., Kudera, S., Liedl, T., Javier, A. M., Manna, L., & Parak, W. J. (2005). On the development of colloidal nanoparticles towards multifunctional structures and their possible use for biological applications. *Small*, *1*(1), 48–63. doi:10.1002/smll.200400071

Pilehvar, S., Ahmad Rather, J., Dardenne, F., Robbens, J., Blust, R., & De Wael, K. (2014). Carbon nanotubes based electrochemical aptasensing platform for the detection of hydroxylated polychlorinated biphenyl in human blood serum. *Biosensors & Bioelectronics*, *54*, 78–84. doi:10.1016/j.bios.2013.10.018

Protti, P. (2001). Introduction to Modern Voltammetric and Polarographic Analisys Techniques. *Amel Electrochemistry*. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Introduction+to+Modern+Voltammetric+and+Polarographic+Analisys+Techniques#0\n http://www.amelchem.com/wp-content/uploads/2011/10/VPAT_manual_eng.pdf

R.A. Durst, A.J. Baummer, R.W. Murray, R.P. Buck, C. P. A. (1997). Chemically modified electrodes : Recommended terminology and definitions. *Pure and Appl. Chem*, *69*(6), 1317–1323.

Raj, C. R., Okajima, T., & Ohsaka, T. (2003). Gold nanoparticle arrays for the voltammetric sensing of dopamine. *Journal of Electroanalytical Chemistry*, *543*, 127–133. doi:10.1016/S0022-0728(02)01481-X

Rajarao, R., Prasad, R., & Sahajwalla, V. (2014). Green Approach to Decorate Multi-Walled Carbon Nanotubes by Metal / Metal Oxide Nanoparticles. *Procedia Materials Science*, *5*, 69–75. doi:10.1016/j.mspro.2014.07.243

Raqi, M. H. S. Arnold, G.F. Ali, Z. A. (1995). *Adsorptive stripping voltammetry as a method of analysis of some pharmaceutical and other purine derivatives* (pp. 27–57).

Rassaei, L., Marken, F., Sillanpää, M., Amiri, M., Cirtiu, C. M., & Sillanpää, M. (2011). Nanoparticles in electrochemical sensors for environmental monitoring. *TrAC - Trends in Analytical Chemistry*, *30*(11), 1704–1715. doi:10.1016/j.trac.2011.05.009

Reeves, T. (2011). *Chemical Analysis of Antibiotic Residues in Food*. *John Wiley and Sons, Inc.* (pp. 1–60). doi:10.1002/9781118067208

Rezaei, B., & Damiri, S. (2009). Electrochemistry and adsorptive stripping voltammetric determination of amoxicillin on a multiwalled carbon nanotubes modified glassy carbon electrode. *Electroanalysis*, *21*(14), 1577–1586. doi:10.1002/elan.200804571

Rinzler, A. G., Liu, J., Dai, H., Nikolaev, P., Huffman, C. B., Rodríguez-Macías, F. J., … Smalley, R. E. (1998). Large-scale purification of single-wall carbon nanotubes: process, product, and characterization. *Applied Physics A: Materials Science & Processing*, *67*, 29–37. doi:10.1007/s003390050734

Sadeghi, S., & Motaharian, A. (2013). Voltammetric sensor based on carbon paste electrode modified with molecular imprinted polymer for determination of sulfadiazine in milk and human serum. *Materials Science and Engineering C*, *33*(8), 4884–4891. doi:10.1016/j.msec.2013.08.001

Sadiković, M., Nigović, B., Jurić, S., & Mornar, A. (2014). Voltammetric determination of ropinirole in the presence of levodopa at the surface of a carbon nanotubes based electrochemical sensor in pharmaceuticals and human serum. *Journal of Electroanalytical Chemistry*, *733*, 60–68. doi:10.1016/j.jelechem.2014.09.020

Sahin, M., & Ayranci, E. (2015). nomaterialElectrooxidation of NADH on Modified Screen-Printed Electrodes: Effects of Conducting Polymer and Nas. *Electrochimica Acta*, *166*, 261–270. doi:10.1016/j.electacta.2015.03.030

Saleh Ahammad, A. J., Lee, J.-J., & Rahman, M. A. (2009). Electrochemical sensors based on carbon nanotubes. *Sensors (Basel, Switzerland)*, *9*, 2289–319. doi:10.3390/s90402289

Salimi, A., Banks, C. E., & Compton, R. G. (2004). Abrasive immobilization of carbon nanotubes on a basal plane pyrolytic graphite electrode: application to the detection of epinephrine. *Analyst*, *129*, 225–228. doi:10.1039/b315877b

Santos, D. P., Bergamini, M. F., & Zanoni, M. V. B. (2008). Voltammetric sensor for amoxicillin determination in human urine using polyglutamic acid/glutaraldehyde film. *Sensors and Actuators, B: Chemical*, *133*, 398–403. doi:10.1016/j.snb.2008.02.045

Scida, K., Stege, P. W., Haby, G., Messina, G. A., & García, C. D. (2011). Recent applications of carbon-based nanomaterials in analytical chemistry: Critical review. *Analytica Chimica Acta*, *691*(1-2), 6–17. doi:10.1016/j.aca.2011.02.025

Shah, P., & Murthy, C. N. (2013). Studies on the porosity control of MWCNT/polysulfone composite membrane and its effect on metal removal. *Journal of Membrane Science*, *437*, 90–98. doi:10.1016/j.memsci.2013.02.042

Shahrokhian, S., & Rastgar, S. (2012). Electrochemical deposition of gold nanoparticles on carbon nanotube coated glassy carbon electrode for the improved sensing of tinidazole. *Electrochimica Acta*, *78*, 422–429. doi:10.1016/j.electacta.2012.06.035

Sharma, R., & Kar, K. K. (2015). Particle size and crystallographic orientation controlled electrodeposition of platinum nanoparticles on carbon nanotubes. *Electrochimica Acta*, *156*, 199–206. doi:10.1016/j.electacta.2015.01.046

Shi, Y., Yang, R., & Yuet, P. K. (2009). Easy decoration of carbon nanotubes with well dispersed gold nanoparticles and the use of the material as an electrocatalyst. *Carbon*, *47*(4), 1146–1151. doi:10.1016/j.carbon.2008.12.049

Shinohara, N., Matsumoto, K., Endoh, S., Maru, J., & Nakanishi, J. (2009). Toxicology Letters. *Toxicology Letters*, *191*, 289–96. doi:10.1016/j.toxlet.2009.09.012

Si, W., Lei, W., Zhang, Y., Xia, M., Wang, F., & Hao, Q. (2012). Electrodeposition of graphene oxide doped poly(3,4-ethylenedioxythiophene) film and its electrochemical sensing of catechol and hydroquinone. *Electrochimica Acta*, *85*, 295–301. doi:10.1016/j.electacta.2012.08.099

Sims, M. J., Li, Q., Kachoosangi, R. T., Wildgoose, G. G., & Compton, R. G. (2009). Using multiwalled carbon nanotube modified electrodes for the adsorptive striping voltammetric determination of hesperidin. *Electrochimica Acta*, *54*, 5030–5034. doi:10.1016/j.electacta.2008.10.056

Soliwoda, K., Rosowski, M., Tomaszewska, E., Tkacz-Szczesna, B., Celichowski, G., Psarski, M., & Grobelny, J. (2015). Synthesis of monodisperse gold nanoparticles via electrospray-assisted chemical reduction method in cyclohexane. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *482*, 148–153. doi:10.1016/j.colsurfa.2015.04.040

Sotiropoulou, S., & Chaniotakis, N. A. (2003). Carbon nanotube array-based biosensor. *Analytical and Bioanalytical Chemistry*, *375*, 103–105. doi:10.1007/s00216-002-1617-z

Stolker, A. A. M., Zuidema, T., Nielen, M. W. F., & Nielen, M. W. F. (2007). Residue analysis of veterinary drugs and growth-promoting agents. *TrAC Trends in Analytical Chemistry*, *26*(10), 967–979. doi:10.1016/j.trac.2007.09.008

Stoytcheva, M. (2011). *Pesticides in the Modern World -Trends in Pesticides Analysis* (p. 526). Intech.

Stuttgen, S. (2011). Target Residues, *Beef quality assurance*, 1–3.

Teresa, M., & Briones, C. (2008). Electrochemical Stripping Analysis and Nanoparticles for Affinity Biosensors. *Biosensors*, pp 23-29.

Thiyagarajan, N., Chang, J. L., Senthilkumar, K., & Zen, J. M. (2014). Disposable electrochemical sensors: A mini review. *Electrochemistry Communications*, *38*, 86–90. doi:10.1016/j.elecom.2013.11.016

Treacy, M. M. J., Ebbesen, T. W. Gibson, J. M. (1996). Exceptional high Young's modulus observed for individuals carbon nanotubes. *Letters to Nature*, *381*, 678–680.

Turco, A., Corvaglia, S., & Mazzotta, E. (2015). Electrochemical sensor for sulfadimethoxine based on molecularly imprinted polypyrrole: Study of imprinting parameters. *Biosensors and Bioelectronics*, *63*, 240–247. doi:10.1016/j.bios.2014.07.045

Turkevich, J., Stevenson, P. C., & Hillier, J. (1951). A study of the nucleation and growth processes in the synthesis of colloidal gold. *Discussions of the Faraday Society*, *11*(c), 55–75. doi:10.1039/DF9511100055

Uslu, B., & Biryol, I. (1999). Voltammetric determination of amoxicillin using a poly (N-vinyl imidazole) modified carbon paste electrode. *Journal of Pharmaceutical and Biomedical Analysis*, *20*, 591–598. doi:10.1016/S0731-7085(99)00059-X

Valentini, F., Amine, A., Orlanducci, S., Terranova, M. L., & Palleschi, G. (2003). Carbon Nanotube Purification: Preparation and Characterization of Carbon Nanotube Paste Electrodes. *Analytical Chemistry*, *75*(20), 5413–5421. doi:10.1021/ac0300237

Van der Kreek, F. W. (1984). *Veterinary drug residues in food*. *Tijdschrift voor diergeneeskunde* (Vol. 109, pp. 81–89). Woodhead Publishing Limited. doi:10.1533/9780857095794.2.148

Vashist, S. K. (2012). Carbon Nanotubes-Based Electrochemical Sensors and Drug Delivery Systems: Prospects and Challengesc. *Journal of Nanomedicine & Nanotechnology*, *03*(8), 1–2. doi:10.4172/2157-7439.1000e121

Vashist, S. K., Zheng, D., Al-Rubeaan, K., Luong, J. H. T., & Sheu, F.-S. (2011). Advances in carbon nanotube based electrochemical sensors for bioanalytical applications. *Biotechnology Advances*, *29*(2), 169–188. doi:10.1016/j.biotechadv.2010.10.002

Vinoth, V., Wu, J. J., Asiri, A. M., & Anandan, S. (2015). Simultaneous detection of dopamine and ascorbic acid using silicate network interlinked gold nanoparticles and multi-walled carbon nanotubes. *Sensors and Actuators, B: Chemical*, *210*, 731–741. doi:10.1016/j.snb.2015.01.040

Vire, J.C. Kauffmann, J.M. Patriarche, G. J. (1990). Adsorptive stripping voltammetry applied to drug analysis: a powerful tool. *Journal of Pharmaceutical & Biomedical Analysis*, *7*(12), 1323–1335. doi:10.1016/0731-7085(89)80138-4

Vuković, G. D., Marinković, A. D., Čolić, M., Ristić, M. D., Aleksić, R., Perić-Grujić, A. A., & Uskoković, P. S. (2010). Removal of cadmium from aqueous solutions by oxidized and ethylenediamine-functionalized multi-walled carbon nanotubes. *Chemical Engineering Journal*, *157*, 238–248. doi:10.1016/j.cej.2009.11.026

Wang, J. (1995). Electrochemical Sensors for Environmental Monitoring : *National Expososure Research Laboratory U.S*. doi:10.1351/pac200173121969

Wang, X., Yang, L., Jin, X., & Zhang, L. (2014). Electrochemical determination of estrogenic compound bisphenol F in food packaging using carboxyl functionalized multi-walled carbon nanotubes modified glassy carbon electrode. *Food Chemistry*, *157*, 464–9. doi:10.1016/j.foodchem.2014.02.079

Wong, A., Scontri, M., Materon, E. M., Lanza, M. R. V., & Sotomayor, M. D. P. T. (2015). Development and application of an electrochemical sensor modified with multi-walled carbon nanotubes and graphene oxide for the sensitive and selective detection of tetracycline. *Journal of Electroanalytical Chemistry*, *757*, 250–257. doi:10.1016/j.jelechem.2015.10.001

Wooten, M., A, Shim, J. H., A, B., & Gorsk, W. (2010). Amperometric Determination of Glucose at Conventional vs. Nanostructured Gold Electrodes in Neutral Solutions.

Wu, J., Yan, F., Tang, J., Zhai, C., & Ju, H. (2007). A disposable multianalyte electrochemical immunosensor array for automated simultaneous determination of tumor markers. *Clinical Chemistry*, *53*, 1495–1502. doi:10.1373/clinchem.2007.086975

Xiao, F., Zhao, F., Li, J., Yan, R., Yu, J., & Zeng, B. (2007). Sensitive voltammetric determination of chloramphenicol by using single-wall carbon nanotube-gold nanoparticle-ionic liquid composite film modified glassy carbon electrodes. *Analytica Chimica Acta*, *596*, 79–85. doi:10.1016/j.aca.2007.05.053

Xu, T., Zhang, L., Yang, J., Li, N., Yang, L., & Jiang, X. (2013). Development of electrochemical method for the determination of olaquindox using multi-walled carbon nanotubes modified glassy carbon electrode. *Talanta*, *109*, 185–90. doi:10.1016/j.talanta.2013.02.004

Xu, Y., Gao, M., Zhang, G., Wang, X., Li, J., Wang, S., & Sang, Y. (2015). Electrochemically reduced graphene oxide with enhanced electrocatalytic activity toward tetracycline detection. *Chinese Journal of Catalysis*, *36*(11), 1936–1942. doi:10.1016/S1872-2067(15)60956-1

Xueji, Zhang.Huangxian,Ju. Joseph, W. (2008). *Electrochemical Sensors And Their Biomedical Applications* (pp. 479–490).

Yang, G., & Zhao, F. (2015). Electrochemical sensor for chloramphenicol based on novel multiwalled carbon nanotubes@molecularly imprinted polymer. *Biosensors & Bioelectronics*, *64*, 416–22. doi:10.1016/j.bios.2014.09.041

Yang, S., Qu, L., Li, G., Yang, R., & Liu, C. (2010). Gold nanoparticles/ethylenediamine/carbon nanotube modified glassy carbon electrode as the voltammetric sensor for selective determination of rutin in the presence of ascorbic acid. *Journal of Electroanalytical Chemistry*, *645*(2), 115–122. doi:10.1016/j.jelechem.2010.04.019

Yola, M. L., & Atar, N. (2014). A novel voltammetric sensor based on gold nanoparticles involved in p-aminothiophenol functionalized multi-walled carbon nanotubes: Application to the simultaneous determination of quercetin and rutin. *Electrochimica Acta*, *119*, 24–31. doi:10.1016/j.electacta.2013.12.028

Yola, M. L., Eren, T., & Atar, N. (2014). Molecular imprinted nanosensor based on surface plasmon resonance: Application to the sensitive determination of amoxicillin. *Sensors and Actuators B: Chemical*, *195*, 28–35. doi:10.1016/j.snb.2014.01.011

Zardini, H. Z., Amiri, A., Shanbedi, M., Maghrebi, M., & Baniadam, M. (2012). Enhanced antibacterial activity of amino acids-functionalized multi walled carbon nanotubes by a simple method. *Colloids and Surfaces B: Biointerfaces*, *92*, 196–202. doi:10.1016/j.colsurfb.2011.11.045

Zhang, L., Duan, X., Wen, Y., Xu, J., Yao, Y., Lu, Y., … Zhang, O. (2012). Electrochemical behaviors of roxithromycin at poly(3,4-ethylenedioxythiophene) modified gold electrode and its electrochemical determination. *Electrochimica Acta*, *72*, 179–185. doi:10.1016/j.electacta.2012.04.019

Zhang, L., Kucera, L. R., Ummadisetty, S., Nykaza, J. R., Elabd, Y. A., Storey, R. F., … Weiss, R. A. (2014). Supramolecular Multiblock Polystyrene–Polyisobutylene Copolymers via Ionic Interactions. *Macromolecules*, *47*, 4387–4396. doi:10.1021/ma500934e

Zhang, R., Hummelgård, M., & Olin, H. (2009). Simple and efficient gold nanoparticles deposition on carbon nanotubes with controllable particle sizes. *Materials Science and Engineering: B*, *158*, 48–52. doi:10.1016/j.mseb.2008.12.038

Zhao, Z., Yang, Z., Hu, Y., Li, J., & Fan, X. (2013). Multiple functionalization of multi-walled carbon nanotubes with carboxyl and amino groups. *Applied Surface Science*, *276*, 476–481. doi:10.1016/j.apsusc.2013.03.119