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Review Article: Synthesis of Fe_3O_4 Nanoparticle and Its Application for Glassy Carbon Electrode Modification

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Abstract: Nanomaterials have various unique properties and characteristics so that they can apply in many sectors. One of the most popular nanoparticles today is magnetite nanoparticles. Magnetite particles have several properties such as being super magnetic, having a high saturation field, chemical stability, biocompatibility, and low production costs. The purpose of this article is to review the synthesis of magnetite nanoparticles and their application to Glassy Carbon Electrode (GCE) modification. This modified GCE can applied as an electrochemical sensor to detect various organic and inorganic substances. In this study, type synthesis methods of magnetite nanoparticles which taken from kind literature well investigation include coprecipitation, sol-gel, microemulsion, hydrothermal, and thermal decomposition. The five routes have their respective advantages and disadvantages. Then the nano magnetite made can applied to modify the GCE as an electrochemical sensor that can detect uric acid, bacteria, and even metals dissolved in water.

Keywords: Fe_3O_4 Nanoparticle, modification GCE, Application of modified GCE

***Abstrak*:** *Material nano memiliki berbagai sifat dan karakteristik unik sehingga dapat dimanfaatkan dalam berbagai bidang. Salah satu nanopartikel yang populer saat ini adalah nanopartikel magnetit. Partikel magnetit memiliki beberapa seperti bersifat supermagnetik, memiliki medan saturasi yang tinggi, stabil secara kimia, biocompability, dan biaya produksi yang rendah. Tujuan dari penulisan artikel ini adalah untuk mereview sintesis nanopartikel magnetit dan pengaplikasiannya terhadap modifikasi GCE. GCE termodifikasi ini dapat diaplikasikan untuk menjadi sensor elektrokimia untuk mendeteksi berbagai zat baik organik maupun anorganik. Dalam studi ini, dibahas berbagai metode sintesis nanopartikel magnetit dari berbagai literatur yang meliputi kopresipitasi, sol-gel, mikroemulsi, hidrotermal, dan dekomposisi termal. Kelima metode tersebut memiliki kekurangan dan kelebihan masing-masing. Kemudian nano magnetit yang telah dibuat diaplikasikan untuk memodifikasi GCE sebagai sensor elektrokimia yang dapat untuk mendeteksi asam urat, bakteri, bahkan logam-logam terlarut dalam air.*

Kata kunci: *Nanopartikel Fe3O4, modifikasi GCE, aplikasi GCE termodifikasi*

INTRODUCTION

Nanostructured materials have dimensions of about 1-100 nm. Nanostructures can be divided into 0 dimensions/uniform, 1-dimensional/elongated, and 2-dimensional/planar (Xia *et al*. 2003). Nanomaterials have unique mechanical, optical, electrical, magnetic, and thermal properties (Nigam *et al*. 2018), therefore it can be used in various sectors. One of the popular nanomaterials is nano magnetite (Fe_3O_4) (Ghandoor *et al*. 2012).

Magnetite has the shape of an inverted spinel cube crystal. Magnetite is a semiconductor that can be either n-type or p-type this is due to the small bandgap (0.1 eV). Magnetite has the lowest resistivity among other iron oxides (Boxall *et al*. 1996). In addition magnetite particles also have several other advantages such as being super magnetic, having a high saturation field, being chemically stable, biocompatible, and having low production costs (Chifiriuc *et al*. 2013).

Magnetite nanoparticles have properties that depend on size, crystal morphology, and surface chemistry, so the synthesis of magnetite nanoparticles must be simple and easy to do (Niculescu *et al*. 2021). Many studies have been carried out related to the synthesis of magnetite nanoparticles. Examples of methods to synthesize magnetite nanoparticles are co-precipitation (Ahmadi *et al*. 2011), microemulsion (Malik *et al*. 2012), hydrothermal (Ahmadi *et al*. 2013), thermal decomposition (Glasgow *et al*. 2016), and sol-gel (Lemine *et al*. 2012).

Magnetite nanoparticles have beneficial properties that make them useful in various applications such as preparation of cellulose acetate nanofibers–nano magnetite for lead removal (Shalaby *et al*. 2017), magnetite for cancer hyperthermia (Li *et al*. 2010), modifying glassy carbon electrodes as electrochemical sensors (Yang *et al*. 2013; Sohouli *et al*. 2020), and many other useable applications.

Based on the previous description, the purpose of this article is to present information about several methods of synthesizing Fe_3O_4 nanoparticles and their application to modify GCE. Modification of GCE with magnetite nanoparticles is interesting to study because this modified GCE can be an easy-to-use electrochemical sensor and low production cost and can be applied in various sectors, including medical, environmental, and food.

SYNTHESIS OF Fe_3O_4 NANOPARTICLE

A common strategy for the preparation of monodisperse nanoparticles in the liquid phase is to separate the nucleation from the growth of the nanocrystals. (Hao *et al*. 2010). To synthesize magnetite nanoparticles there are currently three routes that can be used, namely chemistry, physics, and biology. The chemical method is preferred over other methods because it has efficiency, good reproducibility with quite simple route (Ali *et al*. 2016). Various studies have been carried out related to the synthesis of magnetite nanoparticles either by chemical, physical, or biological routes.

Co-Precipitation

The co-precipitation method is likely to be the most simple and most efficient method as a route for synthesizing magnetic particles (Li *et al*. 2011). This co-precipitation method uses $FeCl_3.6H_2O$ dan $FeCl_2.4H_2O$ precursors. Both reagents were mixed in distilled water (Ahmadi *et al*. 2011; Meng *et al*. 2013; Wei *et al*. 2012), then the solution was heated and stirred. Then added a precipitating solution, namely $NH_3.H_2O$, and the mixture is stirred at a speed of 800 rpm for 30 minutes. After that, sodium oleate dissolved in distilled water at the same time as the ultrasonic process. Then the mixture was added to the reaction solution and pH was kept at a value of 5. After 30 minutes, the crystals formed were collected and washed then freeze-dried (Meng *et al*. 2013).

The reactions that occur in the magnetite synthesis process by the coprecipitation method is presented in Eq. (1).

$$Fe^{2+} + 2Fe^{3+} + 8OH^- \rightarrow Fe_3O_4 + 4H_2O \ldots (1)$$

(Meng *et al*., 2013)

The Fe_3O_4 nanoparticles synthesized by the coprecipitation method are shown in Figure 1.

The particle size of Fe_3O_4 measured using the Debye-Scherrer equation obtained particle sizes around 12.6 nm, 13.4 nm, 14.2 nm, and 13.8 nm (Wei *et al*. 2012). The crystal morphology of Fe_3O_4 nanoparticles obtained from the XRD analysis is cubes (Wei *et al*. 2012; Meng *et al*. 2013).

Sol-gel Synthesis

Sol-gel synthesis is a conventional wet chemical method that widely used for the preparation of nanosized metal oxides. In sol-gel processing, a 'sol' of nanometric particles is prepared through the hydroxylation and condensation of the molecular precursor (Koo *et al*. 2019).

For the preparation of Fe_3O_4 nanoparticles, Fe^{3+} ions of the precursor are hydrolyzed and condensed, based on reaction mechanism shown in Eq. (2) and (3) respectively. From the equation, Fe^{3+} ions are readily hydrolyzed and condensed to form ferrous hydroxides or oxides.

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ \ldots (2)$$
$$12Fe(OH)_3 \rightarrow 4Fe_3O_4 + 18H_2O + O_2 \ldots (3)$$

(Koo *et al*. 2019)

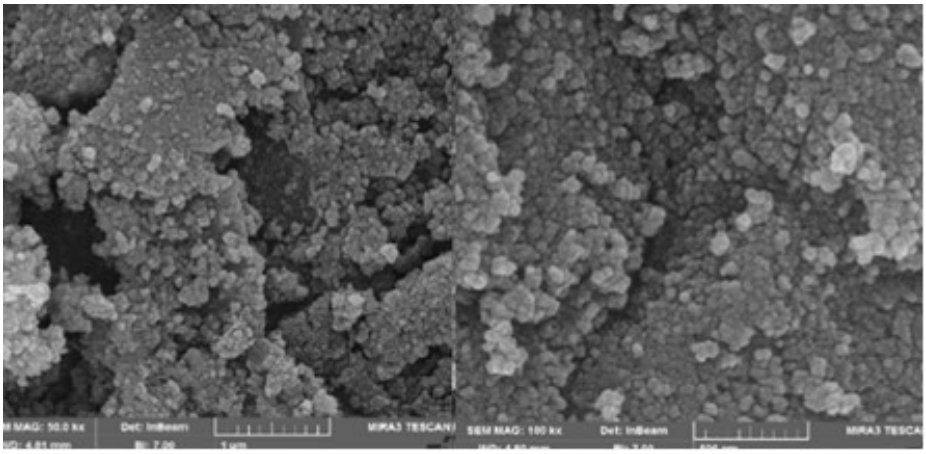

Figure 1. SEM image of Fe_3O_4 nanoparticles synthesized by coprecipitation method. Taken from reference Sohouli *et al*. (2020).

Many studies have been carried out regarding the synthesis of Fe_3O_4 through the sol-gel pathway. Lemine *et al*. (2012) synthesized Fe_3O_4 nanoparticles using $Fe(acac)_3$ precursor dissolved in methanol. After 15 min of magnetic stirring, the solution was placed in an autoclave and dried under supercritical conditions of EtOH. In addition, Qi *et al*. (2011) did the synthesis Fe_3O_4 sol-gel materials were prepared from ethanolic solutions of metal chlorides without the need for alkoxides, polymeric gel agents, or elaborate reaction schemes. Lemine *et al*. (2012) and Shaker *et al*. (2013) used $Fe(NO_3)_3.9H_2O$ as a precursor and ethylene glycol then reacted at 40°C for 2 hours. Then heated at a temperature of 80°C until a brown gels obtained. The gel was then allowed to stand at room temperature and then heated at 200 to 500°C to obtain nanoparticles of various sizes (Shaker *et al*. 2013; Xu *et al*. 2007; Worawong *et al*. 2014).

In addition, $FeCl_3$ and $FeCl_2$ precursors can be used with ethanol as a solvent (Zhang *et al*. 2014). With the same precursor, magnetite synthesis by the sol-gel method can also use as solvent ethylene glycol (Takai *et al*. 2019).

The average crystallite size obtained from XRD using the most intense peak, corresponding to (311) reflection by using the Debye-Scherer formula and TEM images is about 8 nm (Lemine *et al*. 2012) 28.7 nm, 30.5 nm, 34.9 nm (Shaker *et al*. 2013) while based on the results of Worawong *et al*. the average particle size of pure Fe_3O_4 is about 30 nm (Worawong *et al*. 2014).

Fe_3O_4 particles synthesized through the sol-gel method are shown in Figure 2.

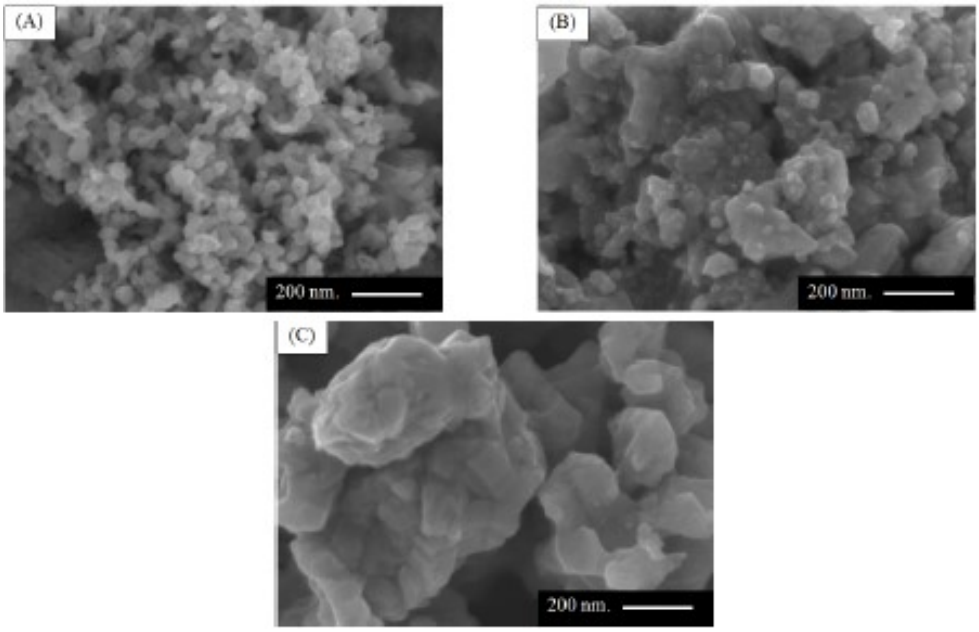

Figure 2. FE-SEM micrographs of calcined powder (A) at 400°C, (B) at 450°C, and (C) at 500°C in Ar at 1 atm. Taken from reference Worawong *et al*. (2014).

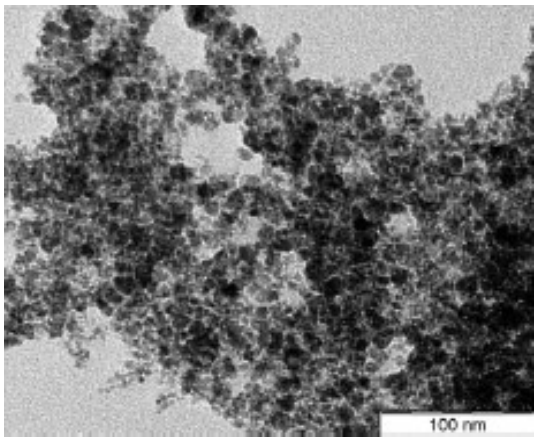

Figure 3. TEM image of Fe_3O_4 nanoparticles synthesized by microemulsion method. Taken from reference Vidal-vidal *et al*. (2006)

Microemulsion

Microemulsions are isotropic, macroscopically homogeneous, and thermodynamically stable solutions containing at least three components, namely a polar phase (usually water), a nonpolar phase (usually oil) and a surfactant. On a microscopic level the surfactant molecules form an interfacial film separating the polar and the non-polar domains. Different types of microemulsions are known, such as water-in-oil (W/O), oil-in-water (O/W) and water-in-sc-CO_2 (w/sc-CO_2) (Malik 2012). The Fe_3O_4 nanoparticles were prepared via the reaction shown in Eq. (4).

$$8OH^- + Fe^{2+} + 2Fe^{3+} \rightarrow Fe_3O_4 \downarrow + 4H_2O \ldots (4)$$

In a typical synthesis, 2.0 g surfactant was dissolved in 20 mL *n*-heptane and 12 mL *n*-hexanol to obtain a transparent solution by ultrasound or stirring. The above solution was then put into a three-necked flask and stirred for 20 min at 40°C under an argon atmosphere. 0.5 mol/L of freshly prepared aqueous iron(II) sulfate in 0.6 mL double distilled water was then injected rapidly. After 2 min, 1.0 mL aqueous ferric chloride solution (0.5 mole/L) was added. The solution turned into light brown color. The emulsion containing 2 mL ammonia water (25% NH_3) as the water phase was also prepared using the same oil and surfactant phase. After 20 min, the emulsion containing ammonia was injected dropwise into the above three-necked flask with vigorous stirring at 70°C. The color of the solution quickly turned from light brown to black. The entire solution was heated at 70°C for 3 h. The whole procedure was carried out under an argon atmosphere to prevent the oxidation of ferrous ions. Finally, the crude product was aged for 2 h at room temperature before being repeatedly washed with ethanol and water. The crude product was then retrieved by centrifugation and dried in a vacuum oven at 80°C for 8 h (Lu *et al.* 2013).

Fe_3O_4 nanoparticles synthesized using the microemulsion method is shown in Figure 3.

Fe_3O_4 crystallite size measured using the Debye-Scherrer equation obtained a crystallite size of around 14-16 nm. And the crystal diameter ranges from 13-14.8 nm (Lu *et al*. 2013).

Hydrothermal

Hydrothermal synthesis is normally used for the synthesis of single crystals of minerals in hot water under high pressure in an autoclave (Fan *et al*. 2001). In a hydrothermal synthesis, usually one ferrous precursor is used as the starting material contrary to the stoichiometric mixture used in the co-precipitation process (Li *et al*. 2011). In general, in a hydrothermal synthesis, relatively larger particles are yielded compared to co-precipitation (Li *et al*. 2011).

Reagents used were with analysis-pure grade from commercial source. Ferrous sulfate ($FeSO_4$) (1.39 g (0.005 mole)) and sodium thiosulfate ($Na_2S_2O_3$) (1.24 g (0.005 mol)) was dissolved with 14 mL distilled water in a Teflon-lined stainless autoclave 10 mL of 1.0 mole/L NaOH solution was added into above autoclave from a burette under constant stirring to produce a black colloid medium. This autoclave was maintained at 140°C for 12 hours, and then allowed to cool to room temperature. A dark gray precipitate was filtered, washed several times with warm distilled water and absolute ethanol, and then dried in a vacuum at 70°C for 4 hours. In order to investigate the role of $Na_2S_2O_3$, the experiments with $FeSO_4$ and NaOH in various ratios were also carried out under the same condition (Fan *et al*. 2001).

Meanwhile, Ahmadi *et al*. (2013) did the synthesis of Fe_3O_4 by reacting a solution of 0.6 M $FeSO_4.7H_2O$ in distilled water with 7 mL of DMSO and 3 mL of oleic acid. These three solutions react while flowing with argon gas at a temperature of 140°C. After that, 1.4 mL of 25% v/v tetramethyl ammonium hydroxide was added as a reducing agent and stirred for 1 hour. After forming a black precipitate, the black sediment separated using centrifugation method then the sediment was washed several times with acetone.

The nanoparticles synthesized by the hydrothermal method are shown in Figure 4.

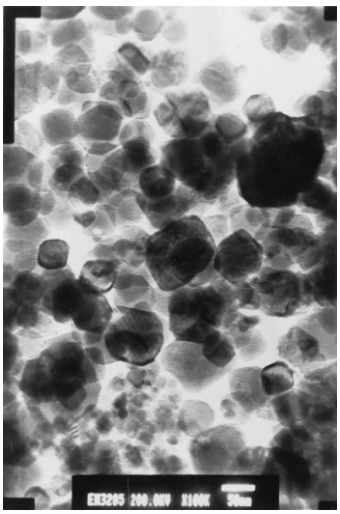

Figure 4. TEM image of Fe_3O_4 nanoparticles synthesized by hydrothermal method. Taken from reference Fan *et al*. (2001)

Overall, hydrothermal synthesis can yield particles with high crystallinity and controlled morphology, but the nanoparticles are bigger in particle diameter in contrast to co-precipitation. It should be noted that larger magnetic nanoparticles especially larger than 50 nm may display ferromagnetic behavior instead of superparamagnetic behavior, which may be a problem in their handling and further application (Li *et al*. 2011).

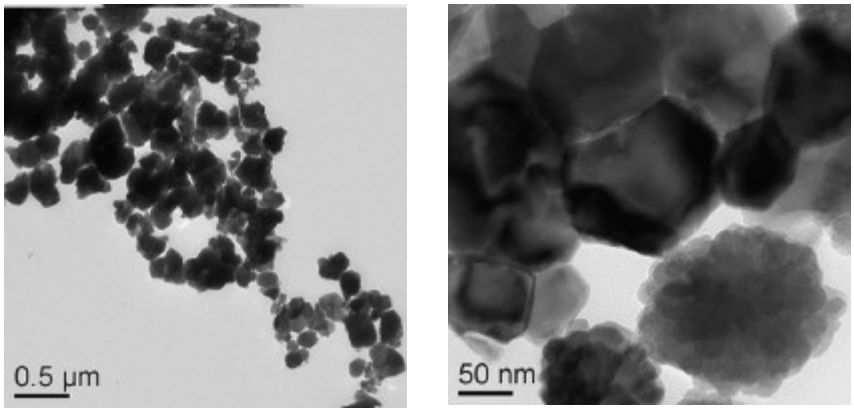

Figure 5. TEM image of Fe_3O_4 nanoparticles synthesized through thermal decomposition pathway using $[Fe(CON_2H_4)_6](NO_3)_2$ as precursor and processed at 250°C for 2 hours. Taken from reference Asuha *et al*. (2011).

With a similar study, Ahmadi *et al*. (2012) found that the average size of Fe_3O_4 crystals synthesized using the hydrothermal method at a temperature of 100°C was 13.4 nm, and the average particle size was 19.7 nm, at a temperature of 150°C and 500°C the average particle size was 24.0 nm and 27.0 nm while the average size of the crystals is 20.8 nm and 22.8 nm.

Thermal Decomposition

Thermal decomposition is one of the most effective synthesis methods of magnetite particles. The main advantages of this method include excellent particle size controllability with narrow size distribution and high crystallinity of productions (Ghazanfari *et al*. 2016).

The synthesis of Fe_3O_4 nanoparticles can be traversed through the thermal decomposition of Fe(acetylacetonate)$_3$ or Fe(acac)$_3$ molecules. (Chin *et al*. 2011; Maity *et al*. 2009a; Maity *et al*. 2009b; Vuong *et al*. 2015). Maity *et al*. (2009a) carried out the thermal decomposition of Fe(acac)$_3$ dissolved in hydrophilic TREG and irrigated with argon gas. The solution was dehydrated at 120°C for 1 hour and then heated to 280°C for 2 hours. The magnetite nanoparticles formed were precipitated by adding ethyl acetate and isolated by the centrifugation, while Chin *et al*. (2011) did a similar experiment but Fe(acac)3 was dissolved in PEO and flowed with nitrogen gas and then refluxed for 1 hour.

In addition to using the Fe(acac)$_3$ precursor, there are several other studies related to the synthesis of Fe_3O_4 nanoparticles using thermal decomposition method but using different precursors. Glasgow *et al*. (2016) used iron oleate precursors obtained from the reaction between ferric chloride hexahydrate and sodium oleate in a mixed solvent of ethanol, hexane, and distilled water. In addition, Asuha *et al*. (2011) used a precursor $[Fe(CON_2H_4)_6](NO_3)_2$ which dissolved in a stainless autoclave with a Teflon liner, then heated for 2 hours to form a black solid.

Fe_3O_4 nanoparticles synthesized through the thermal decomposition pathway are shown in Figure 5.

The particle size of Fe_3O_4 synthesized through thermal decomposition pathway is around 37-50 nm using raw material $[Fe(CON_2H_4)_6](NO_3)_2$ (Asuha *et al*. 2011) 11 nm using Fe(acac)$_3$ as raw material and argon gas flow (Maity *et al*. 2009b) 2-7 nm with Fe(acac)$_3$ as feedstock and nitrogen gas flow (Chin *et al*. 2011) and 6.97-10.85 nm using iron chloride hexahydrate as feedstock (Glasgow *et al*. 2016).

MODIFICATION GCE WITH Fe_3O_4 NANOPARTICLE

Fe_3O_4 nanoparticles have attracted an increasing interest for application to sensors because of their good biocompatibility, strong superparamagnetic property, low toxicity, easy preparation and high adsorption ability. Moreover, Fe_3O_4 nanoparticles exhibit high surface area and low mass transfer resistance. (Yin *et al*. 2011) Recently, magnetic Fe_3O_4 nanoparticles have attracted many interests due to their special attributes and they have been widely investigated and applied in electrochemical sensor and biosensor (Yin *et al*. 2011).

Iron oxide nanoparticles (Fe_3O_4 NPs) are getting considerable attention, due to their unique magnetic properties, biocompatibility, high electric conductivity, and chemical stability. It has been recognized that the activity of magnetite (Fe_3O_4) NPs intensively depends on their shape, size and crystal phase. Particularly, shape and size have a striking impact on the properties of magnetite Fe_3O_4 NPs with 1 to 100 nm because of the high surface area and their potential applications (Panhwar *et al*. 2019).

Fe_3O_4 NPs have excellent properties so that they be used in various sectors. For example, to modify the Glassy Carbon Electrode (GCE) (Yin *et al*. 2011; Yin *et al*. 2011; Panhwar *et al*. 2019). Many studies have been conducting to modify GCE with Fe_3O_4 nanoparticles with different applications.

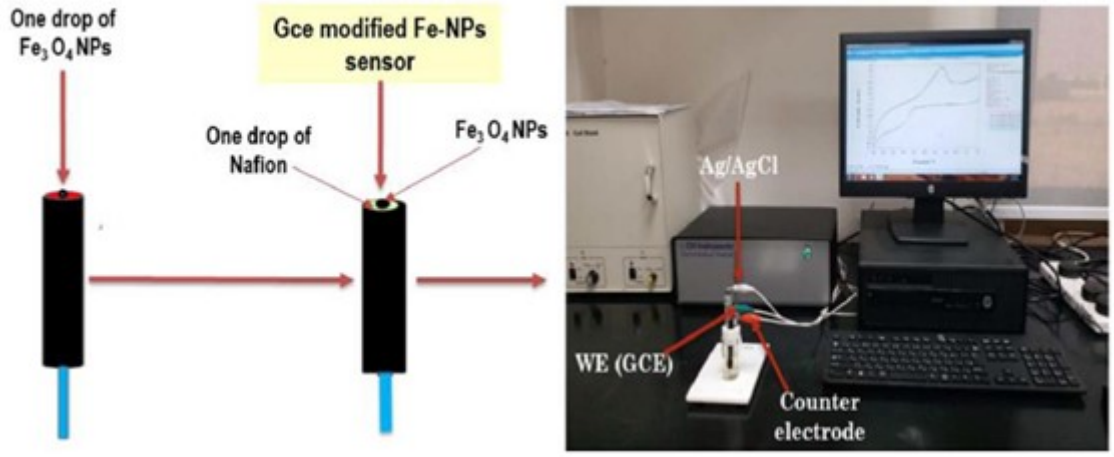

Figure 6. Schematic of GCE modification using Fe_3O_4 NPs. Taken from reference Panhwar *et al*. (2019)

Sohouli *et al*. (2020) have conducted research on GCE modification with mixed methylcellulose (MC) particles and graphene oxide (GO) and Fe_3O_4 nanoparticles composite. They synthesized GO nanoparticles from graphite precursors with sulfuric acid and phosphoric acid as solvents. Then Fe_3O_4 NPs were synthesized through a coprecipitation pathway using $FeCl_3$ and $FeCl_2$ precursors. Then MC-GO nanocomposite was made by dissolving the MC in distilled water, ultrasonically for 20 minutes, and adding GO until form a suspension. Then glutaraldehyde and polyethylene glycol were added to the suspension, the product formed was isolated by centrifugation. After that, MC-GO-Fe_3O_4 was prepared by dissolving MC-GO and Fe_3O_4 in distilled water and then homogenized by sonication, and the product formed was washed with ethanol and dried at 100°C. After the MC-GO-Fe_3O_4 nanocomposite was formed, the GCE was modified and carried out by the drop-drying method. Previously the electrode surface was completely polished by alumina powder for cleaning the electrode surface. Then the electrode is inserted into sulfuric acid and is electrified -1 to 1 V. Then the Fe_3O_4 hydrogel was prepared by dissolving the prepared nanocomposite in water. The hydrogel that has been made is dripped onto the surface of the electrode and the electrode is dried using an oven at a temperature of 50°C.

Sun *et al*. (2014) conducted similar research. They modified GCE with magnetite-reduced graphene oxide (Fe_3O_4-RGO) nanocomposite. GO was synthesized using a graphite precursor and using Hummer's method. The Fe_3O_4 used was synthesized by a hydrothermal pathway with $FeCl_3$ as the precursor. After the Fe_3O_4-RGO nanocomposite was made, the particles were dissolved in alcohol and sonicated to obtain a homogeneous suspension. Then the composite solution was dripped on the surface of the GCE the modified GCE was dried at room temperature.

There is much more research on GCE modification using Fe_3O_4 NPs. For example, the modification of GCE with graphene-chitosan-nano Fe_3O_4/GCE composite was performed by a drop-drying method. Yin *et al*. (2010) modify GCE with Fe_3O_4 particles and Poly amidoamine (PAMAM) by drip suspension of Fe_3O_4 nanoparticles followed by a drip of PAMAM on the surface of GCE to be modified. In addition, GCE modification can also be performed with the addition of an L-Cys/Fe_3O_4 composite. GCE modification is done by the drop-cast method. Then an electrodeposition method is performed to deposit the nanocomposites that have been made on the surface of GCE. After nanocomposite testing, the modified GCE was tested with AuNPs on its surface. Then the nafion ball rn50 was dripped to stabilize the GCE surface. Nafion can protect the L-Cys/Fe3O4 NPs layer from the leaching process which can degrade the layer from the GCE surface (Panhwar *et al*. 2019). An illustration of GCE modification using Fe_3O_4 is shown in Figure 6.

In addition to being composite with other particles, Fe_3O_4 NPS can also be used to directly modified GCE. Such research was conducted by Yang *et al*. (2013) they modify the surface of GCE with Fe_3O_4 NPs, that had been dissolved in DMF by drop method then the modified GCE was dried. Then Yin *et al*. (2011) conducted a similar study but used an aqueous solvent for the suspension of Fe_3O_4 nanoparticles and flowed with N_2 gas. Modification of GCE with Fe_3O_4 nanoparticles was performed by the same method.

APPLICATION OF MODIFICATED GCE

Glassy carbon has found extensive use in voltammetric electrodes in the last twenty years (Kamau 1988). Because of a low residual current over a range of about + 1 V in aqueous media (Zittel & Miller, 1965; Van der Linden & Dieker, 1980) and even more extended range in aqueous micellar solutions (Kamau *et al*. 1987) and in organic

solvents (Thornton *et al*. 1985), glassy carbon has been used extensively as an indicator electrode (Kamau 1988).

One of the most common applications for glassy carbon is its use as electrodes for electrochemical sensors. The performance of electrochemical sensors with glassy carbon electrodes can be improved by various modifications. Many studies have been carried out to modify the glassy carbon electrode. (Saby *et al*. 1997; Kim *et al*. 2007; Shahrokhian *et al*. 2009; Thiagarajan *et al*. 2009; Oztekin *et al*. 2010; Mostafavi *et al*. 2011; Yan *et al*. 2013). For example, detecting metal ions can be performed by GCE modified with nanoparticles (Gong *et al*. 2010; Yin *et al*. 2010).

The application-modified GCE allows its users to be more widely used so that it can use as a sensor for detecting various materials, both organic and inorganic. An example of an application of a modified GCE is to be a sensor for the presence of lead dissolved in water (Yang *et al*. 2013), ascorbic acid, dopamine, uric acid (Thiagarajan *et al*. 2009; Yan *et al*. 2013), thioridazine, (Shahrokhian *et al*. 2009), and copper metal (Oztekin *et al*. 2010).

Modification of GCE with Fe_3O_4 nanoparticles also has various attractive applications for detecting several materials. For example, the modification of GCE with Fe_3O_4 NPs combined with methylcellulose/graphene oxide (MC/GO) to become MC/GO/Fe_3O_4 NPs can be used as an electrochemical sensor to detect uric acid levels in urine (Sohouli *et al*. 2020). Uric acid is a product of the enzymatic procesing of purines. (Pachla *et al*., 1987). It has higher toxicity properties than its constituent molecules, namely xanthine and hypoxanthine, because in high concentrations uric acid can cause hyperuricemia. (Dutt & Mottola 1974; Mazzali *et al*. 2001) Therefore, the detection of uric acid becomes very important to do.

In addition to the health sector, modification of GCE with Fe_3O_4 NPs can be used in the food sector. Research relevant to the application of GCE modified with Fe_3O_4 in the food sector is its use in detecting Sudan I (1-Phenylazo-2-naphthol). Sudan I causes tumors in the liver and bladder of mice and can be a potential carcinogen and mutagen for humans. (Stiborová *et al*. 2002) which has been classified as a category 3 carcinogen by the International Agency for Research on Cancer (IARC). Therefore, GCE modified with Fe Fe_3O_4 can be a solution as a simple, easy, and accurate method to identify Sudan I in food (Yin *et al*. 2011).

The modified GCE with Fe_3O_4 NPS can also be applied in the field of biochemistry. For example, it is used to detect *Escherichia coli*. In order it can be used as a sensor for *E. coli*, GCE was modified with Fe_3O_4 combined with L-Cysteine to form a composite of L-Cys/Fe_3O_4 NPs. *E. coli* is one of the pathogenic bacteria that is harmful to human health. In Pakistan, 40% of deaths that occur are caused by poor water quality due to contamination with *E. coli*, *Salmonella typhimurium*, *Vibrio cholera*, and *Shigella* bacteria. (Panhwar *et al*. 2019) Conventional methods used to detect the presence of microorganisms in water require a lot of time, require qualified instruments and trained human resources. (Wang *et al*. 2017) Thus, GCE modified with L-Cys-Fe_3O_4 composite can be a solution to detect *E. coli* quicker.

Furthermore, GCE modified with Fe_3O_4 NPs can be utilized in the environmental field. The modified GCE can be used to detect the content of dissolved metals in water such as Cd^{2+} ions. To detect Cd^{2+} in water, GCE was modified with Fe_3O_4 combined with reduced graphene oxide (RGO) (Sun *et al*. 2014). Besides being used to detect Cd^{2+}, Fe_3O_4 NPs modified GCE can also be used to detect Pb (II) (Yang *et al*. 2013).

CONCLUSIONS

Nano-sized materials have unique properties and characteristics. So it can be used in various fields. One of the popular nanoparticles is magnetite nanoparticles. Magnetite particles have several advantages such as being super magnetic, having a high saturation field, chemical stability, biocompatibility, and low production costs. Many methods can be used to synthesize magnetite nanoparticles including coprecipitation, microemulsion, sol-gel, hydrothermal, and thermal decomposition. With various advantages of magnetite nanoparticles, these particles can be used to modify GCE. The GCE proposed by magnetite nanoparticles can have more use. Some examples of GCE applications that have been tested by nano magnetite were to detect uric acid in the urine, Sudan I in food, *E. coli*, and water-soluble metals such as Pb (II) and Cd (II).

REFERENCES

Ahmadi, R., Hosseini, M.H. & Masoudi, A. (2011). Avrami behavior of magnetite nanoparticles formation in co-precipitation process. *Journal of Mining and Metallurgy B: Metallurgy*. **47(2)**: 211-218.

Ahmadi, R., Masoudi, A., Hosseini, H.R.M. & Gu, N. (2013). Kinetics of magnetite nanoparticles formation in a one step low temperature hydrothermal process. *Ceramics International*, **39(5)**: 4999-5005.

Ahmadi, S., Chia, C.H., Zakaria, S., Saeedfar, K. & Asim, N. (2012). Synthesis of Fe_3O_4 nanocrystals using hydrothermal approach. *Journal of Magnetism and Magnetic Materials*, **324(24)**: 4147-4150.

Ali, A., Zafar, H., Zia, M., ul Haq, I., Phull, A.R., Ali, J.S. & Hussain, A., (2016). Synthesis, characterization, applications, and challenges of iron oxide nanoparticles. Nanotechnology, Science and Applications. **9**: 49-67.

Asuha, S., Suyala, B., Siqintana, X. & Zhao, S. (2011). Direct synthesis of Fe_3O_4 nanopowder by thermal decomposition of Fe–urea complex and its properties. *Journal of Alloys and Compounds*. **509(6)**: 2870-2873.

Boxall, C., Kelsall, G. & Zhang, Z. (1996). Photoelectrophoresis of colloidal iron oxides. Part 2.—Magnetite (Fe_3O_4). *Journal of the Chemical Society, Faraday Transactions*. **92(5)**: 791-802.

Chifiriuc, M.C., Grumezescu, A.M., Andronescu, E., Ficai, A., Cotar, A.I., Grumezescu, V., Bezirtzoglou, E., Lazar, V. & Radulescu, R. (2013). Water dispersible magnetite nanoparticles influence the efficacy of antibiotics against planktonic and biofilm embedded *Enterococcus faecalis* cells. *Anaerobe*. **22**: 14-19.

Chin, S.F., Pang, S.C. & Tan, C.H. (2011). Green synthesis of magnetite nanoparticles (via thermal decomposition method) with controllable size and shape. *Journal of Materials and Environmental Science*. **2(3)**: 299-302

Dutt, V.V.S.E. & Mottola, H.A. (1974). Determination of uric acid at the microgram level by a kinetic procedure based on a pseudo-induction period. *Analytical Chemistry*. **46(12)**: 1777-1781.

El Ghandoor, H., Zidan, H.M., Khalil, M.M. & Ismail, M.I.M. (2012). Synthesis and some physical properties of magnetite (Fe_3O_4) nanoparticles. *International Journal of Electrochemical Science*. **7(6)**: 5734-5745.

Fan, R., Chen, X.H., Gui, Z., Liu, L. & Chen, Z.Y. (2001). A new simple hydrothermal preparation of nanocrystalline magnetite Fe_3O_4. *Materials Research Bulletin*. **36(3-4)**: 497-502.

Ghazanfari, M.R., Kashefi, M., Shams, S.F. & Jaafari, M.R. (2016). Perspective of Fe_3O_4 nanoparticles role in biomedical applications. *Biochemistry Research International*. **2016**: 7840161.

Glasgow, W., Fellows, B., Qi, B., Darroudi, T., Kitchens, C., Ye, L., Crawford, T.M. & Mefford, O.T. (2016). Continuous synthesis of iron oxide (Fe_3O_4) nanoparticles via thermal decomposition. *Particuology*. **26**: 47-53.

Gong, J., Zhou, T., Song, D. & Zhang, L. (2010). Monodispersed Au nanoparticles decorated graphene as an enhanced sensing platform for ultrasensitive stripping voltammetric detection of mercury (II). *Sensors and Actuators B: Chemical*. **150(2)**: 491-497.

Hao, R., Xing, R., Xu, Z., Hou, Y., Gao, S. & Sun, S. (2010). Synthesis, functionalization, and biomedical applications of multifunctional magnetic nanoparticles. *Advanced Materials*. **22(25)**: 2729-2742.

Kamau, G.N. (1988). Surface preparation of glassy carbon electrodes. *Analytica Chimica Acta*. **207**: 1-16.

Kamau, G.N., Leipert, T., Shukla, S.S. & Rusling, J.F. (1987). Electrochemistry of bipyridyl derivatives of cobalt in solutions of anionic and cationic micelles. *Journal of Electroanalytical Chemistry and Interfacial Electrochemistry*. **233(1-2)**: 173-187.

Kim, S.H., Kim, M.J. & Choa, Y.H. (2007). Fabrication and estimation of Au-coated Fe_3O_4 nanocomposite powders for the separation and purification of biomolecules. *Materials Science and Engineering: A*. **449**: 386-388.

Koo, K.N., Ismail, A.F., Othman, M.H.D., Bidin, N. & Rahman, M.A. (2019). Preparation and characterization of superparamagnetic magnetite (Fe_3O_4) nanoparticles: A short review. *Malaysian Journal of Fundamental and Applied Science*. **15(1)**: 23–31.

Lemine, O.M., Omri, K., Zhang, B., El Mir, L., Sajieddine, M., Alyamani, A. & Bououdina, M. (2012). Sol–gel synthesis of 8 nm magnetite (Fe_3O_4) nanoparticles and their magnetic properties. *Superlattices and Microstructures*. **52(4)**: 793-799.

Li, X.M., Xu, G., Liu, Y. & He, T. (2011). Magnetic Fe_3O_4 nanoparticles: Synthesis and application in water treatment. *Nanoscience & Nanotechnology-Asia*. **1(1)**: 14-24.

Li, Z., Kawashita, M., Araki, N., Mitsumori, M., Hiraoka, M. & Doi, M. (2010). Magnetite nanoparticles with high heating efficiencies for application in the hyperthermia of cancer. *Materials Science and Engineering: C*. **30(7)**: 990-996.

Lu, T., Wang, J., Yin, J., Wang, A., Wang, X. & Zhang, T. (2013). Surfactant effects on the microstructures of Fe_3O_4 nanoparticles synthesized by microemulsion method. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. **436**: 675-683..

Maity, D., Choo, S.G., Yi, J., Ding, J. & Xue, J.M. (2009a). Synthesis of magnetite nanoparticles via a solvent-free thermal decomposition route. *Journal of Magnetism and Magnetic Materials*, **321(9)**: 1256-1259.

Maity, D., Kale, S.N., Kaul-Ghanekar, R., Xue, J.M. & Ding, J. (2009b). Studies of magnetite nanoparticles synthesized by thermal decomposition of iron (III) acetylacetonate in tri (ethylene glycol). *Journal of Magnetism and magnetic Materials*. **321(19)**: 3093-3098.

Malik, M.A., Wani, M.Y. & Hashim, M.A. (2012). Microemulsion method: A novel route to synthesize organic and inorganic nanomaterials: 1st Nano Update. *Arabian Journal of Chemistry*. **5(4)**: 397-417.

Mazzali, M., Hughes, J., Kim, Y.G., Jefferson, J.A., Kang, D.H., Gordon, K.L., Lan, H.Y., Kivlighn,

S. & Johnson, R.J. (2001). Elevated uric acid increases blood pressure in the rat by a novel crystal-independent mechanism. *Hypertension*. **38(5)**: 1101-1106.

Meng, H., Zhang, Z., Zhao, F., Qiu, T. & Yang, J. (2013). Orthogonal optimization design for preparation of Fe_3O_4 nanoparticles via chemical coprecipitation. *Applied Surface Science*. **280**: 679-685.

Mostafavi, S.M., Rouhollahi, A., Adibi, M., Mohajeri, A., Pashaee, F. & Pyriaee, M. (2011). Modification of glassy carbon electrode by a simple, inexpensive and fast method using an ionic liquid based on immidazolium as working electrode in electrochemical determination of some biological compounds. *Asian Journal of Chemistry*. **23(12)**: 5247-5252

Niculescu, A.G., Chircov, C. & Grumezescu, A.M. (2021). Magnetite nanoparticles: Synthesis methods–a comparative review. *Methods*. **199**: 16-27

Nigam, B., Mittal, S., Prakash, A., Satsangi, S., Mahto, P.K. & Swain, B.P. (2018). Synthesis and characterization of Fe_3O_4 nanoparticles for nanofluid applications-a review. IOP Conference Series: Materials Science and Engineering. **377(1)**: 012187.

Oztekin, Y., Tok, M., Nalvuran, H., Kiyak, S., Gover, T., Yazicigil, Z., Ramanaviciene, A. & Ramanavicius, A. (2010). Electrochemical modification of glassy carbon electrode by poly-4-nitroaniline and its application for determination of copper (II). *Electrochimica Acta*. **56(1)**: 387-395.

Pachla, L.A., Reynolds, D.L., Wright, D.S. & Kissinger, P.T. (1987). Analytical methods for measuring uric acid in biological samples and food products. *Journal of the Association of Official Analytical Chemists*. **70(1)**: 1-14.

Panhwar, S., Hassan, S.S., Mahar, R.B., Carlson, K. & Talpur, M.Y. (2019). Highly sensitive and selective electrochemical sensor for detection of *Escherichia coli* by using L-cysteine functionalized iron nanoparticles. *Journal of the Electrochemical Society*. **166(4)**: B227.

Qi, H., Yan, B., Lu, W., Li, C. & Yang, Y. (2011). A non-alkoxide sol-gel method for the preparation of magnetite (Fe_3O_4) nanoparticles. *Current Nanoscience*. **7(3)**: 381-388.

Saby, C., Ortiz, B., Champagne, G.Y. & Bélanger, D. (1997). Electrochemical modification of glassy carbon electrode using aromatic diazonium salts. 1. Blocking effect of 4-nitrophenyl and 4-carboxyphenyl groups. *Langmuir*. **13(25)**: 6805-6813.

Shahrokhian, S., Ghalkhani, M., Adeli, M. & Amini, M.K. (2009). Multi-walled carbon nanotubes with immobilised cobalt nanoparticle for modification of glassy carbon electrode: Application to sensitive voltammetric determination of thioridazine. *Biosensors and Bioelectronics*. **24(11)**: 3235-3241.

Shaker, S., Zafarian, S., Chakra, C.S. & Rao, K.V. (2013). Preparation and characterization of magnetite nanoparticles by sol-gel method for water treatment. *International Journal of Innovative Research in Science, Engineering and Technology*. **2(7)**: 2969-2973.

Shalaby, T.I., El-Kady, M.F., Zaki, A.E.H.M. & El-Kholy, S.M. (2017). Preparation and application of magnetite nanoparticles immobilized on cellulose acetate nanofibers for lead removal from polluted water. *Water Science and Technology: Water Supply*. **17(1)**: 176-187.

Sohouli, E., Khosrowshahi, E.M., Radi, P., Naghian, E., Rahimi-Nasrabadi, M. & Ahmadi, F. (2020). Electrochemical sensor based on modified methylcellulose by graphene oxide and Fe_3O_4 nanoparticles: Application in the analysis of uric acid content in urine. *Journal of Electroanalytical Chemistry*. **877**: 114503.

Stiborová, M., Martínek, V., Rýdlová, H., Hodek, P. & Frei, E. (2002). Sudan I is a potential carcinogen for humans: evidence for its metabolic activation and detoxication by human recombinant cytochrome P450 1A1 and liver microsomes. *Cancer Research*. **62(20)**: 5678-5684.

Sun, Y.F., Chen, W.K., Li, W.J., Jiang, T.J., Liu, J.H. & Liu, Z.G. (2014). Selective detection toward Cd^{2+} using Fe_3O_4/RGO nanoparticle modified glassy carbon electrode. *Journal of Electroanalytical Chemistry*. **714**: 97-102.

Takai, Z.I., Mustafa, M.K., Asman, S. & Sekak, K.A. (2019). Preparation and characterization of magnetite (Fe_3O_4) nanoparticles by sol-gel method. *International Journal of Nanoelectronics and Materials*. **12(1)**: 37-46.

Thiagarajan, S., Tsai, T.H. & Chen, S.M. (2009). Easy modification of glassy carbon electrode for simultaneous determination of ascorbic acid, dopamine and uric acid. *Biosensors and Bioelectronics*. **24(8)**: 2712-2715.

Thornton, D.C., Corby, K.T., Spendel, V.A., Jordan, J., Robbat, A., Rutstrom, D.J., Gross, M. & Ritzler, G. (1985). Pretreatment and validation procedure for glassy carbon voltammetric indicator electrodes. *Analytical Chemistry*. **57(1)**: 150-155.

Van der Linden, W.E. & Dieker, J.W. (1980). Glassy carbon as electrode material in electro-analytical chemistry. *Analytica Chimica Acta*. **119(1)**: 1-24.

Vidal-Vidal, J., Rivas, J. & López-Quintela, M.A. (2006). Synthesis of monodisperse maghemite nanoparticles by the microemulsion method. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. **288(1-3)**: 44-51.

Vuong, T.K.O., Le, T.L., Pham, D.V., Pham, H.N., Le Ngo, T.H., Do, H.M. & Nguyen, X.P. (2015). Synthesis of high-magnetization and monodisperse Fe_3O_4 nanoparticles via thermal decomposition. *Materials Chemistry and Physics*. **163**: 537-544.

Wang, D., Chen, Q., Huo, H., Bai, S., Cai, G., Lai, W. & Lin, J. (2017). Efficient separation and quantitative detection of *Listeria monocytogenes* based on screen-printed interdigitated electrode, urease and magnetic nanoparticles. *Food Control*. **73**: 555-561.

Wei, Y., Han, B., Hu, X., Lin, Y., Wang, X. & Deng, X. (2012). Synthesis of Fe_3O_4 nanoparticles and their magnetic properties. *Procedia Engineering*. **27**: 632-637.

Worawong, A., Jutarosaga, T. & Onreabroy, W., (2014). Influence of calcination temperature on synthesis of magnetite (Fe_3O_4) nanoparticles by sol-gel method. *Advanced Materials Research*. **979**: 208-211.

Xia, Y., Yang, P., Sun, Y., Wu, Y., Mayers, B., Gates, B., Yin, Y., Kim, F. & Yan, H. (2003). One-dimensional nanostructures: synthesis, characterization, and applications. *Advanced Materials*. **15(5)**: 353-389.

Xu, J., Yang, H., Fu, W., Du, K., Sui, Y., Chen, J., Zeng, Y., Li, M. & Zou, G. (2007). Preparation and magnetic properties of magnetite nanoparticles by sol–gel method. *Journal of Magnetism and magnetic Materials*. **309(2)**: 307-311.

Yan, J., Liu, S., Zhang, Z., He, G., Zhou, P., Liang, H., Tian, L., Zhou, X. & Jiang, H. (2013). Simultaneous electrochemical detection of ascorbic acid, dopamine and uric acid based on graphene anchored with Pd–Pt nanoparticles. *Colloids and Surfaces B: Biointerfaces*. **111**: 392-397.

Yang, Y., You, Y., Liu, Y. & Yang, Z. (2013). A lead (II) sensor based on a glassy carbon electrode modified with Fe_3O_4 nanospheres and carbon nanotubes. *Microchimica Acta*. **180(5)**: 379-385.

Yin, H., Cui, L., Chen, Q., Shi, W., Ai, S., Zhu, L. & Lu, L. (2011). Amperometric determination of bisphenol A in milk using PAMAM–Fe_3O_4 modified glassy carbon electrode. *Food Chemistry*. **125(3)**: 1097-1103.

Yin, H., Zhou, Y., Ma, Q., Ai, S., Chen, Q. & Zhu, L. (2010). Electrocatalytic oxidation behavior of guanosine at graphene, chitosan and Fe_3O_4 nanoparticles modified glassy carbon electrode and its determination. *Talanta*. **82(4)**: 1193-1199.

Yin, H., Zhou, Y., Meng, X., Tang, T., Ai, S. & Zhu, L. (2011). Electrochemical behaviour of Sudan I at Fe_3O_4 nanoparticles modified glassy carbon electrode and its determination in food samples. *Food Chemistry*. **127(3)**: 1348-1353.

Yin, Z., Wu, J. & Yang, Z. (2010). A sensitive mercury (II) sensor based on CuO nanoshuttles/poly (thionine) modified glassy carbon electrode. *Microchimica Acta*. **170(3)**: 307-312.

Zhang, Y., Chai, C.P., Luo, Y.J., Wang, L. & Li, G.P. (2014). Synthesis, structure and electromagnetic properties of mesoporous Fe_3O_4 aerogels by sol–gel method. *Materials Science and Engineering: B*. **188**: 13-19.

Zittel, H.E. & Miller, F.J. (1965). A glassy-carbon electrode for voltammetry. *Analytical Chemistry*. **37(2)**: 200-203.