

## Ultrasonic assisted Preparation and Characterization of conductive Polyaniline-Modified Magnetite nanocomposites (PAni/Fe<sub>3</sub>O<sub>4</sub> nanocomposites)

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### Abstract

Polyaniline (PAni) is one of the most widely studied conducting polymers due to its easy synthesis method, reversible chemical reaction, and high environmental stability, low cost and flexible electrical conductivity. Blending PAni with some quantity of aniline dimer-COOH modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles, form novel composites with suitable electric and magnetic properties. Standard four-point probe apparatus were used to measure the conductivity of pure Aniline, Polyaniline (PAni) and PAni/Fe<sub>3</sub>O<sub>4</sub> nanocomposites, while magnetic properties of the magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles and PAni/Fe<sub>3</sub>O<sub>4</sub> nanocomposites were recorded on Vibrating Sample Magnetometer (VSM). It was found that the electrical conductivity was increase and decrease with addition of Fe<sub>3</sub>O<sub>4</sub> nanoparticles ( $1.8 \times 10^{-9}$  S/cm,  $6.32 \times 10^{-1}$  S/cm, and  $2.3 \times 10^{-3}$  S/cm). It was also observed that the composites exhibit super paramagnetic performance with saturation magnetization ( $M_s$ ) of  $M_s = 22.5 \text{ emug}^{-1}$ . The morphology and elemental composition analysis of the modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PAni/Fe<sub>3</sub>O<sub>4</sub> nanocomposites was study by Field Emission Scanning Electron Microscope (FESEM). However, the obtained Fe<sub>3</sub>O<sub>4</sub> nanoparticles result was found to be spherical and agglomerated, due to higher magnetic attraction between the particles, while the modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles embedded in the PAni nanotubes lead to the formation of the composites with clear nanofibers structure, furthermore the EDS result indicated the present if Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PAni nanotubes contain Fe<sub>3</sub>O<sub>4</sub> nanoparticles. The absorption analysis of the modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PAni/Fe<sub>3</sub>O<sub>4</sub> nanocomposites studied by UV-visible found to be 370 nm and 650 nm respectively which is attributed  $\pi$ - $\pi$  transition of benzenoid ring of PAni, suggesting that the conductive PAni was formed. However, this result was further supported by XRD and FTIR analysis.

**Keyword;** Polyaniline, Fe<sub>3</sub>O<sub>4</sub> nanoparticles, Composites, Conductivity, FESEM.

### Introduction

Nowadays, the functionalized electromagnetic nanostructure of the conducting polymers has become field of interest by many researchers, owing to their potential application in the field of science and engineering due to their unique optical, electric and magnetic properties [1, 2].

One of the major taxes is to design a nanostructure that would have a significant effect on the magnetic and dielectric properties. Blending magnetic nanoparticles with conducting polymers has become a promising and most considerable approach to achieve desired modulated electromagnetic functional nanomaterials [3, 4]. Polyaniline (PAni) is one of the outstanding conducting polymer with essential electrical conductivity, its good reversible redox reaction, excellent processibility and high environmental stability, as well as several potentials applications make it suitable candidate for many application [5, 6].

The magnetite ( $\text{Fe}_3\text{O}_4$ ) nanoparticles have been extensively studied owing to their unique and tenable magnetic properties, drug/gene delivery, their magnetic feature has been widely used in application as diverse as environmental remediation [7], biomacromolecule separation, magnetic resonance imaging [8], catalyst separation [9], and Magnetic recording release. Blending PAni nanotubes with certain quantity of modified  $\text{Fe}_3\text{O}_4$  nanoparticles, form suitable matrix for achieving PAni/ $\text{Fe}_3\text{O}_4$  nanocomposites or absorption materials by doping with iron oxide nanoparticles, PAni is commonly prepared by oxidizing aniline monomer in acid solution via either chemical or electrochemical method. In comparison with electrochemical method, the chemical preparation of PAni is widely used for mass production [10][11]. Different class of oxidants such as  $(\text{NH}_4)_2\text{S}_2\text{O}_8$ ,  $\text{H}_2\text{Cr}_2\text{O}_7$ ,  $\text{KIO}_3$ , and  $\text{H}_2\text{O}_2$  can be used in the preparation of PAni. Among these oxidants  $(\text{NH}_4)_2\text{S}_2\text{O}_8$  is the most commonly used oxidant [12, 13].  $\text{Fe}_3\text{O}_4$  possesses very good ferromagnetic properties and resistance toward the corrosion due to acid solution. Since  $\text{Fe}_3\text{O}_4$  is hydrophobic material, chemical reaction with PAni increases its dispersion in solution. It also exhibits good electrical behaviour when external electric field is applied to materials [14, 15].

In the current study, polyaniline/iron oxide (PAni/ $\text{Fe}_3\text{O}_4$ ) nanocomposites were prepared by ultrasonic dispersion method. The polymerization of aniline was chemically produced using hydrochloric acid (HCl) as acidic medium and ammonium persulfate  $(\text{NH}_4)_2\text{S}_2\text{O}_8$  as oxidizing agent which leads to the formation of electromagnetic PAni/ $\text{Fe}_3\text{O}_4$  nanocomposites. These composites were synthesized using uniform dispersion of  $\text{Fe}_3\text{O}_4$  nanoparticles in hydrochloric acid, aniline and  $\text{Fe}_3\text{O}_4$  nanoparticles were polymerized together, to obtain homogeneous composites of PAni/ $\text{Fe}_3\text{O}_4$  nanocomposites. This work was based on ultrasonic technique to produce stable PAni nanotubes containing modified  $\text{Fe}_3\text{O}_4$  nanoparticles. However, the electric and magnetic properties of the composites were further analyzed using standard four point probe apparatus and Vibrating Sample Magnetometer

(VSM) respectively, furthermore the composites were characterized by Field Emission Scanning Electron Microscope (FESEM), Fourier Transformation Infrared Spectroscopy (FTIR), X-ray diffraction Spectra (XRD) and Ultraviolet (UV-vis)

## Materials

In this work, PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites were synthesis using ultrasonic techniques. (FeCl<sub>3</sub>) (Guangdong Xirong Chemical Plan), ferrous chloride (FeCl<sub>2</sub>) (Chongqing Beibei Chemical Reagent Factory), ammonium hydroxide (NH<sub>4</sub>OH) (R & M Chemical), N-phenyl-1,4-phenylenediamine (Tianjin Tiantai Fine Chemical Co., Ltd), Succinic anhydride (Sinopharm Chemical Reagent Co., Ltd), Diethyl ether, and dichloromethane CH<sub>2</sub>Cl<sub>2</sub> (R & M Chemical). Aniline (C<sub>6</sub>H<sub>5</sub>NH<sub>2</sub> R & M chemicals) ammonium peroxodisulfate (NH<sub>4</sub>)<sub>2</sub>S<sub>2</sub>O<sub>8</sub> and hydrochloric acid (HCl R & M 37%) were used in the production of PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites, the entire chemical was use without further purification.

### Aniline dimer-COOH Preparation

The preparation aniline dimer-COOH was carryout under 200-ml round bottom flask using mechanical stirrer. 0.721 g of N-phenyl-1, 4-phenylenediamine and 3.5 g of succinic anhydride were dissolved into a 30 ml of dichloromethane (CH<sub>2</sub>Cl<sub>2</sub>) under mechanical stirrer for a period of 5h. As the reaction attend some period of time, the white grey precipitate was achieved, finally, the precipitate was washed, filtered and then dried in the vacuum for 24h.

### Preparation of magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles

The Fe<sub>3</sub>O<sub>4</sub> nanoparticles was achieved when 1.82g of FeCl<sub>2</sub> .4H<sub>2</sub>O and 3.7 g of FeCl<sub>3</sub> .6H<sub>2</sub>O was dissolved in 60 ml distilled water the influence of magnetic stirrer. The reaction was allowed to be heated to 60<sup>0</sup>C, then 10 ml ammonium (NH<sub>4</sub>) was added into the reaction, followed by addition of 400 mg of aniline dimer-COOH in 5 ml of acetone the reaction was then allowed to continue for 1.5h at 90<sup>0</sup>C under mechanical stirrer to obtained stable water base suspension. The reaction was allowed to cool to ambient temperature, then filtered, washed and dried for 12h in the vacuum.

### Preparation of polyaniline/magnetite (PANi/Fe<sub>3</sub>O<sub>4</sub>) nanocomposites

PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites were synthesized by ultrasonic irradiation method. In the typical procedure, 500 mg of Fe<sub>3</sub>O<sub>4</sub> nanoparticles modified with aniline dimer-COOH were successfully dispersed in 30 ml of HCl solution in 200 ml beaker under magnetic stirrer at 0-10 °C. However, 0.5 g of aniline was added to the above mixture. A solution of 1.22 g

ammonium persulfate (APS) was dissolved in 30 ml of HCl solution and then added in drop wise to the to the above reaction for a period of 10 min. The reaction was stirred under ultrasonic disperser for 7h and filtered. The precipitate were washed with distilled water and methanol several times; the product was then dried under vacuum at 50<sup>0</sup>C for 24h.

### Characterization

The conductivity of PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites and PANi were measured by standard four-point probe apparatus (Guangzhou semiconductor materials) at ambient temperature. The magnetic properties of the modified magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles, as well as PANi/Fe<sub>3</sub>O<sub>4</sub>, were measured using vibrating sample magnetometer JDM-1 in the magnetic field of 15kOe at room temperature. Fourier Transformation infrared spectroscopy (FTIR) was used to record the molecular structure and functional group of Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites samples (Nicolet 560 FTIR spectrometer brand). The phase structure of the modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites was estimated using X-ray diffraction analysis (XRD) at a radiation wavelength of ( $\lambda = 0.154$  nm) on X-pert pro MPD diffractometer using Cu K $\alpha$  radiation. The optical absorption spectrum of modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites was taken through ultraviolet UV-vis. The morphologies of PANi nanotubes containing modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles were investigated by Field Scanning Electron Microscopes (FESEM) (JEOL JSM-7600F) equipped with energy dispersive X-ray spectra.

### Result and Discussion

#### UV-vis Analysis

The absorption spectra of the magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles modified aniline dimer-COOH and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites were investigated using UV-vis spectroscopy. The absorption band of the Fe<sub>3</sub>O<sub>4</sub> nanoparticles modified aniline dimer-COOH was observed at a wavelength of 250 nm and 370 nm. That corresponds to the  $\pi$ - $\pi^*$  transition in the benzenoid ring of the aniline dimer-COOH [16, 17]. However, Fe<sub>3</sub>O<sub>4</sub> nanoparticles sample modified with aniline dimer-COOH was repeatedly washed with acetone and ethanol which can easily dissolve aniline dimer-COOH completely strongly indicated that there is some interaction between aniline dimer-COOH and Fe<sub>3</sub>O<sub>4</sub> nanoparticles. The absorption spectra of PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites was observed at 370 nm and 650 nm as shown in Fig. 1, the first

absorption band can be attributed due to partial  $\pi$ - $\pi^*$  transition of benzenoid ring and partly polaron band transition due to broad feature  $\text{Fe}_3\text{O}_4$  nanoparticles while the second transition can be assigned to the polaron band transition, suggesting that the conductive PANi was formed [18, 19].

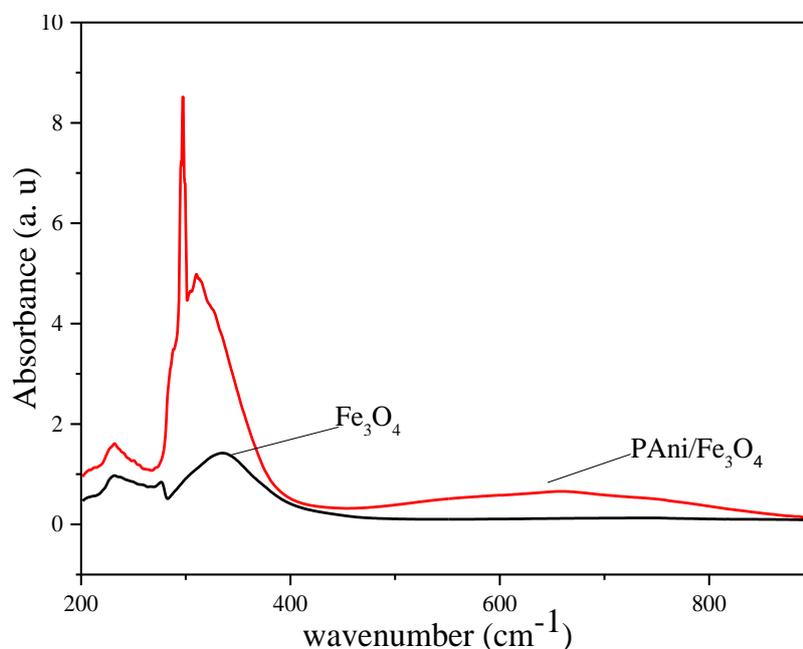


Fig. 1: UV-vis of modified  $\text{Fe}_3\text{O}_4$  nanoparticles and PANi/ $\text{Fe}_3\text{O}_4$  nanocomposites

### FTIR Analysis

The IR spectra of  $\text{Fe}_3\text{O}_4$  nanoparticles modified with aniline dimer-COOH indicate the existence of peak at  $3238\text{ cm}^{-1}$ ,  $2819\text{ cm}^{-1}$  and  $1663\text{ cm}^{-1}$ ,  $1415\text{ cm}^{-1}$ ,  $1214\text{ cm}^{-1}$ ,  $1089\text{ cm}^{-1}$  and  $832\text{ cm}^{-1}$  are assigned for O-H stretching, C-H stretching, C=C stretching, C=O stretching and C-O stretching bands respectively indicating the acidic medium condition of  $\text{Fe}_3\text{O}_4$  preparation. A peak at  $557\text{ cm}^{-1}$  is representing the characteristic peak of Fe-O stretching band [20]. While, PANi/ $\text{Fe}_3\text{O}_4$  nanocomposites spectra, it was found that a peak at  $3328\text{ cm}^{-1}$  (N-H stretching) is slightly disappeared due to a weak vibration, thus a chemical interactions of the nanocomposites attachment occurred. A peaks at  $2828\text{ cm}^{-1}$ ,  $2258\text{ cm}^{-1}$ ,  $1767\text{ cm}^{-1}$ ,  $1588\text{ cm}^{-1}$  and  $1588\text{ cm}^{-1}$  represent of C=O, C=H, C=N and C=C stretching of quinoid and benzeoid rings, respectively. Meanwhile, a peak at  $1303\text{ cm}^{-1}$  assigned for C-N secondary aromatic amine stretching [21]. The C-H deformation bond at 1,4-disubstituted benzene ring is confirmed at peaks  $943\text{ cm}^{-1}$  and  $825\text{ cm}^{-1}$ . The differences of peaks shifting on both  $\text{Fe}_3\text{O}_4$  nanoparticles and PANi/ $\text{Fe}_3\text{O}_4$  nanocomposites spectra are occurred due to the

weakening in the PANi bonds [22]. Most of those peaks are slightly diminished in the PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites spectra, thus showing that the blending of Fe<sub>3</sub>O<sub>4</sub> on the PANi matrix is successfully formed [23].

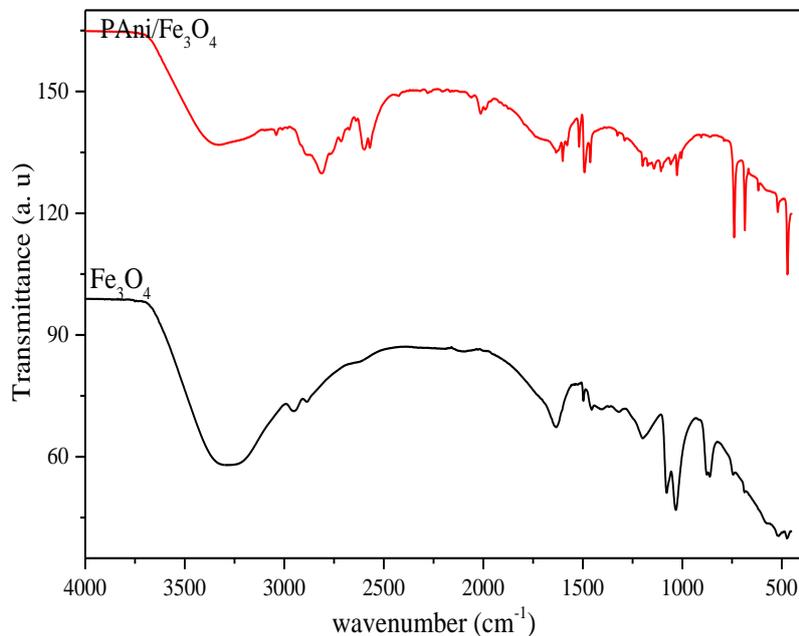


Fig. 2: FTIR analysis of modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites

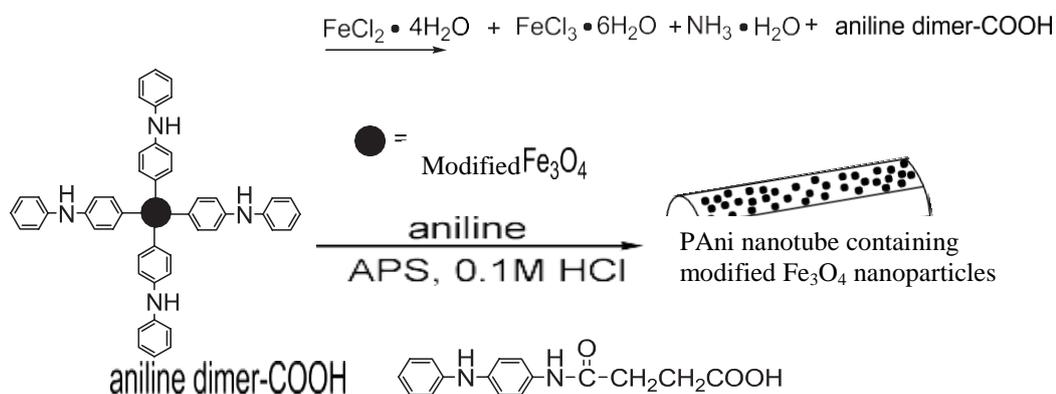


Fig 3. Scheme representation of modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposite prepared by ultrasonic irradiation

### VSM Analysis

The magnetic properties of the modified Aniline dimer-COOH magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites were recorded on the standard vibrating sample magnetometer (VSM) apparatus at room temperature. A typical magnetization curve

was plotted as a function of applied field at ambient temperature (300K) as shown in Fig 3, the  $\text{Fe}_3\text{O}_4$  nanoparticles exhibit soft magnetism with a low remanence (13.85 emu/g) and low coercive force (25.95 Oe). The saturation magnetization of the magnetic nanoparticles is found to be 58.10 emu/g, which is much higher than that of the nanoparticles prepared by the common microwave irradiation method (about 40–55 emu/g) [21], while PAni/ $\text{Fe}_3\text{O}_4$  nanocomposites was observed at 22.5 emu/g. The high drying temperature in the modified  $\text{Fe}_3\text{O}_4$  nanoparticles results in a higher crystallinity and consequently leads to a higher saturation magnetization [24]. While in the observation of the hysteresis loop of the particles exhibits essentially no remanence or coercive force. This interesting result explodes the previous conclusion that ferromagnetic particles can be dispersed in aqueous media. The remanence and the coercive force of the  $\text{Fe}_3\text{O}_4$  nanoparticles dispersed in aqueous solution are found to decrease to 0.042 emu/g and 1.94 Oe, respectively.

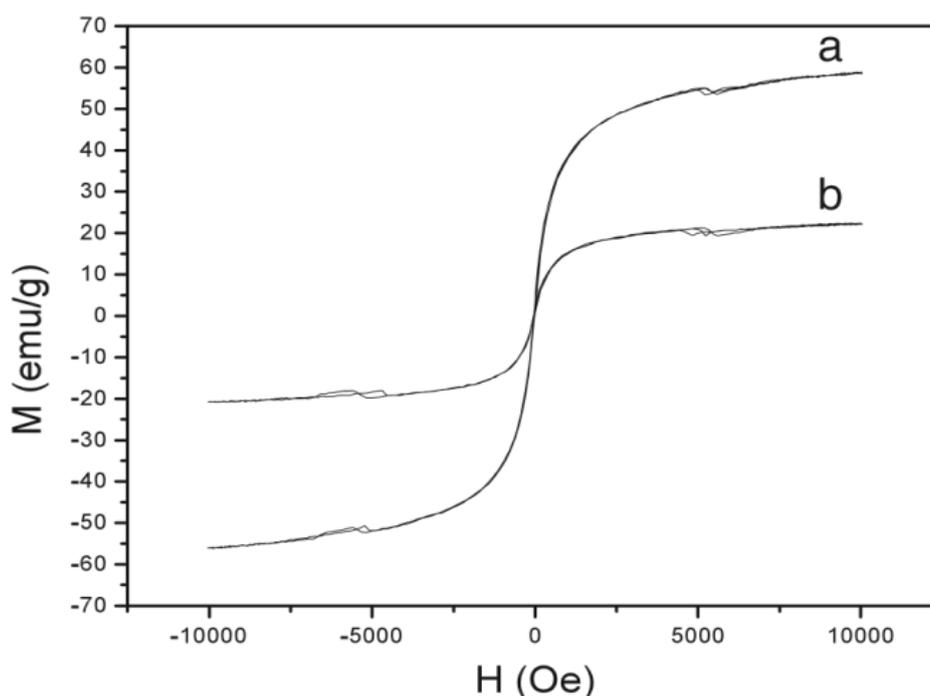


Fig. 4: Magnetization versus applied magnetic field at room temperature for the (a) aniline dimer–COOH capped  $\text{Fe}_3\text{O}_4$  nanoparticles and (b) PAni/ $\text{Fe}_3\text{O}_4$  nanocomposite.

This phenomenon indicates that if suitable surface modification is performed to decrease the magnetic force between the adjacent nanoparticles, the ferromagnetic particles can rely on the Brownian motion to disrupt the chain-like structure induced by the magnetic moment, and then a transformation from ferromagnetism of the particles to a hysteresis loop with much small remanence and coercive force of the particles suspension appears. In this case, there

will be no significant magnetic interactions remaining after removing the external magnetic field, which is important for achieving a reproducible and reversible optical response [25].

## XRD Analysis

The phase structure of modified  $\text{Fe}_3\text{O}_4$  nanoparticles and PAni/ $\text{Fe}_3\text{O}_4$  nanocomposites were estimated using X-ray diffraction spectra (XRD) the polymeric composite was achieved under chemical state of iron oxide after being incorporated into the PAni matrix. However, the characteristic peaks for the composites were identified, the peaks at  $2\theta = 24.2^\circ, 32.3^\circ, 35.65^\circ, 41.3^\circ, 43.4^\circ, 47.3^\circ, 49.6^\circ, 54.2^\circ, 58.42^\circ, 63.2^\circ, 64.3^\circ, 72.12^\circ$  and  $78.7^\circ$  correspond to the (101), (110), (311), (202), (302), (222), (122), (331), (112), (401), (501), (411), (143), and (201) Bragg reflection respectively, absence of peaks from  $10^\circ$  to  $20^\circ$  indicated the amorphous behaviour of PAni containing  $\text{Fe}_3\text{O}_4$  nanoparticles [26][27]. Furthermore, these results indicated that  $\text{Fe}_3\text{O}_4$  nanoparticles are still present in the structure, while the average size of the particles was calculated from half-width of the diffraction peaks using equation (1).

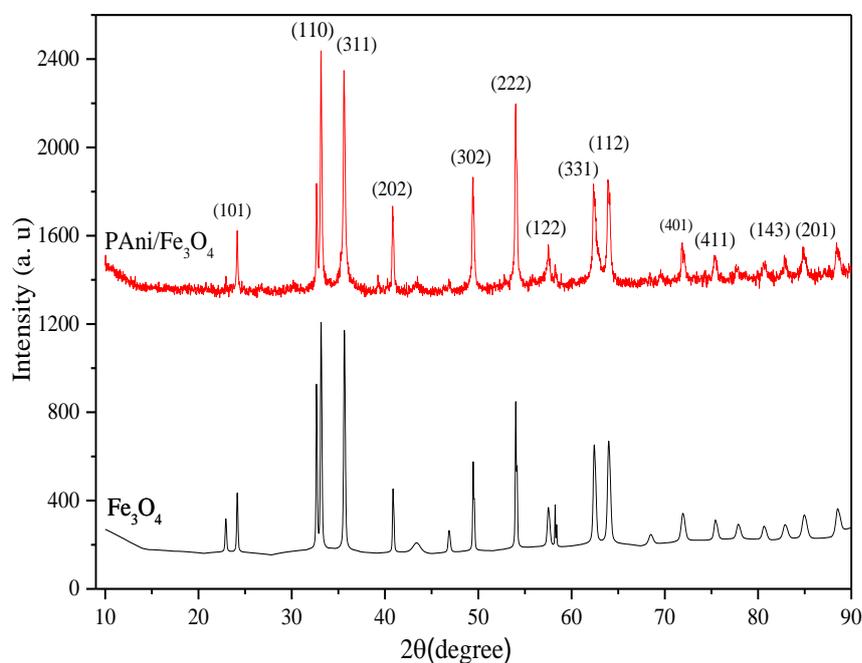


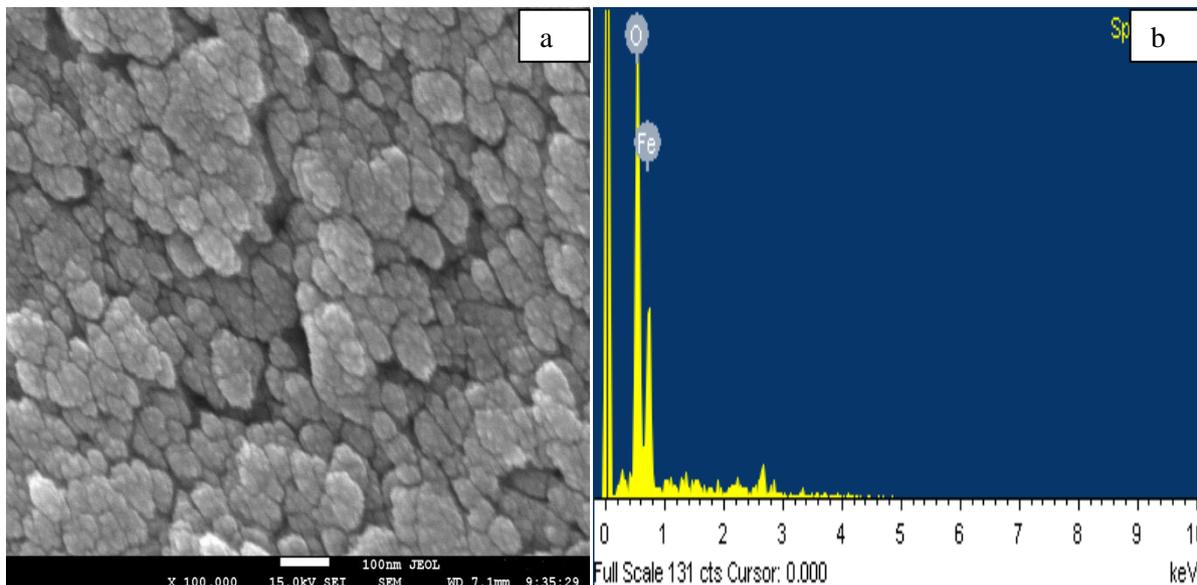
Fig. 5: XRD analysis of modified  $\text{Fe}_3\text{O}_4$  nanoparticles and PAni/ $\text{Fe}_3\text{O}_4$  nanocomposites

$$D = \frac{K \cdot \lambda}{\beta \cdot \cos \theta} \quad (1)$$

Where K (0.94) is a dimensionless quantity,  $\lambda$  is the X-ray wavelength,  $\beta$  is the line broadening at half-maximum intensity (FWHM) and  $\theta$  is the Bragg angle. Therefore, the obtained particles size was calculated using equation (1), the result showed the average particles size was calculated by Scherer's formula and found to be 30 nm.

### FESEM Analysis

The morphologies of the  $\text{Fe}_3\text{O}_4$  nanoparticles and PANi/ $\text{Fe}_3\text{O}_4$  nanoparticles and EDX was investigated using Field Emission Scanning Electron Microscopes (FESEM) equipped with energy dispersive X-ray (EDX), it was observed that the morphology of  $\text{Fe}_3\text{O}_4$  nanoparticles modified aniline dimer-COOH was found to be spherical. However, the spherical nanoparticle has higher internationalization rate and high cellular take up than another shape like nanorod or nanodisk [29]. The tendency of agglomeration of nanomaterials is a direct consequence with enhancement of surface energy and small grain sizes of the particles [28]. The  $\text{Fe}_3\text{O}_4$  nanoparticles exhibit small grain size and consequently enhanced surface energy, hence, their agglomeration is expected and clearly observed in the FESEM analysis, and this agglomeration could be attributed to magnetic dipole interaction with neighbouring  $\text{Fe}_3\text{O}_4$  nanoparticles [27]. Reduction in surface energy and magnetic dipolar interaction prompt the modified  $\text{Fe}_3\text{O}_4$  nanoparticles to surround the PANi nanotubes and settle at the surface of the PANi matrix [25].



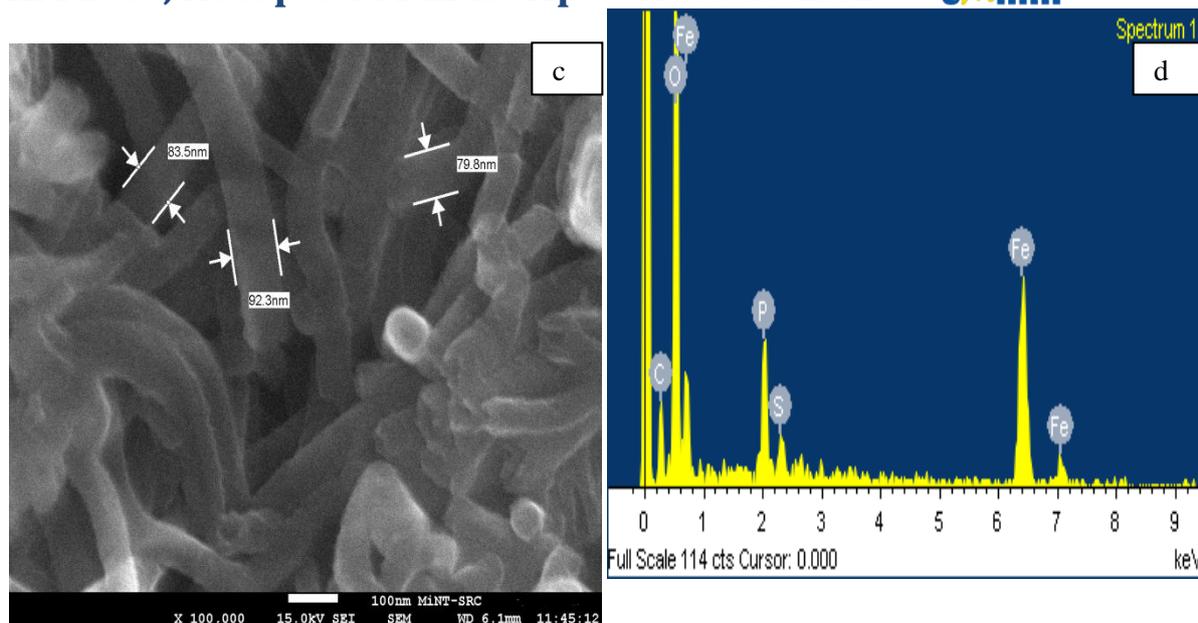


Fig. 6: FESM image of a & b) modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles and EDX spectra c & d) PANi nanotubes containing Fe<sub>3</sub>O<sub>4</sub> nanoparticles

While embedding PANi nanotubes with certain quantity of modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles leads to the formation of PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites with very clear nanofibers structures, are due to possible interaction between PANi and modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles the aniline molecules may be absorbed on the surface of Fe<sub>3</sub>O<sub>4</sub> nanoparticles [30]. The PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites was successfully synthesized through ultrasonic irradiation method, the Fig 5 present the typical FESEM and EDX image of Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites, the result proven the appearance nanofiber in the PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites, while the EDX result indicate the present of Fe<sub>3</sub>O<sub>4</sub> nanoparticles and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites.

### Electrical Conductivity Study

The electrical conductivity of pure aniline, polyaniline (PANi) and PANi nanotube congaing modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles was estimated using four-point probe method. It was found that the conductivity of pure aniline (acid free) is  $1.8 \times 10^{-9}$  S/cm. While the electric conductivity of polyaniline (PANi) was found to increase to  $6.32 \times 10^{-1}$  S/cm, further addition of modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles decrease the conductivity of PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites to  $2.3 \times 10^{-3}$  S/cm. This fluctuation of the conductivity values is due to insulation behaviour of Fe<sub>3</sub>O<sub>4</sub> nanoparticles introduce in to PANi matrix[31]. Fig. 6 shows the variation of conductivities of aniline, Polyaniline and PANi/Fe<sub>3</sub>O<sub>4</sub> nanocomposites

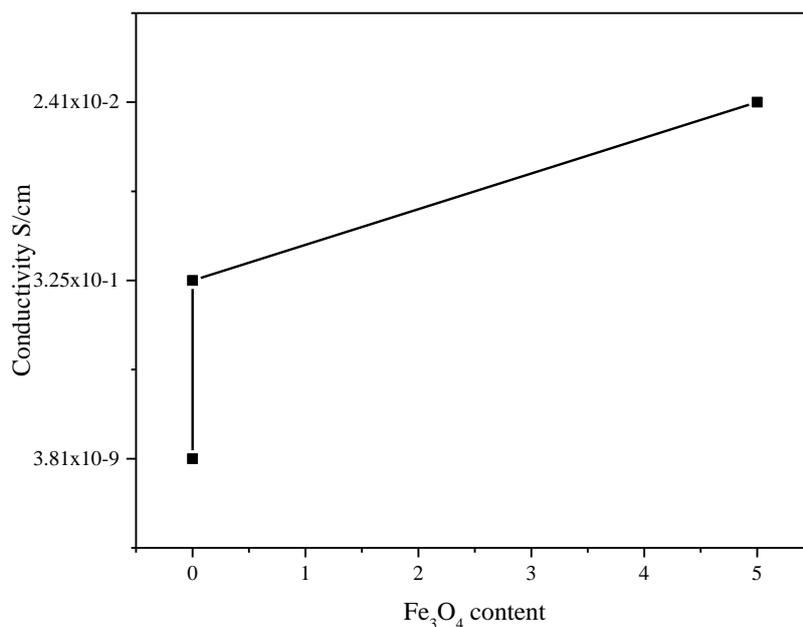


Fig. 7: variation of conductivities of Aniline, Polyaniline and PAni/Fe<sub>3</sub>O<sub>4</sub> nanocomposites

## Conclusion

Polyaniline (PAni) containing modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles was successfully prepared via ultrasonic irradiation method, the polymerization of aniline was carried out in the presence of HCl and ammonium persulfate (APS) as oxidant. The electrical conductivity of aniline, polyaniline and PAni/Fe<sub>3</sub>O<sub>4</sub> nanocomposites was recorded on four-point probe apparatus. It was found that the conductivity initially increased and then decreased due to the addition of Fe<sub>3</sub>O<sub>4</sub> nanoparticles in the composites ( $1.8 \times 10^{-9}$ ,  $6.32 \times 10^{-1}$  and  $2.3 \times 10^{-3}$ ). Furthermore, the magnetic properties of the magnetite nanoparticles and PAni/Fe<sub>3</sub>O<sub>4</sub> nanocomposites were measured by VSM, the results of the Fe<sub>3</sub>O<sub>4</sub> nanoparticles were found to be within the range of ferromagnetic magnetic nanoparticles and decreased with the addition of polyaniline in the matrix. Moreover, the morphology analysis investigated by FESEM showed that Fe<sub>3</sub>O<sub>4</sub> nanoparticles are spherical in nature while PAni nanotubes containing modified Fe<sub>3</sub>O<sub>4</sub> nanoparticles show the morphology of nanofibers. However, the composites were further characterized by FTIR, XRD and UV-vis. The obtained XRD results indicate the presence of PAni containing Fe<sub>3</sub>O<sub>4</sub> nanoparticles were further supported by FTIR and UV-vis analysis.

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