



## Synthesis, Characterization, Morphology and Adsorption Performance towards $\text{Cu}^{+2}$ Ions of Nano-Sized Copolymers of Anthranilic Acid and *o*-phenylenediamine Poly(AA-co-*o*-PD)



**Abdel-Fattah F. Shaaban\***, Amal M. Metwally, Mohamed M. Azab, Amaal A. Mahmoud and Hager M. Ali

*Chemistry Department, Faculty of Science, Benha University, Benha, Egypt.*

**N**ANORODES, nanosheets, nanospheres and nano-amorphous shape with different particles size of copolymer of anthranilic acid with *o*-phenylenediamine poly(AA-co-*o*-PD) were synthesized by redox polymerization initiated by  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  as redox initiator and ammonium peroxydisulfate (APS) as oxidant in different concentrations of aqueous solutions of hydrochloric acid. The influence of synthetic parameters such as acid concentration and the presence of redox initiator were investigated. The morphology and particles size were studied by transmission electron microscope (TEM) and scanning electron microscope (SEM). The results showed that the morphology and average particle size of polymeric nano particles according to SEM and TEM analyses were different based upon the conditions of the copolymerization. The physico-chemical characterization of the prepared nanoparticles was carried out by Fourier transform infrared spectroscopy (FT-IR), X-ray powder diffraction (XRD). Which FT-IR confirmed the structure of poly(AA-co-*o*-PD) nanoparticles in emeraldine form. The molecular weight was determined by gel permeation chromatography (GPC). The surface area of nanocopolymer particles was determined also by Brunauer-Emmett-Teller (BET). The competition of the prepared nano-sized copolymers particles towards the adsorption of copper ions from aqueous solutions was investigated. The results showed that the adsorption capacity was based on particle size of nanocopolymers and their surface area. The adsorption capacity increased with decreasing the particle size. On the other hand the adsorption capacity increased with increasing the surface area of the prepared nano-sized copolymers of poly(AA-co-*o*-PD).

**Keywords:** Polymeric nanoparticles (PNPs), Copolymerization, Anthranilic acid, *o*-phenylenediamine, Ammonium peroxydisulfate (APS),  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , adsorption.

### Introduction

Polymeric nanoparticles (PNPs) are defined as solid particles with size between 10-1000 nm which are prepared from biodegradable polymers. The field of polymer nanoparticles is quickly expanding and playing an important role in a wide spectrum of areas ranging from electronics, photonics, conducting materials, sensors, medicine, biotechnology, pollution control and environmental technology. The properties of PNPs have to be optimized depending on the

particular application. In order to achieve the properties of interest, the mode of preparation plays a vital role. Thus, it is highly advantageous to have preparation techniques at hand to obtain PNPs with the desired properties for a particular application [1-15]. There are many methods for preparation (PNPs) from dispersion of preformed polymer and from polymerization of monomers, which include Emulsion, Mini-emulsion, Micro-emulsion, Interfacial and controlled radical polymerization [16-18].

\*Corresponding author. e-mail: afshaaban@hotmail.com

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There are a lot of methods for synthesizing of polyaniline (PANI) or polyaniline derivatives which have been applied such as electropolymerization, interfacial polymerization, chemical oxidative polymerization and chemical redox polymerization. However there are many methods for synthesizing polyaniline or its derivatives, the redox chemical polymerization was used due to its advantages such as reduced pollution, rapid, simple, economic and environmental friendly route [19,20].

Anthranilic acid in this polymerization was used due to the limited solubility of polyaniline in most organic solvents so, we can modify some properties of polyaniline by polymerization its derivatives such as, anthranilic acid which is soluble in common organic solvents [21-23]. In addition, polyanthranilic acid (PANA) is the best of polyaniline derivative due to the presence of withdrawing carboxylic group (-COOH) in the polymer backbones and electrochemical activity in wide pH range.

Ortho phenylenediamine (*o*-PD) has a structure consisting of 1,4-substituted benzenoid and quinoid moieties was proposed for the polymer obtained electrochemically and it exhibits high thermostability [24]. *o*-PD is soluble electroactive in the polymer due to its dissolution in organic solvents. The two oxidizable groups attaching to the aromatic ring in *o*-phenylenediamine (-NH<sub>2</sub>) make these sites more reactive, these sites have a very important role in the polymerization. So that, (*o*-PD) has electrochemical behavior as anthranilic acid compared with anilines and phenols.

Although many papers have been published in synthesizing of PANA [1,23,25], the literature is scanty concerning the synthesis of the nanocopolymer of poly(AA-co-*o*-PD) by the redox polymerization.

In this study, for the first time poly(AA-co-*o*-PD) nanostructures have been synthesized using redox copolymerization by APS as oxidant, FeSO<sub>4</sub> as redox initiator in different conditions of aqueous solution of HCl (0.1 M, 0.5 M in the light, 0.5 M in the dark and 0.1 M without using FeSO<sub>4</sub>.7H<sub>2</sub>O). The synthesized nano-sized copolymers of poly(AA-co-*o*-PD) were used in removing the copper ions from aqueous solutions.

#### Experimental & Characterization Techniques

##### Materials

Ammonium peroxydisulfate (APS) was obtained from Merck, India. Anthranilic acid  
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was obtained from Rolex India Ltd, India and *o*-phenylenediamine (FLUKA) was used without further purification. FeSO<sub>4</sub>.7H<sub>2</sub>O was obtained from Aldrich, USA. Hydrochloric acid from (Merck, India). Deionized water was used to the preparation of the aqueous solutions.

##### Synthesis of nano-sized copolymers of poly(AA-co-*o*-PD) by copolymerization initiated by redox initiator

Typically, anthranilic acid (0.096 g, 0.7 mmol), *o*-phenylenediamine (0.075 g, 0.7 mmol) and FeSO<sub>4</sub>.7H<sub>2</sub>O (0.09 g, 0.3 mmol) were dissolved in 20 ml of 0.1 M HCl solution with magnetic stirring until they completely dissolved. A fresh solution of APS (0.12 g, 0.5 mmol) in 20 ml of 0.1 M HCl solution was rapidly added to the above solution containing anthranilic acid, *o*-phenylenediamine and FeSO<sub>4</sub>.7H<sub>2</sub>O. Upon the addition of APS to the transparent solution, turbidity solution was observed with naked eye without any precipitates. The reaction was left on magnetic stirrer for 1hr then, the copolymerization reaction was carried out for 24 hrs at room temperature without any disturbance. The black precipitate was filtered off, washed with 0.1 M of HCl followed by deionized water several times, and dried at room temperature for 24 hrs to give nano-sized copolymer (AA-co-*o*-PD). The same polymerization method was carried out using 0.5 M HCl in the light, 0.5 M HCl in the dark and 0.1 M HCl without adding FeSO<sub>4</sub>.7H<sub>2</sub>O to give different nanostructures and different nanoparticle sizes of these different conditions.

##### Adsorption of copper ions using nano-sized copolymers of poly(AA-co-*o*-PD)

The adsorption experiment has been studied by batch technique. 0.1 g of the prepared nano-sized copolymers and 100 ml of the labeled 10.5 mmol/L copper solution with uniform speed using a thermostated shaker bath for 3 hrs. The experiment was carried out at 25 °C. Before adding the adsorbent, an aliquot of the bulk solution was withdrawn for the measurement of the initial concentration. For the evaluations of capacity (q<sub>e</sub>) of the prepared nano-sized copolymers. At the end of time, the solution was filtered for phase separation and the concentration of supernatant solutions was measured, then q<sub>e</sub> (adsorption capacity) for adsorbed copper on the prepared nano-sized copolymers was determined from the following equation:

$$q_e = (C_0 - C_e) \times \frac{V}{m} \quad (\text{mg/g}) \quad (1)$$

Where  $C_0$  and  $C_e$  are the initial and equilibrium Cu (II) ion concentration in the aliquots, respectively.  $V$  (L) is the solution volume and  $m$  (g) is the mass of sorbent.

#### Characterization Techniques

##### Morphology properties of poly(AA-co-o-PD)

Morphology and particle size of nano-sized copolymers of poly(AA-co-o-PD) were determined using transmission electron microscopy (TEM) (JEOL [JEM-1230 electron microscopy]), the sample was obtained as follows: ultrafine powder of sample was dispersed in water under ultra-sonication, and then one drop of the suspension was suspended and evaporated on a carbon coated copper grid and placed in the Phillips (CM/TEM). Also scanning electron microscope (SEM) (QUANTA 250 SEG, HOLANDA) microanalyzer microscope was used to determine the morphology and particle size of nano-sized copolymers.

##### FT-IR measurements

The IR spectra for the prepared nano-sized copolymers of poly(AA-co-o-PD) were measured using Thermofisher Nicolette IS10, USA in the range of 400–4000  $\text{cm}^{-1}$  Spectrophotometer.

##### Surface area

Porous structure parameters of the nano-sized copolymers of poly(AA-co-o-PD) were described by Brunauer–Emmett–Teller (BET) and BJH methods through  $\text{N}_2$  adsorption–desorption methods to inspect the porous properties of the nano-sized copolymers using nitrogen as the adsorbent at 77.35 K. The measurements were executed using a model NOVA 3200 automated gas sorption system (Quantachrome, USA).

##### X-Ray Diffraction (XRD)

The X-ray diffraction of the prepared nano-sized copolymers of poly(AA-co-o-PD) were obtained from Diano X-ray diffractometer using Cu  $K\alpha$  radiation ( $\lambda = 1.5418 \text{ \AA}$ ).

##### Determination of molecular weight by gel permeation chromatography (GPC)

Molecular weight of the prepared nano-sized copolymers was measured using Gel permeation Chromatography type; 1,100, Germany. The measurements were conducted at ambient temperature using dimethyl formamide (DMF) as the mobile phase at flow rate of 1.0 ml/min. poly(AA-co-o-PD) samples were dissolved in the same solvent as the mobile phase at concentration of 5 mg/ml.

##### Determination of the copper ions concentration

Copper ions concentration was determined by using Hitachi atomic absorption Z-6100 polarized Zeeman spectrometer.

## Result and Discussion

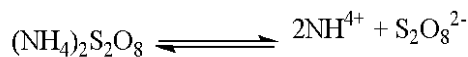
##### Synthesis of nano-sized copolymers of poly(AA-co-o-PD)

poly(AA-co-o-PD) nanospheres, nanorodes, nanosheets and nano amorphous shape structures with different particles size were synthesized by redox copolymerization of anthranilic acid with *o*-phenylenediamine initiated by redox initiator ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ) and using ammonium peroxydisulfate (APS) as an oxidant in different conditions of aqueous solution of HCl (0.1 M, 0.5 M in the light, 0.5 M in the dark and 0.1 M without using  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ). Scheme 1 illustrated the mechanism of copolymerization of anthranilic acid with *o*-phenylenediamine [26]. Table 1 illustrated all the comparisons of the prepared nanoparticles in different conditions of copolymerization.

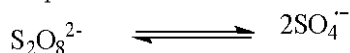
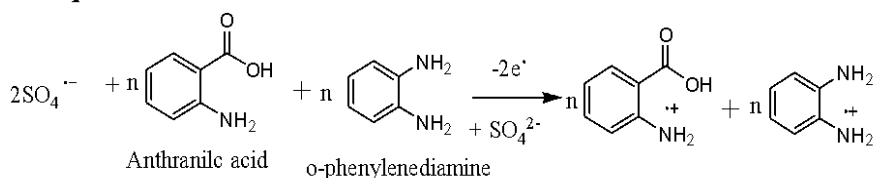
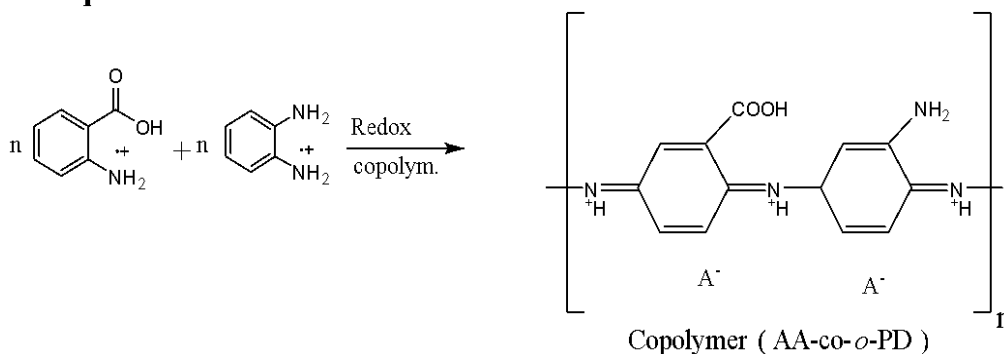
##### Characterization of the prepared nanoparticles

##### Morphology properties of nano-sized copolymers of poly(AA-co-o-PD)

The morphology and particle size of prepared nanoparticles of poly(AA-co-o-PD) samples were investigated by transmission electron microscope (TEM) and scanning electron microscope (SEM). **Figure 1** showed TEM images of the synthesized poly(AA-co-o-PD) prepared by redox copolymerization initiated by  $\text{FeSO}_4$  as redox initiator at different conditions. **Figure 1** showed TEM images of poly(AA-co-o-PD) nano-amorphous shape, nanorodes, nanospheres and nanosheets structure with different particles size with average diameter of 42.5, 297.5, 375 and 452.5 nm in case of 0.1 M, 0.5 M of HCl in light, 0.5 M of HCl in the dark and without using  $\text{FeSO}_4$ , respectively. We observed that the morphology and particle size of nano-sized copolymers were different according to the copolymerization conditions. It can be seen that 0.1 M of HCl showed nano-amorphous shape with average diameter of 42.5 nm. After increasing the concentration of HCl to 0.5 M, we observed that the amorphous shape aggregated in nanorodes structure with increasing the particle size to 297.5 nm. However, poly(AA-co-o-PD) of nanospheres with the average diameter of 375 nm were obtained by the same method except that the copolymerization was carried out in the dark. Finally, the last condition of copolymerization in

**Step i**

Amm.persulfate

**Step ii****Step iii****Scheme 1. Mechanism of copolymerization of anthranilic acid and o-phenylenediamine.****TABLE 1 :Copolymerization of anthranilic acid with o-phenylenediamine at different conditions .**

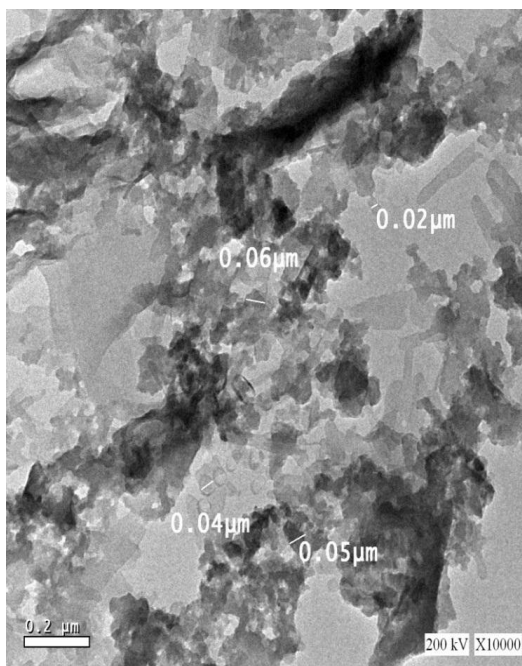
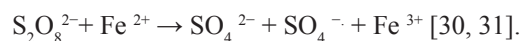
Average particle size in TEM analyses	BET Surface area (m <sup>2</sup> /g)	Morphology (shape of particles)	Copolymerization conditions
nm 42.5	180.49	Nano-amorphous shape	APS, FeSO <sub>4</sub> , 0.1 M of HCl
nm 297.5	155.35	Nanorodes	(APS, FeSO <sub>4</sub> , 0.5 M of HCl (in the light
nm 375	96.52	Nanospheres	(APS, FeSO <sub>4</sub> , 0.5 M of HCl (in the dark
nm 452.5	89.66	Nanosheets	APS, 0.1 M of HCl, without FeSO <sub>4</sub>

the absence of redox initiator (FeSO<sub>4</sub>) at 0.1 M HCl, it appeared as flakes in shape which was nanosheets structure with average diameter of 452.5 nm. The morphologies of the synthesized nano-sized copolymers of poly(AA-co-o-PD) were also analyzed by SEM and their photographs were shown in **Figure 2**. It can be seen that the nano-sized copolymers of poly(AA-co-o-PD)

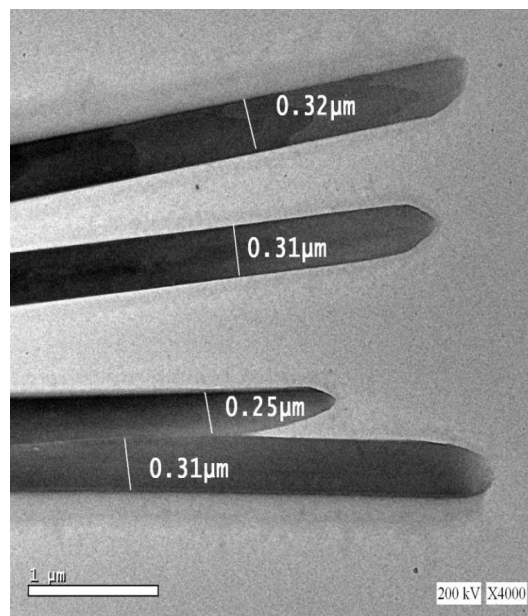
showed lamellar structure and this kind of loose structure has many pores, which is advantageous to the electron transfer processes and doping and dedoping processes of the anions. The redox copolymerization initiated by FeSO<sub>4</sub> as redox initiator at different conditions made the aggregation of the particles more close [27, 28]. The concentration of HCl affects the properties of

the copolymer in morphology and particle size. It has also been shown in SEM analysis figure 2 (a-d) that homogenous nucleation promotes the formation of nanostructures as crystals and sheets at different conditions of copolymerization. The rate of copolymerization of anthranilic acid and *o*-phenylenediamine with the aid of  $\text{Fe}^{2+}$  ions is much faster than that without the aid of  $\text{Fe}^{2+}$  ions [29]. When APS is added into solution containing

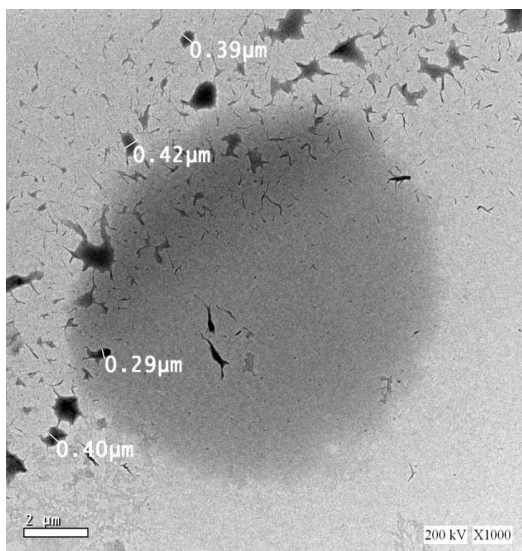
anthranilic acid, *o*-phenylenediamine and  $\text{FeSO}_4$ , APS can react with  $\text{Fe}^{2+}$  ions instantaneously to produce sulfate radical anions because  $\text{Fe}^{2+}$  ions have a lower oxidation potential than anthranilic acid and *o*-phenylenediamine. The classical chemical formula is expressed as follows:



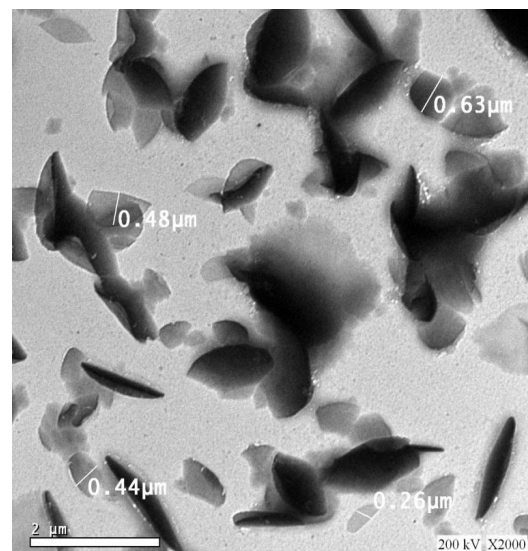
(a)



(b)

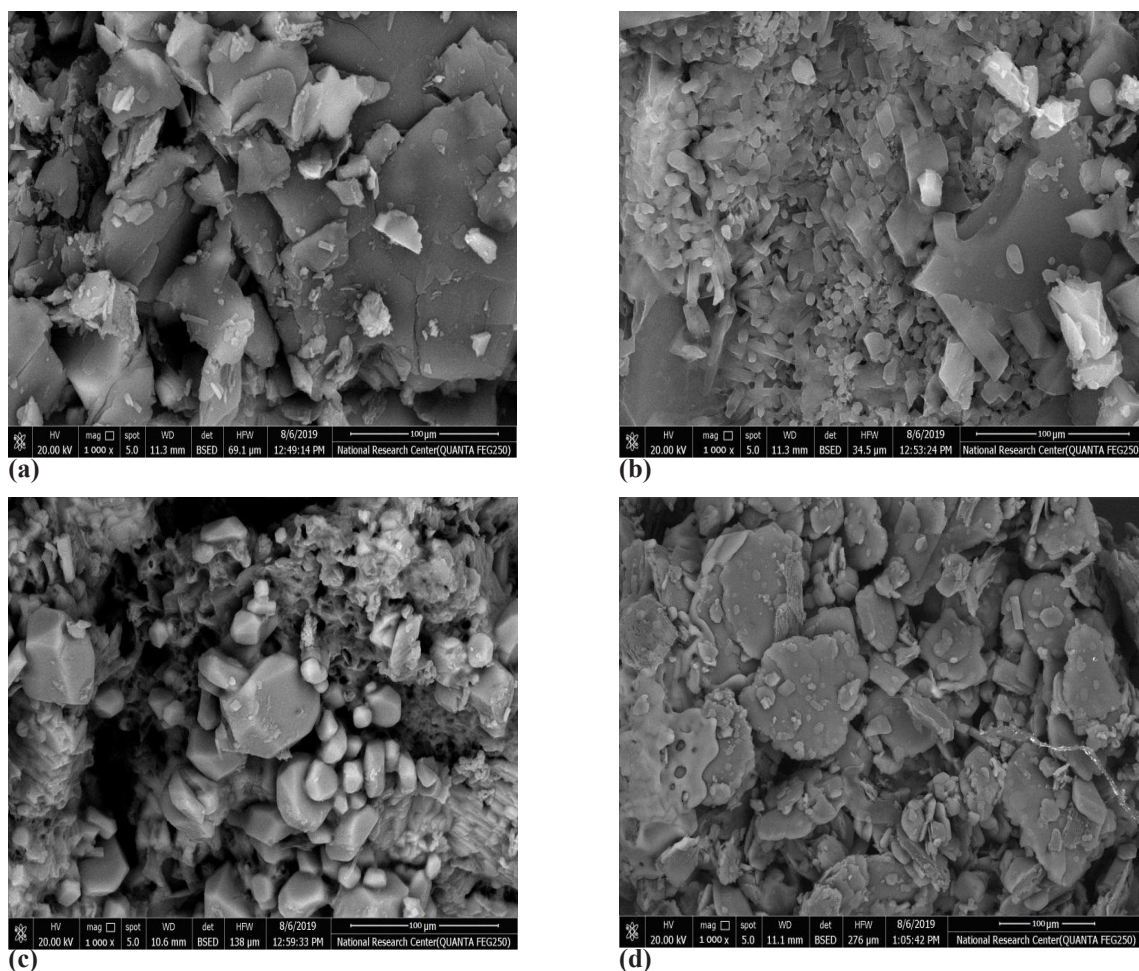


(c)



(d)

**Fig. 1.** TEM images of the prepared nano-sized copolymers of poly(AA-co-*o*-PD) samples at different conditions (a) 0.1 M of HCl, (b) 0.5 M of HCl in the light, (c) 0.5 M of HCl in the dark and (d) 0.1 M of HCl without using  $\text{FeSO}_4$ .



**Fig. 2.** SEM images of the prepared nano-sized copolymers of poly(AA-co-o-PD) samples at different conditions (a) 0.1 M of HCl, (b) 0.5 M of HCl in the light, (c) 0.5 M of HCl in the dark and (d) 0.1 M of HCl without using  $\text{FeSO}_4$ .

#### FT-IR spectra of nano-sized copolymers of poly(AA-co-o-PD)

FT-IR spectra of four different conditions of copolymer of poly(AA-co-o-PD) were given in **Figure 3**. As shown in Figure 3(a-d) nano-sized copolymers of poly(AA-co-o-PD) showed approximately similar bands of FT-IR of function groups which proved that the four different conditions give the same structure of poly(AA-co-o-PD). The presence of ( $-\text{NH}_2$ ) primary amino groups in the IR spectra in all the nanocopolymers indicates that the copolymer was formed through the head-to-tail coupling of the two monomers via  $-\text{NH}-$  groups [32]. The peak that appears in the region  $3410\text{--}3479\text{ cm}^{-1}$  is due to primary amine ( $-\text{NH}_2$ ) group [33]. The range  $1667\text{--}1690\text{ cm}^{-1}$  a strong band appears for the  $\text{C}=\text{O}$  stretching in all nanocopolymers. The peaks in range  $3129\text{--}3237\text{ cm}^{-1}$  can be assigned to  $\text{NH}$  group. The spectra exhibit main bands in the range  $1626\text{--}1638\text{ cm}^{-1}$

and  $1573\text{--}1589\text{ cm}^{-1}$  corresponding to the  $\text{C}=\text{C}$  stretching frequency of benzenoid and quinoid rings, respectively. The peaks  $1045\text{--}1079\text{ cm}^{-1}$  can be assigned to a vibration mode of the  $-\text{NH}^+=$  structure, which is formed by protonation. The range of  $1406\text{--}1412\text{ cm}^{-1}$  is due to  $\text{C}=\text{N}$  stretching in the aromatic ring. Peaks in the range  $856\text{--}922\text{ cm}^{-1}$  can be assigned to 1,2,4- tri-substituted benzene structure [34]. The remaining range of bands  $746\text{--}762\text{ cm}^{-1}$  could be attributed to the out-of-plane  $\text{C-H}$  bending vibration of the benzene ring. These data revealed to the emeraldine form for nano-sized copolymers of poly(AA-co-o-PD).

#### Surface area

The BET surface area, BJH pore volume and average pore diameter for nano-sized copolymers of poly(AA-co-o-PD) were determined in **Table 2**. by Brunauer–Emmett–Teller (BET) and BJH methods through  $\text{N}_2$  adsorption–desorption methods at  $77.35\text{ K}$ . These data illustrated that

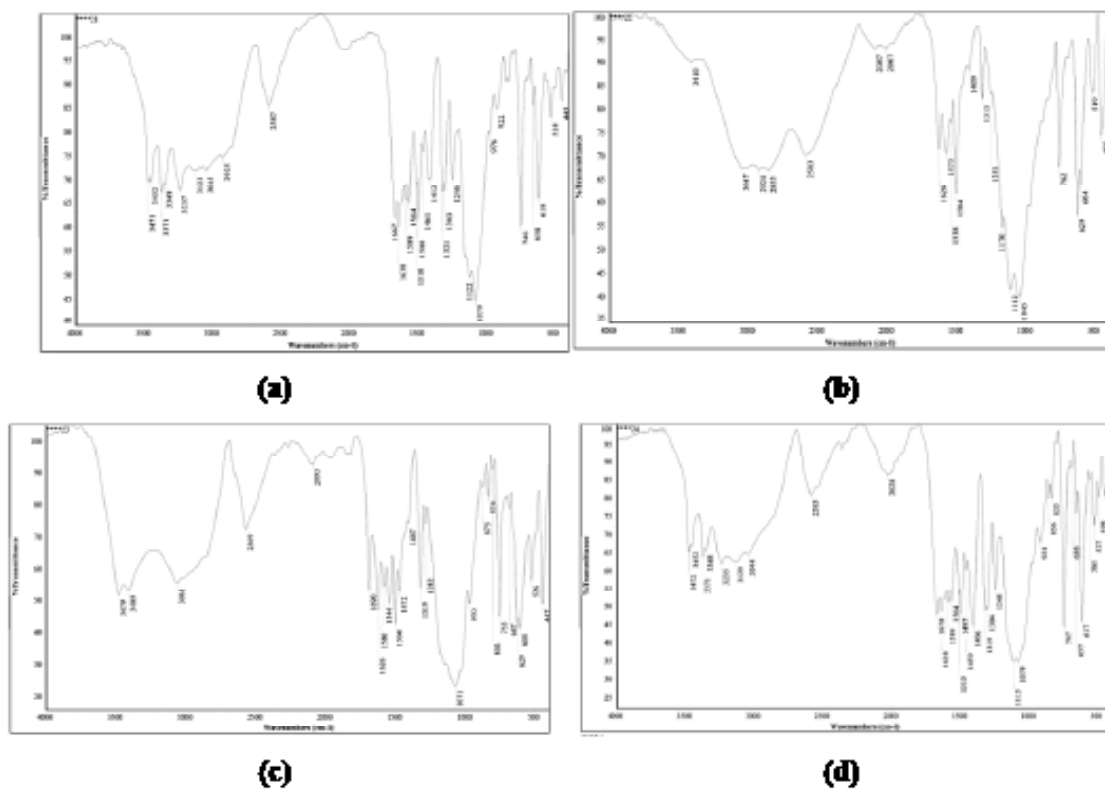


Fig. 3. FT-IR spectra of the prepared nano-sized copolymers of poly(AA-co-o-PD) samples at different conditions (a) 0.1 M of HCl, (b) 0.5 M of HCl in the light, (c) 0.5 M of HCl in the dark and (d) 0.1 M of HCl without using FeSO<sub>4</sub>.

TABLE 2: Porous structure parameters of nano-sized copolymers of poly(AA-co-o-PD).

Copolymerization conditions	BET Surface area (m <sup>2</sup> /g)	BJH desorption average (pore diameter (nm	BJH desorption cumulative (g/ <sup>3</sup> volume of pores (cm
M of HCl 0.1	180.49	8.653	0.4008
(M of HCl (in the light 0.5	155.35	7.316	0.2617
(M of HCl (in the dark 0.5	96.52	4.523	0.2258
(M of HCl (without FeSO <sub>4</sub> 0.1	89.66	3.887	0.1848

the fourth nano-sized copolymers of poly(AA-co-*o*-PD) have different surface area parameters according to the different copolymerization conditions and this leads to an efficient transfer of the metal ions to the internal adsorption sites [35]. This difference in the surface area was suitable with particle sizes determined by TEM, which showed the higher the value in the surface area, the lower the value in the particle sizes by TEM analysis in nm.

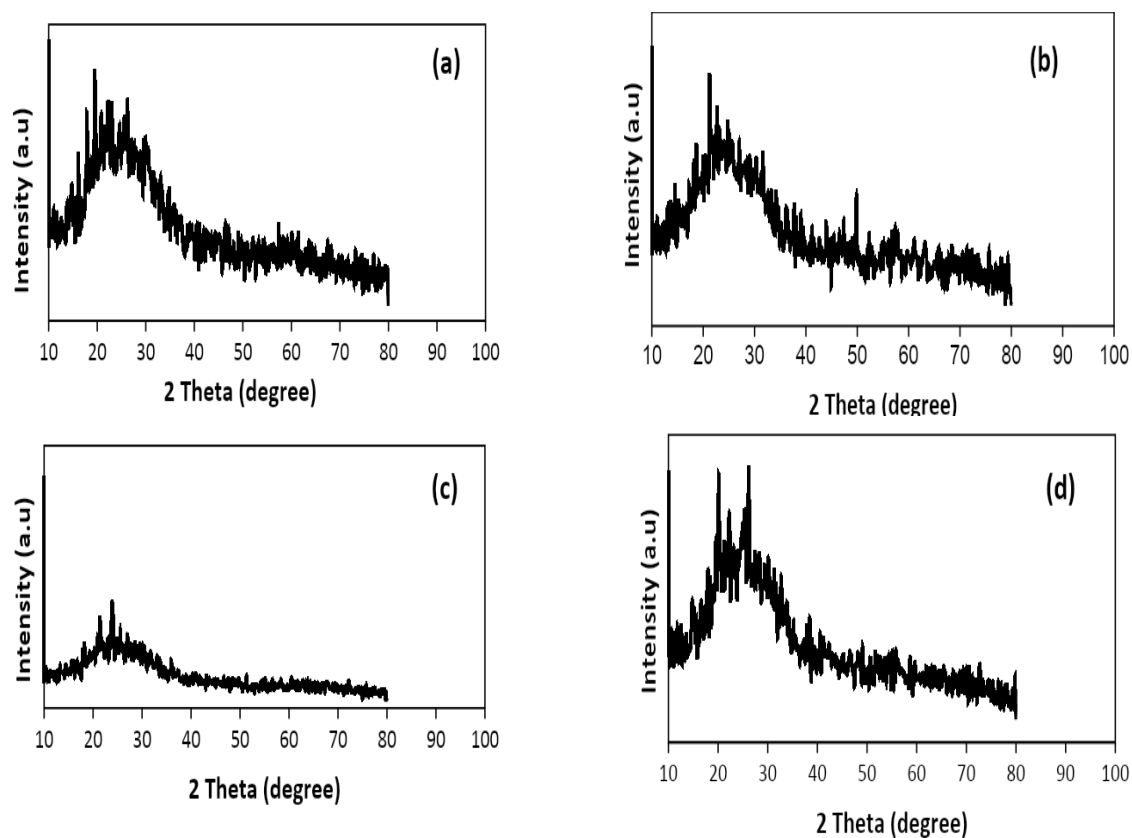
#### *X-Ray Diffraction (XRD)*

The X-ray diffraction patterns of the prepared nano-sized copolymers of poly(AA-co-*o*-PD) were shown in **Figure 4**. They all had similar diffraction peaks in  $2\theta$  from  $10^\circ$  to  $80^\circ$ , which suggested that the structure of the prepared nano-sized copolymers of poly(AA-co-*o*-PD) existed semi-crystalline. From Figure 4 we observed that all peaks of XRD were sharp peaks and there were not any broad peaks which indicated that the all prepared nanocopolymers had semi-crystalline structure. The sharp peaks were observed in all nanocopolymers at  $2\theta = 15, 19, 20, 21, 22$  and  $25^\circ$ . The peak at  $2\theta=25^\circ$  was characteristic of

the van der Waals distances between stacks of phenylene rings (polyanthranilic and poly-*o*-phenylenediamine rings) [36, 37]. The degree of crystalline structural patterns in the prepared nano-sized copolymers of poly(AA-co-*o*-PD) was due to the more intra chain hydrogen bonding through amine group present in the nanocopolymers. The crystallinity was very important in the polymers as the more crystalline system, the more metallic conductive state that may influence the anticorrosion performance [38].

#### *Determination of molecular weight by gel permeation chromatography (GPC)*

Molecular weights of the prepared nano-sized copolymers of poly(AA-co-*o*-PD) were determined by GPC and listed in **Table 3**. Table 3 showed that poly(AA-co-*o*-PD) nano-sized copolymers had high molecular weights (Mw). It can be seen that nano-sized copolymer of poly(AA-co-*o*-PD) of particle size 42.5 nm in case of 0.1M of HCl was recorded the highest molecular weight of 39194, while nano-sized copolymer of poly(AA-co-*o*-PD) of particle size 452.5 nm in case of 0.1M of HCl without using



**Fig. 4.** XRD of the prepared nano-sized copolymers of poly(AA-co-*o*-PD) samples at different conditions (a) 0.1 M of HCl, (b) 0.5 M of HCl in the light, (c) 0.5 M of HCl in the dark and (d) 0.1 M of HCl without using  $\text{FeSO}_4$ .



FeSO<sub>4</sub> as redox initiator was recorded the lowest molecular weight of 23641. It was believed that in the presence of FeSO<sub>4</sub> as redox initiator may bias formation of nano-amorphous shape with different particles size and nanorods by accelerating the growth of the nano-sized copolymers of poly(AA-co-*o*-PD) along the axis of polymer chain leading to higher molecular weight [1].

*Adsorption of copper ions on nano-sized copolymers of poly(AA-co-*o*-PD)*

The competition of the prepared nano-sized copolymer particles towards the adsorption of copper ions from aqueous solutions was investigated. **Table 4** showed that the nano-sized copolymer of particle size 42.5 nm had the highest adsorption capacity with 149.28 mg/g, while the nano-sized copolymer with particle size 452.5 nm had the lowest adsorption capacity with 51.88 mg/g. From the obtained results we concluded that the increase in particle size decreased the surface area of nanocopolymer available for adsorption of copper ions that decreased the capacity of adsorbed copper which appeared in low molecular weight.

### Conclusion

The prepared nano-sized copolymers of poly(AA-co-*o*-PD) have been synthesized by copolymerization of anthranilic acid with *o*-phenylenediamine using ammonium peroxydisulfate (APS) as oxidant and (FeSO<sub>4</sub>·7H<sub>2</sub>O) as redox initiator at different conditions (0.1 M of HCl, 0.5 M of HCl in the light, 0.5 M of HCl in the dark and 0.1 M of HCl without using FeSO<sub>4</sub>) for the first time. There was a difference in the morphology of the prepared nano-sized copolymers of poly(AA-co-*o*-PD) and there also a difference in the particle size of nanostructures with average particle size from 42.5 nm to 452.5 nm which was studied using scanning electron microscope (SEM) and transmission electron microscope (TEM). The surface area of the nano-sized copolymers was studied using BET which indicated that the case of 0.1 M of HCl had the highest surface area and the highest molecular weight among other conditions. The overall results indicated that possibility of using the synthesized nanocopolymers for the efficient removal of copper from aqueous solutions. The adsorption capacity is based on the particle size of nanocopolymers and their surface area. The adsorption capacity increased with decreasing the

**TABLE 3. GPC results of molecular weight for nano-sized copolymers of poly(AA-co-*o*-PD).**

Copolymerization conditions	(Average molecular weight (Mw	Number average (Mn)	Polydispersity
M of HCl 0.1	39194	25567	1.533
M of HCl 0.5 (in the light)	36790	24808	1.483
M of HCl 0.5 (in the dark)	32513	22423	1.450
(M of HCl (without FeSO <sub>4</sub> 0.1	23641	18214	1.298

**TABLE 4. Adsorption capacity for nano-sized copolymers of poly(AA-co-*o*-PD).**

Copolymerization conditions	BET Surface area (m <sup>2</sup> /g)	Average particle size in TEM analyses	Adsorption capacity (mg/g)
M of HCl 0.1 ,APS, FeSO <sub>4</sub>	180.49	nm 24.5	149.28
M of HCl (in 0.5 ,APS, FeSO <sub>4</sub> (the light	155.35	nm 297.5	111.53
M of HCl (in 0.5 ,APS, FeSO <sub>4</sub> (the dark	96.52	nm 375	64.28
APS, 0.1 M of HCl, without FeSO <sub>4</sub>	89.66	nm 452.5	51.88

particle size of the prepared nanocopolymers. On the other hand the adsorption capacity increased with increasing the surface area and increasing the molecular weight of the prepared nano-sized copolymers of poly(AA-co-o-PD).

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## تحضير وتوصيف ودراسة المورفولوجي للبوليمرات النانومترية من حمض الايثانديك مع اورثو فينيلين داي امين وتطبيقاتها من حيث قدرة امتزازها لأيونات النحاس من المحاليل المائية

عبدالفتاح فاضل شعبان، أمل محمد متولى، محمد مرسى عزب، آمال أحمد محمود، هاجر مصطفى على  
قسم الكيمياء - كلية العلوم - جامعة بنها - بنها - مصر.

تم تحضير بوليمرات نانومترية من حمض الأيثانديك مع أورثو فينيلين داي أمين في محلول مائي من حمض الهيدروكلوريك باستخدام أمونيوم بيروكسي داي سلفات كعامل مؤكسد ووجود كبريتات الحديدوز في ظروف مختلفة من البلمرة ، وتم دراسة المورفولوجي والفرق في حجم جسيمات البوليمرات النانومترية المختلفة باستخدام الميكروسكوب الإلكتروني الماسح (SEM) والميكروسكوب الإلكتروني النافذ (TEM) والتي أظهرت نتائجهم تأثير تركيز حمض الهيدروكلوريك ووجود كبريتات الحديدوز على شكل وحجم الجزيئات. وكذلك تم إجراء التوصيف الفيزيائي والكيميائي للجسيمات النانومترية المحضرة بواسطة التحليل الطيفي للأشعة تحت الحمراء (FT-IR) و الأشعة السينية (XRD) التي أكدت نتائجهم على التركيب الكيميائي للبوليمرات النانومترية المحضرة. ودراسة الوزن الجزيئي باستخدام Gel Permeation Chromatography (GPC) ، ودراسة المساحة السطحية باستخدام Brunauer- Emmett-Teller (BET). وقد أوضحت النتائج السابقة إمكانية استخدام هذه البوليمرات النانومترية المحضرة في إزالة أيون النحاس من المحاليل المائية بكفاءة. ودراسة المقارنة بين البوليمرات النانومترية المحضرة نحو امتزاز أيونات النحاس من المحاليل المائية ، أوضحت النتائج أن قدرة الامتزاز تعتمد على حجم جسيمات البوليمرات النانومترية ومساحة سطحها. حيث ان قدرة الامتزاز تزداد كلما قل حجم الجسيمات ، وتزداد بزيادة مساحة السطح والوزن الجزيئي وذلك بالنسبة لجميع البوليمرات النانومترية المحضرة من (poly(AA-co-o-PD).