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**Arabian Journal of Chemistry**

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## ORIGINAL ARTICLE

# A kinetic study for the removal of anionic sulphonated dye from aqueous solution using nano-polyaniline and Baker's yeast



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Received 13 January 2012; accepted 27 April 2012

Available online 17 May 2012

### KEYWORDS

Nano-polyaniline;  
 Acid Red 14;  
 Kinetics;  
 Adsorption;  
 Dye removal

**Abstract** In this study, a method for the removal of anionic sulphonated Acid Red 14 (AR) dye from aqueous solution using the chemical interaction of dye molecules with nano-polyaniline is reported. Nano-polyaniline (PANI) was synthesized by chemical oxidation in presence of different surfactants. The experimental observations from UV/Vis spectroscopy, rule out the possibility of secondary doping of polyaniline salt by AR14 molecules. A possible mechanism for the chemical interaction between the polymer and dye molecules is proposed. In order to get a better comparison, adsorption experiments were also carried out using Baker's yeast (BY) individually and in mixture with nano-PANI. Kinetic parameters for the adsorption of AR dye on the selected adsorbents are also reported. It was found that application of BY with PANI for the removal of anionic sulphonated dyes such as AR dye from aqueous solution is very promising.

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## 1. Introduction

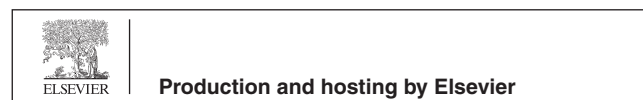
Water pollution by high levels of pollutant dyes from textile industry is a serious problem owing to the toxicity effect of

these compounds (Al-Momani et al., 2002; Işik and Sponza, 2005). Complete removal or at least decolorization of these compounds from the environment is therefore an important issue. The dyes from textile industries are major sources of environmental pollution because they are non biodegradable. Many methods such as flocculation, reverse osmosis and activated carbon adsorption have been used in wastewater treatment. Conducting polymers are becoming the most promising new materials for next-generation electronic devices (Wang et al., 1996). Polyaniline (PANI) is one of the conducting polymers that generated a great interest over the past two decades because of its potential applications in many fields. Its high electrical and electronic properties, ease of preparation,

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Peer review under responsibility of King Saud University.



and low costs render the polymer promising material for several technological applications (Yue and Epstein, 1990; Ferdinando et al., 2001; Mahanta et al., 2008). These applications include rechargeable batteries (Zhang et al., 2007), sensors (Clark and Maher, 2009), separation membranes (Bhattacharya et al., 2008) and corrosion inhibitor (Musiani et al., 1984).

The removal of anionic sulphonated dyes from aqueous solutions using the chemical interaction of dye molecules with polyaniline is reported by Mahanta et al. (2008) and considered as a green method for removal of sulphonated organics from wastewater. Mahanta et al. (2009) have reported an approach for the adsorption and desorption of anionic (sulphonated) dyes from aqueous solution by doped polyaniline. Polyaniline nano-tubes (PANI NTs) base has been utilized as an adsorbent for dye removal from water (Ayad and Abu El-Nasr, 2010).

The use of biomaterials as biosorbents for the treatment of waste waters provides a potential alternate and/or complementary to the conventional treatment methods. The process of uptake of solute using biomaterials including microbial cells, whether dead or alive, is known as biosorption. The main advantages of biosorption are high selectivity, cost effectiveness and good removal performance (El-Khaiary, 2007; Vijayaraghavan and Yun, 2008). Ability of Baker's yeast (*Saccharomyces cerevisiae*) as biosorbent for heavy metals (Strandberg et al., 1981; Vasudevan et al., 2002; Goksungur et al., 2005) and textile dyes (Safrik et al., 2002; Farah et al., 2007; Farah and El-Gendy, 2007; Yu et al., 2009, 2010; Wang and Guo, 2011) has been recognized, which is inexpensive, safe, easily grown, readily available and produces high yields of biomass. That is why it was selected as biosorbent material for the present study.

The present paper aims to study the feasibility of removal of a textile Acid Red 14 dye from aqueous solution using a series of nano-polyaniline salts prepared by different types of commercial surfactants. The effect of some important parameters such as initial concentration of sorbate, sorbent dosage and contact time on adsorption of AR dye using the most efficient prepared PANI, will be studied. The adsorption of AR dye on Baker's yeast (BY) and mixture of PANI<sub>(NPE)</sub>/BY as an efficient commercial adsorbent will be also investigated.

## 2. Materials and methods

### 2.1. Chemicals

Acid Red 14 dye (Ism acid red B), 1/94-95, from Chemical-dye Co. Egypt, was used as received. Ammonium peroxy disulfate (APS), the surfactants; sodium dodecyl sulfate (SDS), cetyltrimethylammonium bromide (CTAB) and nonylphenol ethoxylate (NPE) and aniline were purchased from Aldrich. Other chemicals were of analytical reagent grade and were used directly without further purification.

### 2.2. Biosorbent preparation

Baker's yeast (product of Three Pyramids Company, Egypt, with 70% moisture by weight) was dried in a hot air oven at 60 °C overnight, then powdered using mortar and sieved to select the particle size (0.63–0.8 mm) for use as a biosorbent.

### 2.3. Synthesis of polyaniline nanostructures

A stock micelle solution was prepared by dissolving surfactants into distilled water with continuous stirring. The micelles were formed spontaneously as the concentration of the surfactant in the solution was greater than its critical micelle concentration (CMC).

In a typical fabrication of PANI nano-particles, 1 g (10.7 mL/mol) of aniline monomers was added drop wise to 40 mL of the surfactant solution (0.5 M) and 1.23 g (5.3 mL/mol) of APS and 22 g (33 mL/mol) of 1.5 M HCl were added to the mixed solution. The chemical oxidation polymerization proceeded with vigorous stirring for 3 h at 3 °C. After polymerization, the reaction product was washed with ethanol and distilled water to remove surfactants. The PANI nano-particles were retrieved and dried in a vacuum oven at 40 °C (El-Dib et al., 2012). The nanostructures of the synthesized polyaniline were examined by transmission electron microscopy (TEM) on a JEOL JEM -2000EX, at an accelerating voltage of 100 kV. Specific surface area of different prepared PANI nano-particles were analyzed by means of nitrogen adsorption isotherm, using Nova 2000, Quanta Chrome (commercial Brunauer, Emmett and Teller (BET) unit), according to the method reported by Badawi et al. (2012).

### 2.4. Analysis of dye

$\lambda_{\max}$  of Acid Red dye was determined on a JASCO UV/Vis/NIR spectrophotometer model V-570. The observed  $\lambda_{\max}$  was found to be 519 nm. Standard curve for different concentrations of the dye solution (2.5–500 mg/L) was established.

### 2.5. Adsorption reactions

A stock solution of AR dye with a concentration of 500 mg/L was prepared in double distilled water and was diluted to the desired concentrations according to the experimental conditions. Batch experiments were conducted at fixed agitation speed of 150 rpm and room temperature for 120 min, in 250 mL Erlenmeyer flasks containing 100 mL aqueous solution of AR dye with fixed pH 4 and adsorbent, according to the experiment conditions. Adsorbent was separated from the solution at predetermined time intervals by centrifugation at 4000 rpm for 15 min. The absorbance of the supernatant solution at 519 nm was measured to determine the residual dye concentration and to calculate the percentage of dye removal. Negative controls (with no sorbent) were carried out to ensure that sorption is by adsorbents only and any sorption effect of dye onto the wall of the conical flasks can be ruled out. Triplicate samples were measured for each experiment and the reported data are the average of the measurements with high precision.

## 3. Results and discussion

### 3.1. Preparation of PANI nano-particles

Different types of surfactants with different molecular structures anionic (SDS), cationic (CTAB) and nonionic (NPE) were selected to form the micelle templates for polymerization of aniline. The particles size, surface area and morphology of

Adsorbents	Specific surface area (m <sup>2</sup> /g)	Particles size range (nm)
PANI <sub>(SDS)</sub>	17.344	34–63
PANI <sub>(CTAB)</sub>	23.292	43–45
PANI <sub>(NPE)</sub>	30.684	14–23

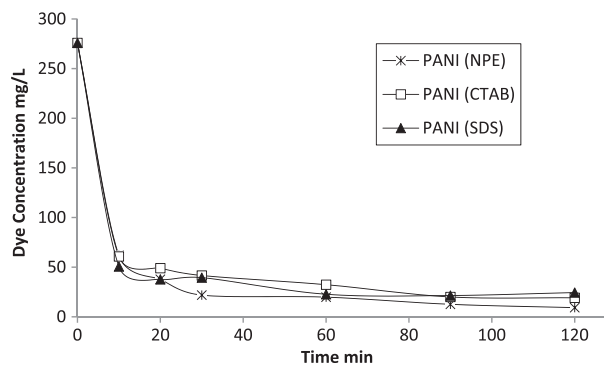
PANI nano-particles were controlled as function of different micelles as shown in Table 1 and Fig. 1.

The TEM images of PANI nano-particles synthesized in SDS micellar solution appeared as rod shapes and their diameter sizes varied from 34 to 63 nm. While, for PANI nano-particles polymerized with CTAB micelles, it appeared as homogeneous rod shapes 43–45 nm in diameter. But, in the NPE micellar solution, some precipitates which had a slightly spherical shape and ranged from 14 to 23 nm in diameter, were formed. The specific surface area of the prepared PANI nano-particles revealed its increase in the following order PANI<sub>(SDS)</sub> < PANI<sub>(CTAB)</sub> < PANI<sub>(NPE)</sub>, recording approximately; 17.3, 23.3, 30.7 m<sup>2</sup>/g, respectively, as listed in Table 1.

### 3.2. Adsorption efficiency of prepared PANI nano-particles

To investigate the effect of different prepared PANI nano-particles on the adsorption of AR dye, batch experiments were conducted at room temperature for 120 min in 250 mL Erlenmeyer flasks with 100 mL aqueous solution of AR dye with initial dye concentration  $C_0$  275 mg/L, fixed adsorbent dosage of 0.1 g, initial pH 4 and fixed agitation speed of 150 rpm.

Fig. 2 shows that, there was no significant difference in adsorption of AR dye using PANI<sub>(SDS)</sub> and <sub>(CTAB)</sub>, recording maximum dye uptake  $q_e$  of 251 and 256 mg/g, with % removal of 91% and 93%, respectively. While PANI<sub>(NPE)</sub> expressed the highest dye uptake, 266 mg/g, with % removal of 97% and it was selected as adsorbent for further experiments. A good evidence for this adsorption behavior comes from the observed difference in particles size, specific surface area and morphology between the prepared nano PANI<sub>(SDS)</sub>, <sub>(CTAB)</sub> and <sub>(NPE)</sub> as shown in Table 1 and Fig. 1. The smaller the particle size

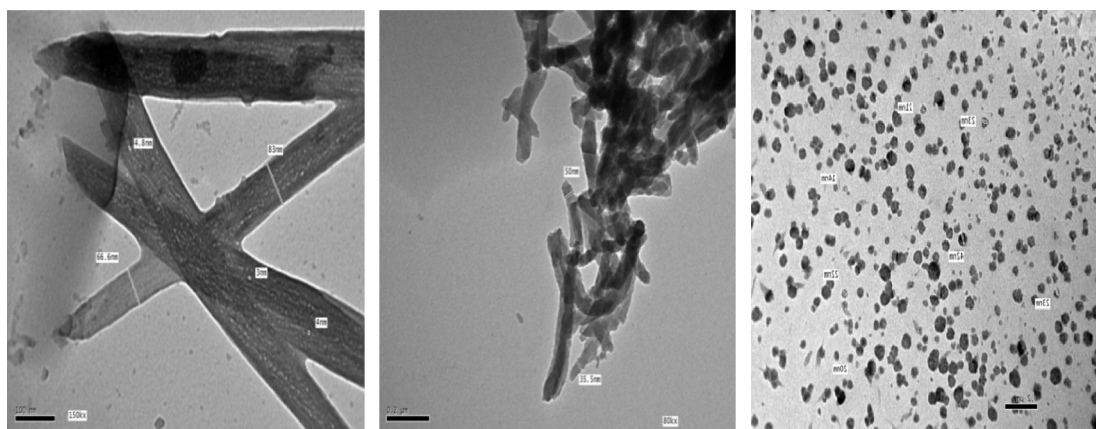


**Figure 2** Removal of AR dye using different prepared PANI.

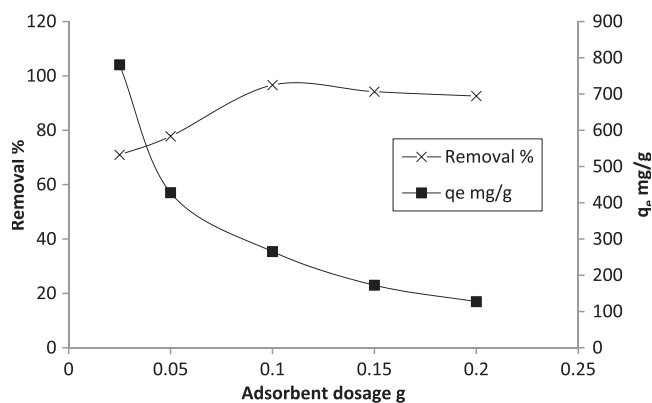
is, the greater the specific surface area, which consequently led to greater adsorption capacity.

### 3.3. Effect of different adsorbent dosages

To investigate the effect of different adsorbent dosages on the adsorption of AR dye, batch experiments were conducted at room temperature for 120 min in 250 mL Erlenmeyer flasks with 100 mL aqueous solution of AR dye ( $C_0$  275 mg/L), different adsorbent dosage (PANI<sub>(NPE)</sub> 0.025–0.2 g), initial pH 4 and fixed agitation speed of 150 rpm. Fig. 3 shows the plot of equilibrium uptake capacity,  $q_e$  (mg/g) and % dye removal against the adsorbent dosage. It was observed that, the % dye removal increased reaching  $\approx 97\%$  at 0.1% (w/v) adsorbent dosage and then slightly decreased as the adsorbent concentration increased, recording  $\approx 94\%$  and  $93\%$  at 0.15% and 0.2% (w/v), respectively. Based on these results, 0.1% (w/v) of adsorbent concentration was used for further experiments. On the other hand as adsorbent dosage increased the adsorbed dye quantity per gram adsorbent  $q_e$  mg/g decreased. The primary factor explaining this performance is that at adsorbent concentration of 0.025% (w/v), adsorption sites remain unsaturated during the adsorption reaction, whereas the number of sites available for adsorption increases by increasing the adsorbent concentration to 0.1% (w/v) due to the increase of available surface area. The presence of relatively higher concentration of adsorbent in the solution resulting



**Figure 1** TEM of the prepared PANI<sub>(SDS)</sub>, PANI<sub>(CTAB)</sub> and PANI<sub>(NPE)</sub>, respectively.

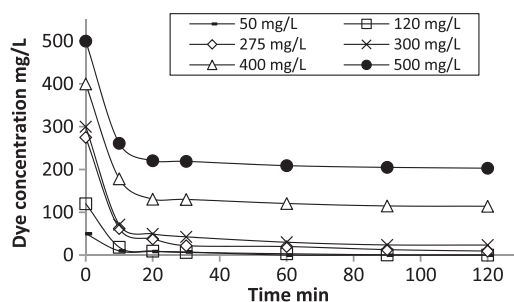


**Figure 3** Effect of adsorbent dosage on AR dye removal.

in reduced distances between the adsorbent particles, thus making many binding sites unoccupied (Farah and El-Gendy, 2007). Also the inter-particles interactions such as aggregation, overlapping and overcrowding occur at high adsorbent concentrations lead to decrease in available total surface area (Iscen et al., 2007). Another reason could be due to the splitting effect of concentration gradient between dye molecules and adsorbent concentration causing a decrease in the amount of dye adsorbed onto unit weight of adsorbent (Malik, 2004).

#### 3.4. Effect of different initial dye concentrations with contact time

The effect of initial dye concentration on the rate of dye uptake was studied in batch experiments conducted at room temperature for 120 min in 250 mL Erlenmeyer flasks with 100 mL aqueous solution of AR dye with different  $C_o$  50–500 mg/L, fixed adsorbent dosage (PANI<sub>(NPE)</sub> 0.1 g), initial pH 4 and fixed agitation speed of 150 rpm. Obtained results are shown in Fig. 4. It was observed that the amount of dye adsorbed per gram adsorbent increased with increasing initial dye concentration and contact time. The rate of dye uptake was observed to be very rapid for the initial period of 10 min and thereafter, the dye uptake process tends to proceed at a very slow rate and finally reached equilibrium within 60 min. The rapid uptake of the dye by the adsorbent indicates high efficiency, and this occurs in physical adsorption or strong chemisorptions. Rapid kinetics has significant practical importance as it will facilitate smaller reactor volumes ensuring efficiency and economy (Aksu, 2001). Complete removal was achieved at low concentrations ( $C_o$  50 and 120 mg/L) after 60 and



120 min, respectively. The dye removal decreased from 97% to 59% with the increase in initial dye concentration,  $C_o$  275 and 500 mg/L, respectively. Initial dye concentration provides the necessary driving force to overcome the resistances against the mass transfer of dye between the aqueous and the solid phases. The increase in the  $C_o$  also enhances the interaction between dye and adsorbent. Therefore, an increase in  $C_o$  of dye enhances the adsorption uptake of AR dye per gram of adsorbent due to the increase in the driving force of the process (Mane et al., 2007), recording equilibrium adsorption capacity of 50 and 297 mg/g at  $C_o$  50 and 500 mg/g, respectively. Also, as adsorption process precedes the driving force decreases with time, indicating that there is a saturation limit for the polymer above which it does not remove the dyes.

#### 3.5. Adsorption kinetic study

In order to investigate the adsorption processes of Acid Red dye onto PANI<sub>(NPE)</sub>, the adsorption kinetics of AR dye onto the PANI<sub>(NPE)</sub> was verified at different initial dye concentrations. Two different kinetic models were tested for the obtained data to elucidate the adsorption mechanism. The classical method to find out the most suitable kinetic model to represent the experimental data was the use of the correlation coefficient ( $R^2$ ).

The percentage removal of dyes was calculated as:

$$\text{Percentage removal} = 100(C_o - C_e)/C_o \quad (1)$$

The dye uptake was calculated as:

$$q_t = (C_o - C_t)V/W \quad (2)$$

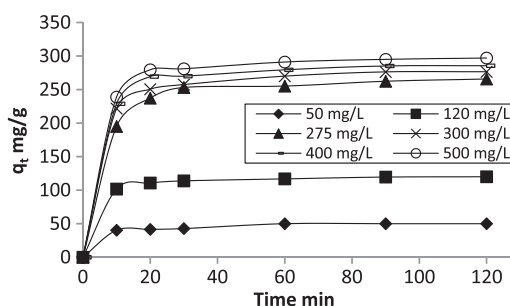
where  $q_t$  (mg/g) is the amount adsorbed at time  $t$  (min),  $C_o$  (mg/L) is the initial dye concentration,  $C_t$  (mg/L) is the dye concentration at time  $t$  (min),  $V$  (L) is the volume of the solution, and  $W$  (g) is the mass of adsorbent taken for the experiment.

##### 3.5.1. Pseudo-second-order kinetic model

This model can be represented in the following form (Ho and McKay, 1999):

$$t/q_t = 1/K_s q_e^2 + t/q_e \quad (3)$$

where  $q_e$  and  $q_t$  are the amount of dye adsorbed (mg/g) at equilibrium and at time  $t$  (min), respectively,  $K_s$  is the pseudo-second-order rate constant (g/mg min) and  $t$  is the time (min). Values of  $q_e$  and  $K_s$  can be determined by plotting  $t/q_t$  against  $t$  and calculated from the slope and intercept of the straight line, respectively.



**Figure 4** Effect of initial dye concentration on adsorption rate.

### 3.5.2. Intraparticle diffusion model

Based on the theory proposed by Weber and Morriss (1963), the intraparticle diffusion model can be expressed as follows:

$$q_t = K_p t^{1/2} + C \quad (4)$$

where  $K_p$  is the intraparticle diffusion rate constant ( $\text{mg/g min}^{1/2}$ ) and  $C$  ( $\text{mg/g}$ ) is a constant that gives idea about the thickness of the boundary layer, i.e. the larger the value of  $C$  the greater is the boundary layer effect (Kannan and Sundaram, 2001). According to this model, the plot of uptake,  $q_t$  versus the square root of time,  $t^{1/2}$  should be linear if particle diffusion is involved in the biosorption process and if these lines pass through the origin so the intraparticle diffusion is the rate controlling step (Chen et al., 2003). When the plots do not pass through the origin, this is indicative that the intraparticle diffusion is not the only rate limiting step (Poots et al., 1978). The plot of the intraparticle diffusion model at different initial dye concentration is shown in Fig. 5. which showed that the plots of the obtained data did not pass through the origin indicating that the intraparticle diffusion is not the sole rate limiting step.

In order to quantitatively compare the applicability of each kinetic model, error analysis was established using the following equations;

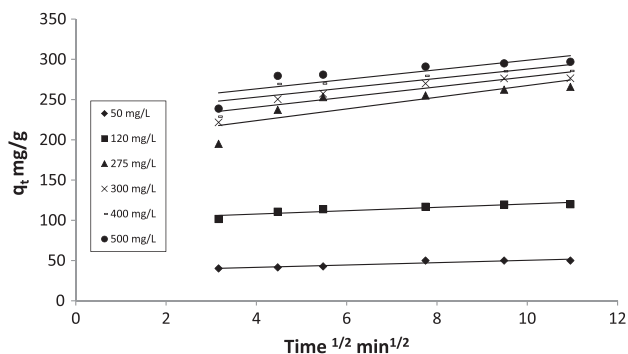


Figure 5 Intraparticle diffusion model plots.

The Chi-square test (Ho et al., 2005):

$$\chi^2 = \sum_{i=1}^N \left( \frac{(q_{t,exp} - q_{t,cal})^2}{q_{t,cal}} \right) \quad (5)$$

The sum of the squares of the errors SSE (Wong et al., 2004):

$$SSE = \sum_{i=1}^N (q_{t,cal} - q_{t,exp})^2 \quad (6)$$

where  $q_{t,exp}$  and  $q_{t,cal}$  are the experimental and calculated data from the models at time  $t$  (min), respectively and  $N$  is the number of the experimental points.

All parameters of each of the used models are summarized in Table 2. The correlation coefficients,  $R^2$ , for the pseudo-second-order kinetic model ( $R^2$  0.999–1) were greater than that of the intraparticle diffusion coefficients ( $R^2$  0.688–0.879). While the error analysis values are lower, confirming the applicability of the pseudo-second order equation. This strongly suggests a chemisorption mechanism (Ho and McKay, 1998). From the pseudo-second-order model, the initial adsorption rate can be calculated, as  $t = 0$ , is  $k_{ads}q_e^2$ , and it was evident that the initial adsorption rate decreased with the increase of initial dye concentration. From the intraparticle diffusion model, it can be detected that, as the initial dye concentration increased, the boundary layer effect  $C$  ( $\text{mg/g}$ ) increased.

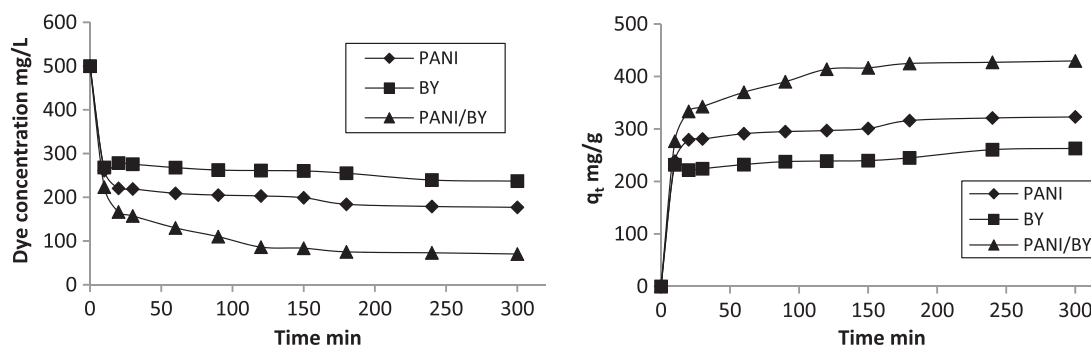
### 3.6. Effect of different adsorbents

To study the effect of different adsorbents; PANI<sub>(NEP)</sub>, BY and PANI<sub>(NPE)</sub>/BY on the adsorption of AR dye, batch experiments were conducted at room temperature for 300 min in 250 mL Erlenmeyer flasks with 100 mL aqueous solution of AR dye ( $C_0$  500 mg/L), fixed adsorbent dosage of 0.1 g, initial pH 4 and fixed agitation speed of 150 rpm.

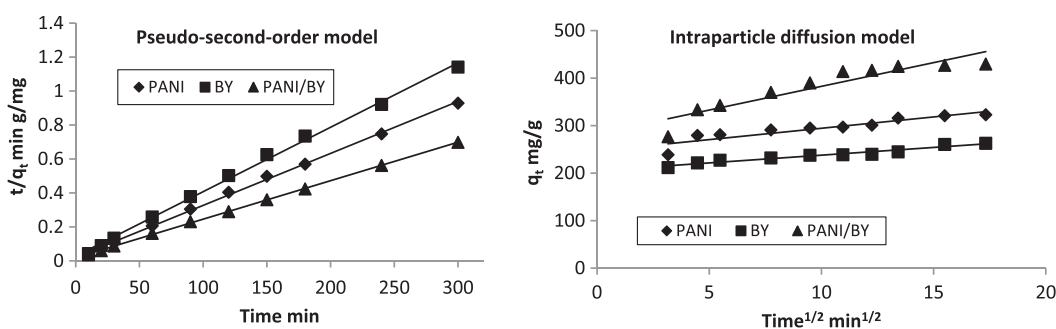
Results illustrated in Fig. 6. indicate that the highest removal efficiency was observed for PANI<sub>(NEP)</sub>/BY at all exposure times followed by PANI<sub>(NEP)</sub> and BY adsorbents, in decreasing order. Where the recorded percentage removal after 300 min was 86%, 65% and 53%, respectively and the maxi-

Table 2 Kinetic parameters for the adsorption of AR dye on PANI<sub>(NPE)</sub>.

Kinetic model	Initial dye concentration (mg/L)					
	50	120	275	300	400	500
<i>Pseudo-second order</i>						
Experimental $q_e$ mg/g	50	120	266	277	286	297
Theoretical $q_e$ mg/g	50	120	270	286	294	303
$K_s q_e^2$ mg/g min	11.9	56	83	101	128	135
$K_s \times 10^{-3}$ g/mg min	4.7	3.9	1.13	1.23	1.48	1.47
$R^2$	0.999	1	0.999	1	0.999	0.999
$\chi^2$	0.283	0.032	0.883	0.114	0.7	0.495
SSE	13.46	3.401	199.9	30.46	175.8	127.8
<i>Intraparticle diffusion</i>						
Experimental $q_e$ mg/g	50	120	266	277	286	297
Theoretical $q_e$ mg/g	40	109	235	264	284	304
$K_p$ mg/g min <sup>1/2</sup>	1.46	2.08	7.25	6.28	5.82	5.92
$C$ mg/g	36	99	195	215	230	240
$R^2$	0.879	0.838	0.696	0.824	0.684	0.688
$\chi^2$	0.677	0.378	4.61	1.558	2.797	2.74
SSE	26.92	41.45	1051	386	715	728.7



**Figure 6** Effect of contact time on the removal AR dye using PANI<sub>(NPE)</sub>, BY and PANI<sub>(NPE)</sub>/BY.



**Figure 7** Pseudo-second order and intraparticle diffusion models plots for the effect of different adsorbents on AR dye removal.

imum adsorption capacity was 430, 323 and 263 mg/g, respectively.

The plots and all parameters of the used models are illustrated and summarized in Fig. 7 and Table 3. The plots of intraparticle diffusion model with different adsorbents showed that obtained data did not pass through the origin indicating that the intraparticle diffusion is not the sole rate limiting step.

The correlation coefficients,  $R^2$ , for the pseudo-second-order kinetic model ( $R^2$  0.997–0.999) were greater than that of the intraparticle diffusion coefficients ( $R^2$  0.842–0.865),

strongly suggesting a chemisorption mechanism (Ho and McKay, 1998) and the adsorption of AR dye onto PANI<sub>(NPE)</sub>, BY and PANI<sub>(NPE)</sub>/BY follows the pseudo-second-order kinetic model. This was also confirmed by error analysis values reported in Table 3 using Eqs. (5) and (6).

From the data of the pseudo-second-order kinetic model listed in Table 3 the initial adsorption rate for the three adsorbents; PANI<sub>(NPE)</sub>/BY, PANI<sub>(NPE)</sub> and BY can be calculated, as  $t = 0$ , is  $k_{ads}q_e^2$ . This showed that, the highest initial rate was PANI<sub>(NPE)</sub>/BY, followed by PANI<sub>(NPE)</sub> and BY in decreasing order, recording 52, 48 and 35 mg/g min, respectively.

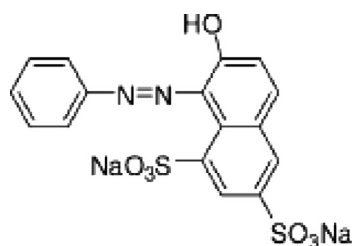
**Table 3** Kinetic parameters for the adsorption of AR dye on different adsorbents.

Kinetic model	Different adsorbents		
	PANI <sub>(NPE)</sub>	BY	PANI <sub>(NPE)</sub> /BY
<i>Pseudo-second order</i>			
Experimental $q_e$ mg/g	323	263	430
Theoretical $q_e$ mg/g	323	263	435
$K_s q_e^2$ mg/g min	52	48	35
$K_s \times 10^{-4}$ g/mg min	4.61	5.07	2.75
$R^2$	0.999	0.997	0.999
$\chi^2$	3.256	1.566	8.808
SSE	878.9	348.22	2751
<i>Intraparticle diffusion</i>			
Experimental $q_e$ mg/g	323	263	430
Theoretical $q_e$ mg/g	329	262	456
$K_p$ mg/g min <sup>1/2</sup>	4.778	3.252	9.975
$C$ mg/g	247	205	283
$R^2$	0.841	0.949	0.865
$\chi^2$	18.969	51.20	10.133
SSE	4150	8092	3189

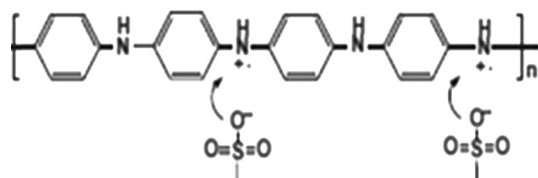
### 3.7. A proposed adsorption mechanism

The adsorption mechanism often depends on the chemical composition of adsorbent, the nature of adsorbate and the solution environment. Mechanisms of pollutants removal by adsorption were assigned to be complicated as they involve several possible interactions. The interactions include acid–base interactions, hydrogen bonding, ion exchange, coordination/chelation, complexation, precipitation, physical adsorption, and electrostatic interactions (Crini, 2005).

In our case, the electrostatic interaction is expected to be the dominant for the removal of AR dye with PANI, owing to the existence of  $\text{NH}^+$  centers of PANI salt and the presence of dye anions generated from the dissociation of the dye molecule ( $-\text{SO}_3^- \text{Na}^+$ ) in solution (Crini, 2008). It is well-known that the degree of ionization of a dye molecule depends on the pH of the aqueous medium. AR dye contains two sulpho-nated groups ( $\text{SO}_3\text{Na}$ ) and one hydroxyl group (OH). The pH of the batch experiments were acidic, pH 4 and did not change



**Scheme 1** Structure of Acidic Red dye.



**Scheme 2** Interaction of AR dye with PANI<sub>(NPE)</sub>.

during the course of adsorption process. AR with sulphonated functional groups would have been dissociated into its anionic form in this acidic medium. The  $\text{SO}_3^-$  groups on the dye could lead to chemical interactions with the positively charged backbone of nano PANI (Schemes 1 and 2). It can be suggested that the yeast can follow the same mechanism as PANI where the yeast mainly consists of proteins, carbohydrates. Akar et al. (2009) have reported that the Beer yeast (*Saccharomyces cerevisiae*) has good biosorption capacity in strong acid conditions due to electrostatic attraction between positively charged protonated amino groups in Beer yeast and negatively charged  $-\text{SO}_3^-$  group in acidic dye.

#### 4. Conclusion

Nano-polyaniline was synthesized by chemical oxidation in presence of different types of commercial surfactants; SDS, CTAB and NPE. The prepared nano polyaniline was used for the adsorption of aqueous solution of sulphonated AR dye. Also biosorbent Baker's yeast (BY) was used for the AR dye adsorption. Removal of AR dye using mixture of PANI<sub>(NPE)</sub>/BY was more efficient than using PANI<sub>(NPE)</sub> or BY, individually. The removal process followed pseudo-second-order kinetics. The rate of dye removal increased with increasing the amount of PANI<sub>(NPE)</sub>, but decreased with increasing the initial dye concentration. The present method is promising and can be considered as one of those methods devoted to treat the wastewater streams with low cost.

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