

Research Article

# Removal of RY42 anionic dye pollutant from aqueous solution using novel reusable adsorbent prepared from water chestnut peel and fruit

Maryam Yousaf<sup>†\*</sup>, Muhammad Ahmad<sup>‡</sup>, Ijaz Ahmad Bhatti<sup>†</sup> and Abdul Nasir<sup>‡</sup>

<sup>†</sup>Department of Chemistry, University of Agriculture Faisalabad (UAF), 38000, Pakistan

<sup>‡</sup>Department of Structure and Environmental Engineering, University of Agriculture Faisalabad (UAF), 38000, Pakistan

Received 14 April 2018, Accepted 15 June 2018, Available online 20 June 2018, Vol.8, No.3 (May/June 2018)

## Abstract

Herein a novel low-cost reusable adsorbent namely water chestnut (WCN) peels and fruit were used for the dye polluted wastewater treatment. Moreover, to enhance the adsorption efficiency of WCN peel and fruit its surface was modified with sodium dodecyl sulphate, whereas surface area of sample was changed via immobilizing the sample in to beads using polyvinyl alcohol- Sodium alginate. Surface modification and change in surface area reduced the adsorption potential of WCN peel and fruit for reactive yellow 42 dye as compared to unmodified sample of WCN. A distinct change in surface morphology after surface modification was observed by scanning electron microscopy. At optimized concentration of dye (50 mgL<sup>-1</sup>) equilibrium was attained within 120 minutes, kinetic data obtained was well interpreted by pseudo-second order kinetic model. Langmuir and Freundlich isothermal models were applied to explain isothermal data. Statistical analysis was done using regression line. A 0.01 M NaOH solution successfully eluted the dye from adsorbent, confirming it as reusable adsorbent.

**Keywords:** The author can include 5-7 words like Thermal Analysis, Pre-conditioner, In-mold, Inoculant's efficiency.

## 1. Introduction

Water pollution is increasing at an alarming rate in current world scenario due to the development of textile industry that results in production of large amount of organic pollutants mainly synthetic dyes (Huang *et al.* 2016). Discharge of large quantities of dyes from textile industries into water bodies has resulted in significant ecological pollution that is of global concern (Geethakarathi and Phanikumar 2011; Geetha *et al.* 2015). Depending upon the chemical composition and structural variety, synthetic dyes are of different types i.e., reactive, acidic, basic, direct and disperse dyes (Handan 2011; Kabbout and Taha 2014). Among synthetic dyes reactive dyes, consisting of azo based chromophore joint with different reactive/vinyl sulfone groups, are most commonly used in textile industries for dyeing fibers because of their bright colors fastness and easy application etc. (Srinivasan and Viraraghavan 2010; Kim *et al.* 2014). About 50 % of reactive dyes are released in the effluent after dyeing process, this colored wastewater causes water pollution in receiving water bodies, that not only become cause of different diseases in humans but also effects the water bodies by effecting light penetration and disturbing the food chain that ultimately leads to

the ecological imbalance. Dyes are difficult to remove by conventional wastewater treatment methods due to their non-biodegradable complex aromatic structure. Considering complex nature of dyes, a lot of methods have been proposed for the treatment of waste water but no single process has proven efficient to remove dyes from effluents (Atafar *et al.* 2010; Naim and El Abd 2002; Khataee *et al.* 2013). Existing methods considered to be efficient for dye removal include coagulation by chemical, physical and biological methods, oxidation using strong or mild oxidizing agents, ion exchange using resins and absorption/adsorption. However, these methods differ in their effectiveness and economics for achieving the same level of sorption from the dye polluted water (Huang *et al.* 2016). Biosorption is a biological method of dye removal from waste water, it uses non-conventional adsorbents i.e., naturally occurring materials, waste from these natural material or waste of agriculture industry (Crini 2006; Wangpradit and Chitprasert 2014). Physicochemical interaction (ion exchange, complexation, and micro precipitation) between biomass and functional groups of dyes are responsible for the binding of dyes during biosorption process (Robalds *et al.* 2016). Recently, a significant amount of research has favorably stressed on the use of sorption method for the eradication of polluting agents owing to their advantages including in situ application, environment friendly nature and cost

\*Corresponding author's ORCID ID: 0000-0002-3313-063  
DOI: <https://doi.org/10.14741/ijcet/v.8.3.28>

effectiveness (Vara Prasad and de Oliveira Freitas 2003).

Keeping in context a novel reusable adsorbent is introduced the above discussion the current research work carried out to investigate the anionic dye pollutant removal efficiency of water chestnut (WCN) adsorbent that is not much expensive and abundantly available. WCN was used in its free, PVA-Na alginate immobilized and sodium dodecyl sulphate treated form for reactive yellow 42 dye removal.

## 2. Methodology

### 2.1. Adsorbent Material

Water chestnut peels (WCN P) and Water Chestnut Fruit (WCN F) were obtained from local market of Faisalabad, Pakistan. Samples were washed, dried, ground and sieved to get particle size of 0.25mm.

### 2.2. Pretreatment of adsorbent

Surface modification with SDS was carried out by shaking 10g of adsorbents with 250 mL of 0.1 N SDS for 24 h in an orbital shaker. After SDS treatment samples slurry was filtered using vacuum suction, oven dried (100°C, 24 h), ground and sieved to get particle size of 0.25 mm. Pretreated samples were named as SDS-WCN P and SDS- WCN F and stored for further use and characterization.

### 2.3. Immobilization of adsorbent

WCN P, WCN F, SDS-WCN P, SDS-WCN F samples were immobilized in beads matrix with the help of polyvinyl alcohol (PVA) - Sodium (Na) alginate. For this 10 g of PVA (10 %) and sodium alginate 1g (1%) was dissolved in 100 mL of water with constant stirring and heating, and then the mixture was allowed to cool at room temperature. WCN P, WCN F, SDS-WCN P and SDS-WCN F adsorbents were added 2g and 1 g respectively in each of above mentioned mixture separately. Then both mixtures were mixed together and poured into the 100 mL burette in order to form beads of sample. Sample solution was allowed to fall drop wise in mixture of 1% (W/V) CaCl<sub>2</sub> and 50% (W/V) NaNO<sub>3</sub> solution. After formation of beads, beads were washed with distilled water and then stored in distilled water at 4 °C. Along with sample beads plane beads were also formed that contain just PVA and sodium alginate in same ratio as for sample beads except the sample.

### 2.4. Anionic dye stock solution

Reactive yellow PFG (Color Index # Reactive yellow 42) was obtained from dyestuff industry located in Faisalabad, Pakistan. For experimental study solution of desired concentration was freshly prepared by dilution of 1000 ppm stock solution of dye.

### 2.5 Adsorption experiment

Different operational parameters i.e., pH (1-6), concentration (25, 50, 100, 150, 200, 250, 300, 350 ppm), and contact time (0, 15, 30, 60,120, 240, 480 and 1440 min) were optimized during batch mode adsorption study of RY 42 dye. Briefly 0.1 g of powdered sample (WCN P, WCN F, SDS-WCN P and SDS-WCN F) and 1.25 g of bead sample (WCN P bead, WCN F bead, SDS-WCN P bead, SDS-WCN F bead and Plane bead) were shaken with different concentration of dye solution in orbital shaker for 24 hr. After that supernatant was taken, centrifuged and analyzed for determining remaining dye concentration using visible spectrometer at maximum wavelength (420 nm). While for kinetics study samples were withdrawn after a regular interval of time at optimized concentration and pH.

Adsorption capacity was determined as:

$$q_e = \frac{V(C_i - C_e)}{W}$$

C<sub>i</sub> is Initial dye ion concentration (mg L<sup>-1</sup>), C<sub>e</sub> is residual dye ion concentration (mg dm<sup>-3</sup>), q<sub>e</sub> is adsorption capacity (mgs<sup>-1</sup>), W is dry weight of WCN (g) and V is volume (dm<sup>-3</sup>)

### 2.6 Desorption study

Process of desorption was carried out by shaking the WCN F and SDS-WCN F with 0.01 N NaOH for the optimized time that is 1 h. Briefly desorption process was carried out by shaking 0.1 g of WCN F and 1.25 g of SDS-WCN F with the 50 ppm solution of RY 42 for 1 h, suspension was allowed to settle down, centrifuged and absorbance was noted to determine the concentration adsorbed. Biomass was washed with distilled water in order to remove the unabsorbed dye. After washing biomass was shaken with 0.01N NaOH solution for 30 min, sample was withdrawn and measured the absorbance of solution to get value of unadsorbed dye at maximum wavelength. This cycle was repeated three times. Percentage desorption was determined as

Percentage desorption was determined as

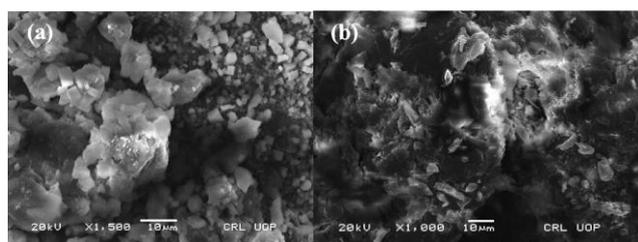
$$\% \text{ Desorption} = \frac{\text{Initially dye sorbed} - \text{desorbed dye}}{\text{Initially dye sorbed}} \times 100$$

## 3. Results and Discussion

### 3.1 Characterization of adsorbent

Scanning electron micrographs of WCN P bead before and after adsorption of dye are shown in Fig. 1. Before adsorption of dye (Fig.1a) surface is granular and contains pore but after the adsorption process (Fig. 1b), new shiny bulky small particles looking like

sponge cover on the corrugated surface of biomass may be attributed to the coverage of the surface by a layer of dyes.



**Fig.1** Morphological characterization of WCN P bead before (a) and after (b) adsorption of dye

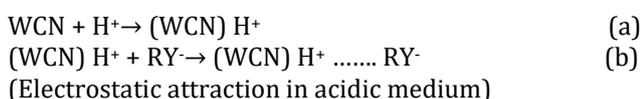
### 3.2 Effect of pH

pH of dye solution is a crucial parameter in adsorption study, as variability in pH mainly changes the ionization state of functional groups present in complex aromatic structure of dye and on the surface of adsorbent affecting the accessibility and solubility of dye molecules in the solution, which result in variation (either decrease or increase) in the adsorption process (Aksakal and Uzun 2010). According to Fig. 2 adsorption capacity (mgg<sup>-1</sup>) decreased with the increase in pH.

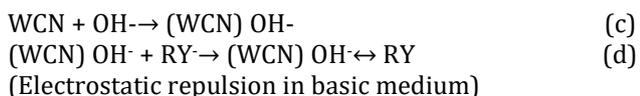
#### 3.2.1 Sorption mechanism

At highly acidic pH biomass is protonated so higher uptake is attributed to the electrostatic attractions between these negatively charged dye anions and positively charged cell surface. Hydrogen ion also acts as a bridging ligand between the sorbent and the dye molecule (Aksu and Çağatay 2006).

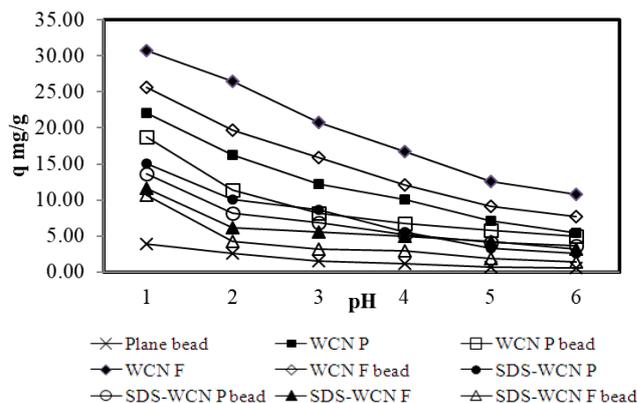
(At acidic pH= 1)



While increase in the pH results in release of OH<sup>-</sup> ion.  
(At basic pH)



So there is a competition between negatively charged dye molecule and OH<sup>-</sup> ion for the attachment over adsorbent surface. OH<sup>-</sup> ions being smaller in size as compared to dye molecule, adhere to the surface of adsorbent readily which results in electrostatic repulsion between negatively charged adsorbent and anionic dye molecules resulted in decrease in sorption capacity (Aksakal and Uzun 2010).

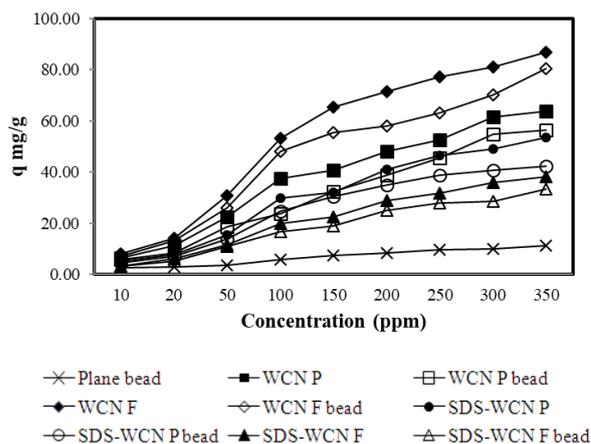


**Fig.2** Effect of pH over rate of RY 42 adsorption over WCN (C<sub>i</sub> mgL<sup>-1</sup>= 50 ppm, temperature= 25 °C and shaking speed= 120 rpm)

### 3.3 Effect of initial dye concentration

Initial concentration of dye solution is considered to be an important driving force that is responsible in controlling the mass transfer resistance of the dye from aqueous solution to the solid adsorbent surface hence resulting in higher uptake of dye (Jaikumar and Ramamurthi 2009). According to the literature of (Sadaf and Bhatti 2013) increase in concentration has a direct relationship with the adsorption capacity of the adsorbent, so adsorption efficiency of the adsorbent can be improved by raising the dye concentration. Fig. 3 shows that sorption capacity (mgg<sup>-1</sup>) of WCN P, WCN F, WCN P bead, WCN F bead, SDS-WCN P, SDS-WCN P bead, SDS-WCN F, and SDS-WCN F bead and Plane bead for RY 42 dye increased.

Increase in adsorption is due to the higher availability of dye anions and binding sites on the adsorbent surface hence greater interaction between dye anions and the sorbent resulting in greater removal of dyes from aqueous solution (Salleh et al. 2011).



**Fig. 3** Effect of different RY 42 dye concentration over adsorption capacity of WCN (pH = 1, temperature= 25 °C and shaking speed= 120 rpm)

**Table 1** Comparison of linearized Langmuir, Freundlich and Temkin isotherm model for RY 42 adsorption by WCN

Adsorbent	Langmuir Isotherm		Freundlich Isotherm				Temkin Isotherm			q <sub>exp</sub> mgg <sup>-1</sup>
	X <sub>m</sub>	R <sup>2</sup>	K <sub>L</sub>	q <sub>eq</sub>	K <sub>F</sub>	R <sup>2</sup>	b <sub>T</sub>	K <sub>T</sub>	R <sup>2</sup>	
	mgg <sup>-1</sup>		mgg <sup>-1</sup>	mgg <sup>-1</sup>	mgg <sup>-1</sup>		KJmole <sup>-1</sup>	dm <sup>3</sup> g <sup>-1</sup>		
Plane bead	13.16	0.94	1.0	10.4	1.06	0.96	1476.5	0.64	0.78	11.1
WCN P	90.91	0.97	1.0	18.0	3.81	0.98	189.71	2×10 <sup>-7</sup>	0.95	63.8
WCN P bead	83.33	0.90	1.1	22.2	2.52	0.98	223.41	7×10 <sup>-9</sup>	0.88	56.5
WCN F	125.0	0.99	1.0	5.63	9.84	0.28	146.08	1×10 <sup>-5</sup>	0.97	86.9
WCN F bead	111	0.97	1.0	50.3	1.93	0.62	158.21	1×10 <sup>-7</sup>	0.96	80.3
SDS-WCN P	83.3	0.96	1.0	30.8	1.87	0.98	201.26	5×10 <sup>-10</sup>	0.93	53.4
SDS-WCN P bead	62.5	0.99	1.0	28.7	1.65	0.98	242.42	2×10 <sup>-8</sup>	0.96	42.2
SDS-WCN F	58.8	0.97	1.0	38.2	1.07	0.99	271.01	1×10 <sup>-8</sup>	0.94	38.0
SDS-WCN F bead	47.6	0.96	1.0	33.4	1.01	0.99	321.26	3×10 <sup>-7</sup>	0.94	33.4

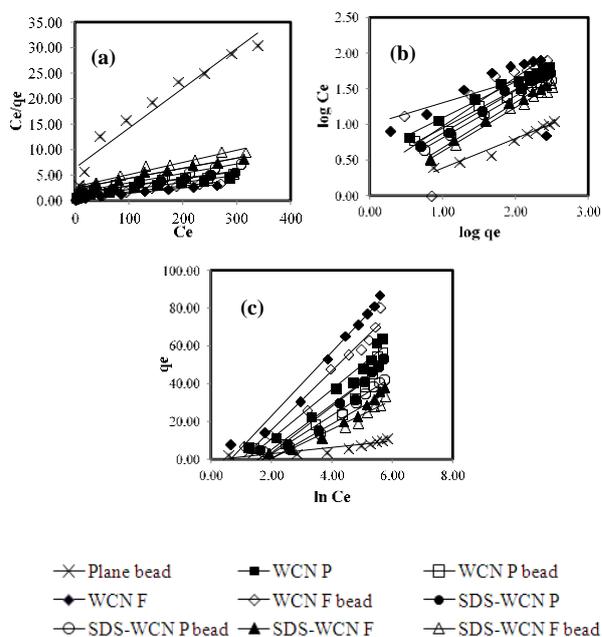
Adsorption isotherms applied over the data was Langmuir, Freundlich and Temkin isotherms models. Equilibrium relationship between the solid phase dye concentration and liquid phase concentration can be described in terms of adsorption isotherms (Geethakarathi and Phanikumar 2011).

Fig. 4 (a, b, c) and Table 1 show Langmuir, Freundlich and Temkin isotherm. Comparison of the correlation coefficient values (R<sup>2</sup>) shows validation of Langmuir isotherm model over some adsorbent as compared to other models.

While on other adsorbent Freundlich model is applicable. Freundlich isotherm model is appropriate in describing the adsorption mechanism of Plane beads (0.969), WCN P (0.988), WCN P bead (0.986), SDS-WCN P (0.988), SDS-WCN F bead (0.991), and SDS-WCN F (0.993) and WCN F bead (0.983) as signified by the R<sup>2</sup> values.

This is further supported by the determination of adsorption capacity (q<sub>max</sub>) that is in agreement with the experimentally determined (q<sub>exp</sub>) sorption capacity. Applicability of Langmuir isotherm model describe that the sorption of dye is monolayer coverage over a homogenous surface of sorbent. While applicability of Freundlich isotherm model on the data illustrates the complex nature of adsorption of RY 42 over the surface of sorbent. Validation of this model also provides information about the heterogeneity in surface of adsorbent.

Evaluation of Temkin isotherm model parameter b<sub>T</sub> values did not in agreement with the experimentally calculated sorption capacity which is an indication of lower relation of Temkin isotherm model with the experimental data. Higher values of b<sub>T</sub> show that heat of adsorption of the molecules does not decreases linearly with coverage due to adsorbate and adsorbent interactions. Lower R<sup>2</sup> values are also supporting the discussion.



**Fig. 4** Linearized (a) Langmuir (b) Freundlich and (c) Temkin isothermal models obtained for RY 42 dye adsorption over WCN at pH = 1, temperature= 25 °C, C<sub>i</sub> mgL<sup>-1</sup>= 50 ppm and shaking speed= 120 rpm)

Value of ΔG<sup>0</sup> can be determined from the following equation

$$\Delta G^0 = -RT \ln Kc$$

Where Kc the adsorption equilibrium constant and T is absolute temperature.

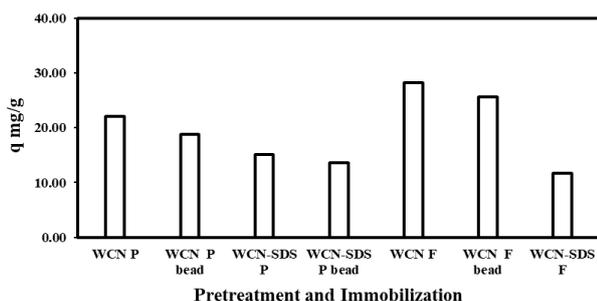
The essential features of a Langmuir isotherm can be expressed in terms of a dimensionless constant separation factor or equilibrium parameter. EP that is defined as:

$$EP = \frac{1}{(1 + bC_i)}$$

The value of EP indicates the shape of the isotherms to be either unfavorable ( $EP > 1$ ), linear ( $EP = 1$ ), favorable ( $0 < EP < 1$ ) or irreversible ( $EP = 0$ ). EP values greater than zero and less than unity ( $0 < EP < 1$ ) for RY 42 adsorption indicates that Langmuir isotherms is favorable for the applicability. The free energy of the process of all adsorbents was negative. This indicates that the adsorption process was spontaneous and thermodynamically favorable at temperature of 30 °C. The more negative values of  $\Delta G^\circ$  imply a greater driving force for the adsorption process.

### 3.4 Effect of immobilization

Immobilization of biomass was carried out via PVA-Na alginate. From results (Fig. 5) it is clear that adsorption capacity of the adsorbents were in this order WCN F > WCN P > WCN P SDS > WCN F SDS. The highest % removal i.e., 62 % was observed in free form as compared to immobilized form that is 53 %. Lower % removal by beads might be because of blockage of binding sites of adsorbent because of immobilization by chemicals hence approach of dyes over the surface is reduced which automatically reduce adsorption capacity (Vijayaraghavan and Yun 2008). While reduction in dye adsorption by SDS modified WCN is because of negatively charged head of SDS over the surface of WCN hence creating an electrostatic repulsion between dye and WCN.



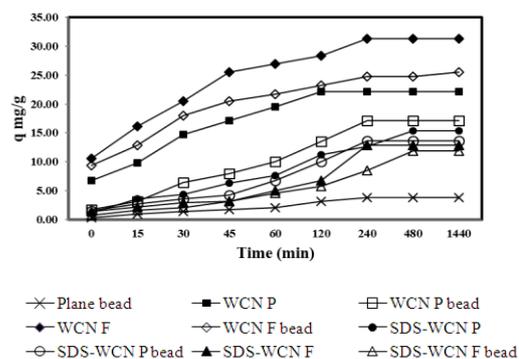
**Fig. 5** Comparison of immobilized, surfactant pretreated and native form for RY 42 dye adsorption over WCN at pH = 1, temperature= 25 °C,  $C_i$  mgL<sup>-1</sup>= 50 ppm and shaking speed= 120 rpm)

### 3.5 Effect of contact time

An important parameter of adsorption study is the time course during which adsorbent-adsorbate remain in contact. As it provides the valuable information about the mechanistic steps involved in adsorption and about the rate controlling steps adsorption taken place via chemical reaction or by mass transport (Caner et al. 2009). So for the evaluation of adsorption kinetics of RY 42 batch experiment were conducted with varying time interval from 0-1440 min with the sampling after every 15 minutes.

Adsorption was rapid during first 30 minutes (Fig. 6) and equilibrium was attained after 60 minutes with maximum removal of (44.24) WCN P, (62.53) WCN F, (30.73) SDS-WCN P and (25.80) SDS-WCN F biomass and after 120 min for the (34.23) WCN P bead, (49.49) WCN F bead, (27.23) SDS-WCN P bead and (23.74) SDS-WCN F bead. Adsorption capacity increases rapidly with the increase in time until equilibrated.

Sorption process occurs in two phases' i.e. initial phase (rapid phase) and final phase (equilibrated phase). Initially higher binding sites are available so higher sorption that reduces with passage of time (Singh et al. 2009).



**Fig. 6** Variation in RY 42 dye adsorption kinetics over WCN at pH = 1, temperature= 25 °C,  $C_i$  mgL<sup>-1</sup>= 50 ppm and shaking speed= 120 rpm)

#### 3.5.1 Kinetic modeling

Pseudo-first order and Pseudo-second order kinetic models were fitted over the kinetic data in order to evaluate the rate controlling step.

##### 3.5.1.1 Pseudo-first order model

According to this model sorption depends only upon the concentration of dye ions in the solution. Pseudo-first order rate equation can be written as

$$\log(q_{eq} - q_t) = \frac{\log q_{eq} - k_1}{2.303 \times t}$$

$k_1$  (min<sup>-1</sup>) = pseudo-first-order adsorption rate constant,  $q_t$  (mg g<sup>-1</sup>) = amount of sorption at time t (min),  $q_{eq}$  (mg g<sup>-1</sup>) = amount of sorption at equilibrium. The  $k_1$  and  $q_{eq}$  values were obtained from the plots of  $\log(q_e - q_t)$  versus t (Reddy et al. 2012).

##### 3.5.1.2 Pseudo-second order model

Pseudo-second order kinetic models describe that adsorption depend upon both the dye concentration and on the active sites available on adsorbent. The pseudo-second-order equation is

$$\frac{t}{q_t} = \frac{1}{k_2 q_e} + \frac{1}{q_e} \times t$$

$k_2$  (gmg<sup>-1</sup> min<sup>-1</sup>) = adsorption rate constant.  $k_2$  and  $q_e$  can be obtained from the intercept and slope of the plot of  $t/q_t$  versus.

**Table 2** Pseudo-First order model and Pseudo-second order model for RY 42 adsorption

Adsorbent	Pseudo-first order model			Pseudo-second order model			q <sub>exp</sub> mgg <sup>-1</sup>
	q <sub>eq</sub>	K <sub>1</sub>	R <sup>2</sup>	q <sub>eq</sub>	K <sub>1</sub>	R <sup>2</sup>	
	mgg <sup>-1</sup>	min <sup>-1</sup>		mgg <sup>-1</sup>	min <sup>-1</sup>		
Plane bead	46.67	4.6×10 <sup>-05</sup>	0.455	3.97	6.43×10 <sup>-03</sup>	0.998	3.84
WCN P	32.58	2.1×10 <sup>-04</sup>	0.295	22.73	4.0×10 <sup>-03</sup>	0.999	22.12
WCN P bead	40.27	2.3×10 <sup>-04</sup>	0.477	17.86	1.3×10 <sup>-03</sup>	0.998	17.11
WCN F	25.64	1.8×10 <sup>-03</sup>	0.363	26.32	3.0×10 <sup>-03</sup>	0.999	31.26
WCN F bead	29.92	2.1×10 <sup>-03</sup>	0.356	15.87	1.1×10 <sup>-03</sup>	0.997	25.54
SDS-WCN P	41.98	2.1×10 <sup>-04</sup>	0.567	32.26	2.5×10 <sup>-03</sup>	0.999	15.37
SDS-WCN P bead	43.05	1.8×10 <sup>-04</sup>	0.586	14.29	1.0×10 <sup>-03</sup>	0.995	13.62
SDS-WCN F	44.46	1.8×10 <sup>-04</sup>	0.736	13.70	9.2×10 <sup>-03</sup>	0.988	12.9
SDS-WCN F bead	44.98	1.6×10 <sup>-04</sup>	0.723	12.66	6.9×10 <sup>-03</sup>	0.988	11.87

Comparative analysis of q<sub>e</sub> (mgg<sup>-1</sup>) values of pseudo-first order and pseudo-second order kinetic models from Table 2, shows that kinetic data was best explained by pseudo-second order kinetic model. q<sub>e</sub> (mgg<sup>-1</sup>) values are in close agreement with q<sub>exp</sub> (mgg<sup>-1</sup>) for all the adsorbents. This was further confirmed by the comparison of regression line value (R<sup>2</sup>) of pseudo-first order and pseudo-second order kinetic models (2) which is close to R<sup>2</sup> ≥ 0.999 for pseudo-second order and lower than R<sup>2</sup> ≥ 0.5 for pseudo-first order kinetic model.

### 3.6 Desorption

Regeneration and reuse of adsorbent for further cycles is important from the economic perspective, and to ensure that resolution of one problem does not create another. Selection of an appropriate eluent is crucial for successful regeneration (Jesus *et al.* 2011). So desorption study was carried out using 0.01 N solution of NaOH in repeated cycles of sorption and desorption. 60.26% (WCN F) and 32 % (WCN F bead) was desorbed from adsorbent. Adsorbent can be reused up to 3 cycles after which percent removal of RY 42 was noticeably decreased (data not shown). The data can be a reference for industrial application of WCN F and WCN F bead for dye removal from aqueous solutions. As it is found that WCN F and WCN F bead can be used repeatedly without significant decline of its adsorption capabilities during adsorption-desorption cycles, especially WCN F therefore, can be regarded as a potential adsorbent in the application of textile waste treatment.

### Conclusions

This research work opens a new gate way for the eradication of reactive textile dye using waste of WCN as an adsorbent that may otherwise cause dumping problem. It is locally available because of its high demand in many industries. This adsorbent WCN can be used in its raw form for adsorption of dyes; its surface modification and immobilization reduce its adsorption ability.

### References

- Aksakal, O., & Uzun, H. (2010). Equilibrium, kinetic and thermodynamic studies of the biosorption of textile dye (Reactive Red 195) onto *Pinus sylvestris* L. Journal of Hazardous Materials, 181(1), 666-672, doi:doi:10.1016/j.jhazmat.2010.05.064.
- Aksu, Z., & Çağatay, Ş. Ş. (2006). Investigation of biosorption of Gemazol Turquoise Blue-G reactive dye by dried *Rhizopus arrhizus* in batch and continuous systems. Separation and Purification Technology, 48(1), 24-35.
- Atafar, Z., Mesdaghinia, A., Nouri, J., Homaei, M., Yunesian, M., Ahmadimoghaddam, M., *et al.* (2010). Effect of fertilizer application on soil heavy metal concentration. Environmental monitoring and assessment, 160(1-4), 83.
- Caner, N., Kiran, I., İlhan, S., & İscen, C. F. (2009). Isotherm and kinetic studies of Burazol Blue ED dye biosorption by dried anaerobic sludge. Journal of hazardous materials, 165(1-3), 279-284.
- Crini, G. (2006). Non-conventional low-cost adsorbents for dye removal: a review. Bioresource technology, 97(9), 1061-1085, doi:doi:10.1016/j.biortech.2005.05.001.
- Geetha, P., Latha, M., & Koshy, M. (2015). Biosorption of malachite green dye from aqueous solution by calcium alginate nanoparticles: equilibrium study. Journal of Molecular Liquids, 212, 723-730.
- Geethakarthy, A., & Phanikumar, B. (2011). Adsorption of reactive dyes from aqueous solutions by tannery sludge developed activated carbon: Kinetic and equilibrium studies. International Journal of Environmental Science & Technology, 8(3), 561-570.
- Handan, U. (2011). Equilibrium, thermodynamic and kinetics of reactive black 5 biosorption on loquat (*Eriobotrya japonica*) seed. Sci Res Essays, 6(19), 4113-4124, doi:DOI: 10.5897/SRE11.674.
- Huang, J., Liu, D., Lu, J., Wang, H., Wei, X., & Liu, J. (2016). Biosorption of reactive black 5 by modified *Aspergillus versicolor* biomass: kinetics, capacity and mechanism studies. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 492, 242-248.
- Jaikummar, V., & Ramamurthy, V. (2009). Effect of biosorption parameters kinetics isotherm and thermodynamics for acid green dye biosorption from aqueous solution by brewery waste. International Journal of Chemistry, 1(1), p2.
- Jesus, A., Romão, L., Araújo, B., Costa, A., & Marques, J. (2011). Use of humin as an alternative material for adsorption/desorption of reactive dyes. Desalination, 274(1-3), 13-21.

- Kabbout, R., & Taha, S. (2014). Biodecolorization of textile dye effluent by biosorption on fungal biomass materials. *Physics Procedia*, 55, 437-444.
- Khataee, A. R., Vafaei, F., & Jannatkah, M. (2013). Biosorption of three textile dyes from contaminated water by filamentous green algal *Spirogyra* sp.: Kinetic, isotherm and thermodynamic studies. *International Biodeterioration & Biodegradation*, 83, 33-40, doi:10.1016/j.ibiod.2013.04.004.
- Kim, S. Y., Jin, M. R., Chung, C. H., Yun, Y.-S., Jahng, K. Y., & Yu, K.-Y. (2014). Biosorption of cationic basic dye and cadmium by the novel biosorbent *Bacillus catenulatus* JB-022 strain. *Journal of Bioscience and Bioengineering*, doi:10.1016/j.jbiosc.2014.09.022.
- Naim, M. M., & El Abd, Y. M. (2002). Removal and recovery of dyestuffs from dyeing wastewaters. *Separation & Purification Reviews*, 31(1), 171-228, doi:DOI:10.1081/SPM-120006116.
- Reddy, M. S., Sivaramakrishna, L., & Reddy, A. V. (2012). The use of an agricultural waste material, Jujuba seeds for the removal of anionic dye (Congo red) from aqueous medium. *Journal of hazardous materials*, 203, 118-127.
- Robalds, A., Naja, G. M., & Klavins, M. (2016). Highlighting inconsistencies regarding metal biosorption. *Journal of hazardous materials*, 304, 553-556.
- Sadaf, S., & Bhatti, H. N. (2013). Biosorption of Foron turquoise SBLN using mixed biomass of white rot fungi from synthetic effluents. *African Journal of Biotechnology*, 10(62), 13548-13554, doi:DOI: 10.5897/AJB11.2080.
- Salleh, M. A. M., Mahmoud, D. K., Karim, W. A. W. A., & Idris, A. (2011). Cationic and anionic dye adsorption by agricultural solid wastes: A comprehensive review. *Desalination*, 280(1-3), 1-13.
- Singh, V., Sharma, A., Tripathi, D., & Sanghi, R. (2009). Poly (methylmethacrylate) grafted chitosan: An efficient adsorbent for anionic azo dyes. *Journal of hazardous materials*, 161(2-3), 955-966.
- Srinivasan, A., & Viraraghavan, T. (2010). Decolorization of dye wastewaters by biosorbents: a review. *Journal of environmental management*, 91(10), 1915-1929.
- Vara Prasad, M. N., & de Oliveira Freitas, H. M. (2003). Metal hyperaccumulation in plants: biodiversity prospecting for phytoremediation technology. *Electronic journal of biotechnology*, 6(3), 285-321.
- Vijayaraghavan, K., & Yun, Y.-S. (2008). Biosorption of CI Reactive Black 5 from aqueous solution using acid-treated biomass of brown seaweed *Laminaria* sp. *Dyes and Pigments*, 76(3), 726-732.
- Wangpradit, R., & Chitprasert, P. (2014). Chitosan-coated *Lentinus polychrous* Lév.: Integrated biosorption and biodegradation systems for decolorization of anionic reactive dyes. *International Biodeterioration & Biodegradation*, 93, 168-176, doi:10.1016/j.ibiod.2014.05.018.