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Adsorptive Removal of Cationic and Anionic Dyes from Aqueous Solutions by Using Eggshell Household Waste as Biosorbent

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Abstract

In the last years, the adsorption processes were proven effective and easy to use techniques to clean polluted wastewater. The purpose of this research is to examine the biosorption method on organic indicators (Methylene Blue, Malachite Green, Congo Red and Bromphenol Blue) in aqueous medium by using chicken eggshell. The adsorption process was investigated in static circumstance. We examined the initial change of concentration (10–50 mg/l), the pH effect on the adsorption process, the equilibrium process, and the sorption kinetics. With scanning electron microscope, we examined the morphology and texture of the eggshell; furthermore, we conducted EDX microanalysis and ecotoxicological tests. Our results support the influence of the parameters on the sorption process.

Keywords: Adsorption; eggshell; cationic dye; anionic dye

1. Introduction

The World Economic Forum has consecutively assessed the water crisis as one of the major global risks over the past five years. In 2016, the water crisis was determined as the global risk of highest concern for people and economies for the next ten years. In global scale it is estimated that 80% of wastewater is released to the environment without adequate treatment.² Water pollution is highly affected by industrial development. Textile industry uses dyes to color their products producing wastewater containing organic matter with strong color.3 Due to low level dye-fiber fixation, approximately 15% of the total dyestuff produced annually is lost during the dyeing process and comes out with waste water.^{4,5} The removal of dyes from water becomes environmentally important because small quantities can be toxic to natural waters causing allergic reactions, skin irritation, cancer, mutations, its color is highly visible and inhibits sunlight penetration into waters like streams, rivers, lakes.⁶ For this reason, the effective removal of these dyes by using clean-up technologies is an outstanding task. Adsorption is a well-known equilibrium separation process and an effective method for water decontamination applications.⁷ Eggshell could be a low-cost adsorbent for dye removal from wastewater because dye molecules can bind to the porous structure of eggshell (17000 pores) having large surface area.^{8–10} Eggs are the most common and widely used natural food on Earth; only in the US 50 billion eggs are consumed per year.¹¹

2. Materials and Methods

2. 1. Preparation of Dye

Methylene Blue (MB) and Malachite Green (MG) cationic dyes were purchased from Loch-Ner.s.r.o., Czech Republic and Loba Chemie, Wien-Fischamend, Austria, respectively and were used without any further purification treatment. Anionic dyes Congo Red and Bromphenol Blue (BPB) were purchased from Merck KGaA, Germanz and Loba Chemie Wien-Fischamend respectively. Chemical structures and characteristics of all four dyes are summarized in Table 1.

Table 1. Description of indicators used in the experiment

Characteristics	Congo Red	Bromphenol Blue	Methylene Blue	Malachite Green		
Chemical formula M (g/mol) anionic/cationic Previous biosorption study	C ₃₂ H ₂₂ N ₆ Na ₂ O ₆ S ₂ 696.66 anionic 12,13	C ₁₉ H ₁₀ Br ₄ O ₅ S 669.96 anionic 14,15	$C_{16}H_{18}CIN_3S$ 373.91 cationic	C ₂₃ H ₂₅ ClN ₂ 364.91 cationic 7,18		
	NH2	Br Br OH	H ₃ C. N CI- CH ₃	CI-0		

Stock solutions of dyes were prepared by dissolving 1 g of each dye in 1 L deionized water. During the adsorption experiments, 1g/L stock solution was diluted to obtain the needed concentration.

2. 2. Preparation of Adsorbent

The chicken eggshell used as biosorbent was gathered from household, kitchen waste. The shells were firstly washed in tap water, then in deionized (MilliQ) water. The cleaned eggshell was dried in drying cabinet (Memmert UN75 PLUS) at 80 $^{\circ}$ C, then powdered and sieved at 160 μ m size fraction geologist sieve. During the biosorption experiments 3–3 g of powdered shell was used without any chemical or physical treatment.

2. 3. Effect of Initial Dye Concentration

The sorption of indicator dyes on chicken eggshell's surface was studied in aqueous solutions using 250 mL Erlenmeyer flasks, where 100 mL dye solutions were constantly mixed (VARIOMAG Electronisher MULTIPOINT HP multi-magnetic shaker) with 3 g of biosorbent (160 µm particle size) at 750 rpm, room temperature (T = 20 \pm 1 °C), and without initial pH adjustment. Spectrophotometer (Agilent Cary 60 UV-Vis spectrophotometer) was used to periodically measure dye concentrations at λ_{max} = 497,580,664,619, respectively for Congo Red, BPB, MB, MG using calibration curve as measuring technique for quantitative analysis.

In each case the samples supernatant were centrifuged (Hettick Zentrifugen Mikro 20) for 5 minutes at 10000 rotation/min, after which the maximum absorption was measured by spectrophotometer.

In order to investigate the effect of concentration on adsorption, 100 mL of Congo Red, BPB, MB, MG solutions were mixed with 3 g of powdered eggshell at different initial concentrations between 10–50 mg/L. In each case, three parallel experiments were executed.

2. 4. Effect of pH

Due to the fact that the solutions' pH highly affects not only the aqueous chemistry but also the biosorbents' active sites, the removal of Congo Red, BPB, MB, MG from aqueous solution was investigated at different pH values between 2–10. pH was adjusted with 0.1 mol/L NaOH and 0.1 mol/L HCl. During the experiment, constant parameters were: c = 30 mg/L, 3 g of 160 μ m particle sized biomass, 750 rpm, $T = 20 \pm 2$ °C.

2. 5. SEM and EDX Analytical Measurement

The texture and morphology of chicken eggshell before and after treatment with dyes was analyzed using Scanning electron microscopy (JEOL(USA)JSM5510 LV SEM). Elemental studies were also carried out using Energy dispersive spectroscopy.

2. 6. Bioconcentration Factor

BCF is a value that gives the dyes' accumulation efficiency in eggshell. It was calculated based on the dye concentrations in the eggshell and the dissolved dye concentration of aquatic solution.

$$BCF = \frac{c_{indicator in eggshell}}{c_{indicator in water}}$$
 (1)

2. 7. Ecotoxicological Tests – the Effect of Dyes on Seedling Growth

Based on Hungarian standard MSZ 21978/8-85 the toxicological effect of Congo Red, BPB anionic and MB, MG cationic dyes was studied on lettuce and mustard seeds. During the experiments, 25 seeds were placed in autoclaved (at 120 °C) Petri-dishes and 5–5 mL dye solution was added at different concentrations (0, 10, 30, 50, 1000 mg/L). The two simultaneous set of samples were put in a dark chamber for 3 days, where the temperature was kept constant $T = 20 \pm 2$ °C. After the passing days the length of the seeds roots were measured and the number of seedling was also examined. With the help of the equation below, by knowing the length of the seeds (using the averages of the 25 seed length) the root growth inhibition was calculated.

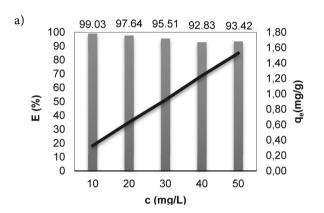
$$X = \frac{K - M}{K} * 100 \tag{2}$$

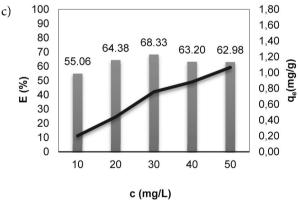
Where: X – Root growth inhibition, K – root length of control seeds (mm), M – root length of dye-contaminated seeds (mm).

3. Results and Discussions

3. 1. Effects of Initial Indicator Dye Concentration

During our research the effect of Congo Red, BPB anionic and MB, MG cationic indicators uptake by chicken eggshell household waste was examined using different initial dye concentrations between 10–50 mg/L. Figure 1 shows the efficiency and quantity in equilibrium of various dyes at different initial concentration, where 3 g eggshell powder of 160 µm particle size was constantly shaken at 75 0rpm with 100 mL solution at room temperature (T = 20 \pm 2 °C) without pH adjustment (pH $_{\rm CR}$ = 8.05, pH $_{\rm BPB}$ = 2.7, pH $_{\rm MB}$ = 3.95, pH $_{\rm MG}$ = 2.76). With the increase of initial dye concentration in case of Congo Red, MB and MG, the adsorption capacity also increased, whereas in case of BPB there was no such trend.

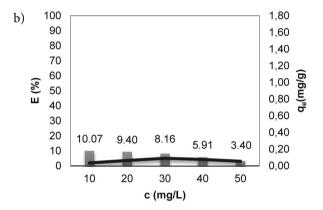




= 2, but in all cases E was above 93%. BPB dyes' highest efficiency was also at pH = 2 (E = 67%). For MB the adsorption was most efficient at pH = 10, achieving 75% efficiency, while the lowest was at pH = 2 where E = 14%. MG is similar to Congo Red dye, with a high percentage efficiency at all pHs. Thus, it can be said that BPB anionic dye preferred acidic medium, while MB cationic dye preferred the basic medium, whereas there was no significant change in case of Congo Red and MG, because the efficiency was high at all pHs. Similar results were obtained by Zeroual et al., 2006; Iqbal and Ashiq, 2010; Salleh et al., 2011; Zulfikar and Setiyanto, 2013; Tiwari et al., 2015; El-Dars et al., 2015. $^{3,14,19-22}$

3. 3. SEM and EDX

Scanning electron microscopy photographs were taken in order to examine the shape of the samples' parti-



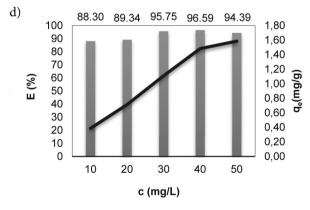


Figure 1. Effect of initial dye concentration for Congo Red (a), BPB (b), MB (c), MG (d) (C_i = 0–50 mg/L, 3 g biomass, 160 μ m, 700 rpm, pH_{Congo} = 8.05; pH_{BPB} = 2.70; pH_{MB} = 3.95; pH_{MG} = 2.76, T = 20 \pm 1 °C)

3. 2. Effect of Solution pH

The pH of aqueous solution can highly affect the biosorbents' (eggshell) surface charge. In acidic media, the surface of the adsorbent is protonated, while in a basic medium its surface deprotonates. During our research, the adsorption processes were studied by varying the aqueous solutions' pH, ranging between 2–10. As seen in figure 2. Congo Red dyes' highest adsorption efficiency was obtained at pH

cle, size of appeared aggregates, porosity and texture before and after adsorption with eggshell biomass. Figure X shows the SEM of the control sample (160 µm sized eggshell without adsorption) and four dye treated samples with 50 mg/L dye solutions. It can be seen that the porous, cross-linked structure of eggshell disappears in comparison to the control sample (Figure 3.a) in case of MB, MG, Congo Red; this is due to the fact that the eggshell has incorporated the color into its "caverns". On the other hand,

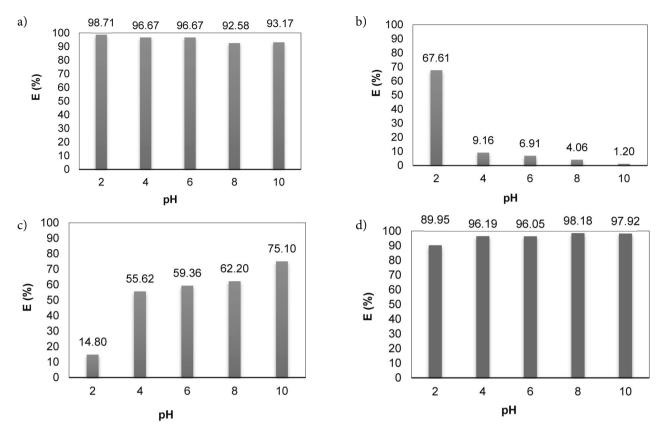


Figure 2. Effect of pH for indicators: Congo Red (a), BPB (b), MB (c), MG (d) ($C_i = 30 \text{ mg/L}$, 1.5 g biomass, 160 μ m, 700 rpm, T = 20 \pm 1 °C)

in case of BPB (Figure 3.e) some of the cross-linked structure is saturated, in other parts smaller or larger aggregates have appeared, but the cross-linked structure, characteristic to eggshell structure, is still visible. This can be explained in the following way: when comparing the result with the amount of bounded material, we can see that BPB has the smallest value ($c_i = 50 \text{ mg/L}$, $q_e = 0.06 \text{ mg/g}$), so we can conclude that there are still free binders and the eggshells' crystal grid structure is still visible.

In order to examine the elemental composition of

the eggshell both for control and dye adsorbed samples X-ray spectroscopy (EDX) was carried out. From Table 2 it can be assumed that the control sample contains mostly carbon, oxygen and calcium. This was expected because eggshell is made of calcium carbonate (approx. 94%). Samples contaminated with dye not only contain elements specific to eggshell but also elements gained from the dye they were adsorbed with, we can see that new elements appeared, some completely disappeared while others only decreased.

 $\textbf{Table 2.} \ \text{Eggshells' elemental composition, results obtained were computed from 9 data} \ (C_{\text{dye}} = 50 \ \text{mg/L}, 160 \ \mu\text{m})$

Elements	Wt(%) control eggshell	Wt(%) MB	Wt(%) MG	Wt(%) Congo Red	Wt(%) BPB 25.092 ± 6.607	
C	22.944 ± 9.144	25.169 ± 2.617	24.662 ± 6.016	23.504 ± 5.877		
N	0.314 ± 0.735	0	0	0	0	
O	43.990 ± 10.782	46.110 ± 1.241	47.633 ± 6.553	45.058 ± 2.076	47.050 ± 8.348	
Na	0.063 ± 0.108	0.046 ± 0.044	0.063 ± 0.067	0.096 ± 0.046	0.050 ± 0.079	
F	0	0.870 ± 0.688	1.763 ± 1.693	2.390 ± 0.805	1.520 ± 1.726	
Mg	0.445 ± 0.237	0.328 ± 0.036	0.312 ± 0.040	0.358 ± 0.034	0.192 ± 0.217	
Al	0.429 ± 0.541	0.340 ± 0.072	0.403 ± 0.180	0.366 ± 0.111	0.690 ± 0.720	
Si	0	0	0.008 ± 0.020	0.018 ± 0.040	0	
P	0.084 ± 0.219	0.084 ± 0.051	0.107 ± 0.045	0.096 ± 0.026	0.085 ± 0.069	
S	0.175 ± 0.328	0.236 ± 0.030	0.2370 ± 0.213	0.238 ± 0.058	0.385 ± 0.196	
Ca	29.245 ± 9.553	26.750 ± 1.265	28.765 ± 5.136	27.864 ± 3.337	28.973 ± 5.117	
Cu	0	0.020 ± 0.020	0.015 ± 0.023	0.008 ± 0.018	0	
K	0.015 ± 0.048	0	0	0	0	
Br	0	0	0	0	0.130 ± 0.162	

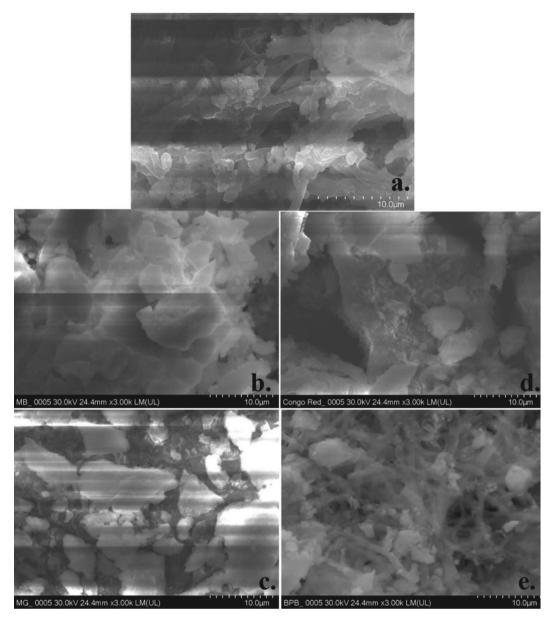


Figure 3. a. control eggshell, 50 mg/L b. MB, c. MG, d. Congo Red, e. BPB adsorbed eggshell household waste.

Figure 4 is a graphical representation of the distribution of trace elements summarized in Table 2. We can see clearly the decrease of Mg while the increase of Sulphur. Furthermore, Sulphur as keystone of dyes can be seen in each sample, while nitrogen is eliminated. In the case of BPB, the presence of bromine proves the eggshells' adsorption ability. Results obtained demonstrate that even in small concentrations (50 mg/L) the elemental composition of the eggshell can change when is used for dye adsorption.

3. 4. Bioconcentration Factor

Figure 5 shows that BCF decreases with the increase of dye concentration in case of Congo Red while BCF increases in case of MG, clearly demonstrating that eggshell

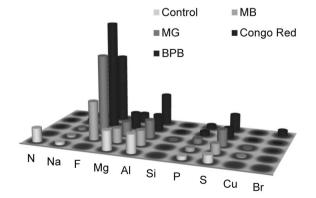


Figure 4. Appearance of trace elements in eggshell before and after adsorption

is a promising biosorbent to remove indicators.¹⁰ On the other hand, there is no significant change in the presence of BPB and MB.

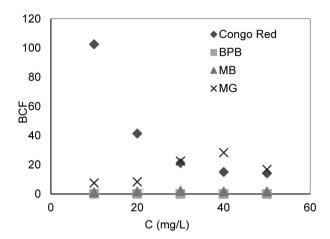


Figure 5. Bioconcentration factor

3. 5. Ecotoxicological Test

During research the toxicity of each indicator was studied by carrying out seed germination, seedling growth test for salad (lettuce) and mustard seeds. Four different concentrations were used beside the control sample. After 72 h. the length of each seeds' root was measured and 2×25 measurements' arithmetic mean was calculated and summarized in tables.

For Congo Red in Table 3 it is obvious that for lettuce seed the inhibition of germination can reach 80%, while for mustard seed negative values were obtained. The growth of the seed roots can be explained by the presence of nitrogen in the dye. Moreover, from the 25 seeds more were germinated in case of mustard than in case of lettuce.

Table 3 shows that the degree of germination is increased by increasing the concentration in case of BPB. The inhibition grows with concentration increase, in high concentrations (1 g/L) for lettuce reaches 100% and for mustard 99.85%.

In case of MB for lettuce seed the inhibition is around 30% for 10 mg/L concentration, the inhibition increases with the increase of dye concentration. For mustard seed, the values are much lower. During the experiments the mustard seed became blue and the seeds also discolored.

Both for the mustard and lettuce seed the inhibition was high in case of MG, more than 88% was obtained even at low concentration (10 mg/L) for mustard seed, whereas in case of lettuce seed more seeds germinated. Mustard seeds have become colored and around them (in the inhibition zone) the dye was discolored.

Figure 5 shows mustard and lettuce seed sprouts. On the left (Figure 6.a,d) side seeds were in control solution while on the right (Figure 6.b,c) side seeds were placed in 50 mg/L MG solution. It can be seen that the sprouts are healthy and long (lettuce 40 mm, mustard 70 mm), while in the dye solution the seeds were colorful and small (barely 10 mm). It is also noteworthy that the control had at least 20 sprouts out of 25 seeds, while in the dye solution it was much less. These observations apply in each case. All



Figure 6. Mustard (a, b) and lettuce (c, d) seeds before (a, d) and after (b, c) seed growth test

Table 3. Seedling growth test containing root growth inhibition data, as the standard method required results obtained were computed from 2 parallel experiments ($C_i = 0-1000 \text{ mg/L}$, T = 20 °C, t = 72h)

Dye	Congo Rec	l BPB	MB	MG					
Concentration (mg/L)	Lettuce (%)	Mustard (%)	Lettuce (%)	Mustard (%)	Lettuce (%)	Mustard (%)	Lettuce (%)	Mustard (%) (%)	
10	-35.75	-5.31	24.84	45.75	30.37	20.25	88.68	63.36	
30	68.88	-25.74	43.43	69.42	49.09	10.81	93.67	83.44	
50	82.62	-21.87	54.97	78.79	79.66	17.43	97.17	83.16	
1000	36.83	18.28	100	99.85	99.19	74.14	100	97.25	

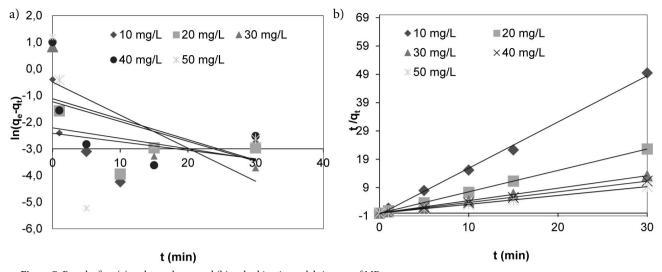


Figure 7. Pseudo-first (a) and pseudo-second (b) order kinetic models in case of MB

in all, we can conclude that seed germination is dye and plant dependent.

3. 6. Adsorption Kinetic Models

Experimental data were analyzed using various kinetic models to describe the mechanism of adsorption process of Congo Red, BPB anionic and MB, MG cationic dyes on chicken eggshell household waste. Linearized graphics are only present in case of MB, but the others show similar trends. The pseudo-first-order (Lagergen) plot is shown in Figure 6.a. From the intercept and slope of the straight lines' plot q_e (quantity in equilibrium) and k_1 (Lagergen rate constant) was calculated and listed in table 4 for all four indicators.

Pseudo-second-order (Ho&McKay) plot is shown in figure 6. b. an as in case of pseudo-first- order kinetic model q_e (quantity in equilibrium) and k_2 (equilibrium rate constant) was calculated from strait lines' intercepts and slopes. Table 4 not only shows the kinetic models' specific parameters but also the linear regression coefficients. Based on received data in all cases pseudo-second-order kinetic model describes the adsorption process.

Similar results were obtained by Rani et al. where they studied Congo Red biosorption on coconut residual fiber. ¹² Mudyawabikwa et al. studied MB removal by activated carbon made from tobacco stems. ²³ They affirm that the study of kinetics of this process is really important "since it is a depiction of adsorbate uptake rate and also controlling parameter to the adsorption process residual time".

Table 4. Adsorption kinetics (C_i = 10–50 mg/L, 3 g biomass, 160 μ m, 700 rpm, T = 20 \pm 2 °C)

MB		Pseudo-first-order			Pseudo-second-order			CongoRed		Pseudo-first-order			Pseudo-second-order		
C (mg/L)	q _e (exp) (mg/g)	k ₁ (1/t)	q _e (calc) (mg/g)	R ²	k ₂ (g/mg × t)	q _e (calc) (mg/g)	R ²	C (mg/L)	q _e (exp) (mg/g)	k ₁ (1/t)	q _e (calc) (mg/g)	R ²	k ₂ (g/mg × t)	q _e (calc) (mg/g)	R ²
10	0.20	-0.04	0.11	0.118	-5.59	0.61	0.997	10	0.33	-0.06	0.36	0.604	0.71	0.99	0.996
20	0.44	-0.03	0.09	0.159	0.42	1.91	0.999	20	0.63	-0.04	0.53	0.847	0.42	1.91	0.999
30	0.76	-0.12	0.61	0.714	0.24	2.75	0.999	30	0.92	-0.02	0.65	0.742	0.24	2.75	0.999
40	0.88	-0.08	0.33	0.292	0.18	3.73	0.999	40	1.24	-0.03	0.91	0.844	0.18	3.73	0.999
50	1.07	-0.07	0.29	0.144	0.12	4.67	0.999	50	1.53	-0.01	0.77	0.555	0.12	4.67	0.999
MG	MG Pseudo-first-order			Pseudo	Pseudo-second-order BPB			Pseudo-first-order			Pseudo-second-order				
C (mg/L)	q _e (exp)	k ₁ (1/t)	q _e (calc)	R ²	k ₂ (g/mg ×	q _e t)(calc)	R ²	C (mg/L)	q _e (exp)	k ₁ (1/t)	q _e (calc)	R ²	k ₂ g/mg ×	q _e t)(calc)	R ²
	(mg/g)		(mg/g)			(mg/g)			(mg/g)		(mg/g)			(mg/g))
10	0.39	0.03	0.05	0.022	-5.92	1.07	0.999	10	0.04	-0.02	0.06	0.731	2.45	0.11	0.995
20	0.71	-0.02	0.12	0.137	-36.46	2.14	0.999	20	0.07	-0.03	0.29	0.262	0.21	0.42	0.919
30	1.11	-0.08	0.25	0.276	8.89	3.30	0.999	30	0.09	-0.07	0.55	0.935	0.25	0.68	0.991
40	1.48	-0.03	0.28	0.050	-18.53	4.31	0.999	40	0.08	-0.03	0.61	0.946	0.11	0.73	0.997
50	1.59	-0.05	0.18	0.073	-34.70	4.71	0.999	50	0.06	-0.06	0.39	0.978	0.40	0.52	0.976

Freundlich Langmuir **Dubinin-Radushkevich Temkin** \mathbb{R}^2 \mathbb{R}^2 \mathbb{R}^2 В \mathbb{R}^2 K_L β E A_T \mathbf{q}_{max} $(mg^{(1-1/n)}L^{1/n}/g)$ (L/mg) $(mol^2 kJ^2)$ (kJ/mol) (L/g)(J/mol) (mg/g)MB 0.87 0.911 0.78 0.930 9×10^{-6} 0.990 2.36 2×10^{-5} 0.989 0.04 36.90 0.24 3×10^{-7} 2.53 7×10^{-5} MG 0.33 2.13 0.856 2.09 0.965 1.29 0.955 0.961 1.46 CongoRed 4×10^{-8} 2×10^{-6} 1.22 0.999 2.50 1.02 0.996 2.66 0.917 3.75 3.54 0.854 8×10^{-7} 2×10^{-7} 0.803 BPB 0.59 0.04 0.827 1.02 1.23 0.811 2.89 0.755 2.13

Table 5. Adsorption isotherm models calculated constants for indicator adsorption onto eggshell surface ($C_i = 10-100 \text{ mg/L}$, 3 g biomass, 160 μ m, 700 rpm, $T = 20 \pm 2$ °C)

Pseudo-second-order kinetic model described the adsorption process in case of MG using nanowires loaded activated carbon as biosorbent and in case of BPB using bentonite carbon composite material. ^{14,24}

3. 7. Adsorption Isotherm Models

Equilibrium processes can be characterized by adsorption isotherm models. In order to characterize the adsorption process and to determine the amount of adsorption, four different isotherm models (Langmuir, Freundlich, Temkin, Dubinin-Radushkevich) were used for all four dyes' equilibrium data, obtained after adsorption with eggshell.

Table 5 contains the calculated parameters characteristic to each isotherm model. Due to the fact that B - Temkin constant is less than 20 kJ/mol and E - energy is less than 8 kJ/mol the adsorption is mostly physical in nature.

As shown in Table 5 MB fits the Dubinin-Radush-kevich isotherm model more closely, which indicates that chemical adsorption also occurs, ion exchange happens, similar results were obtained using walnut as biosorbent for MB removal.²⁵ In case of MG the liner regression coefficients are very near values but it aligned closer to Freundlich isotherm model, Santhi et al. got Freundlich isotherm as well by studying MG adsorption on prawn waste.²⁶ In case of BPB and Congo Red the adsorption process can be described by Langmuir isotherm model. Similar results to Congo Red: ^{27,28} and to BPB:.^{19,29,15}

4. Conclusions

The present study compared two anionic (Congo Red, Bromphenol Blue) and two cationic (Methylene Blue Malachite Green) dyes' adsorption properties on eggshell surface. By studying the effect of pH, results demonstrate that anionic dyes adsorb better in acidic while cationic dyes in basic medium. Highest efficiency occurred at pH = 2 for Congo Red and BPB (98.71, 67.61%) while for MB and MG in basic medium (75.10, 98.18%). SEM images show that the porous, cross-linked structure of eggshell disappeared after dye adsorption in case of Congo Red, MB, MG. From EDX measurements it is obvious that egg-

shell is mostly made of CaCO₃ and after adsorption process the amount of sulphur, chromium and brome increased in samples. With the help of seed germination test, the different effect of each dye on lettuce and mustard seed growth was investigated, where the phytotoxic test was plant and dye dependent. For all four dyes the adsorption mechanism was best described by pseudo-second-order kinetic model. In case of MB Dubinin-Radushkevich, MB-Freundlich, BPB, Condo Red Langmuir isotherm model fitted better the adsorption data.

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Povzetek

V zadnjih letih se je adsorpcija izkazala kot učinkovit in enostaven način čiščenja onesnaženih odpadnih vod. Namen predstavljene študije je preučitev uporabe biosorpcije s pomočjo kokošjih jajčnih lupin za odstranitev organskih indikatorjev (metilensko modro, malahitno zeleno, kongo rdeče in bromfenol modro) in vodnih raztopin. Proces adsorpcije je bil preučevan pod statičnimi pogoji. Preučevali smo vpliv začetne koncentracije (10–50 mg/L), vpliv pH vrednosti, doseženo ravnotežje in kinetiko adsorpcije. S pomočjo vrstične elektronske mikroskopije smo preučili morfologijo in teksturo jajčnih lupin, prav tako pa smo izvedli EDX mikroanalizo in ekotoksikološke teste. Rezultati potrjujejo vpliv preučevanih parametrov na sorpcijski proces.