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REMOVAL OF REACTIVE DYE FROM AQUEOUS SOLUTIONS USING BANANA PEEL AND SUGARCANE BAGASSE AS BIOSORBENTS

The adsorption of Eurozol Navy Blue (ENB) reactive dye was examined using banana peel and sugarcane bagasse powders. Several parameters such as pH, contact time, agitation speed, temperature, initial dye concentration, and adsorbent dosage were considered and their impact on dye adsorption efficiency was evaluated. The removal percentages of ENB dye due to adsorption on banana peel and sugarcane bagasse were 72% and 70%, respectively. Simultaneous dosing of both biosorbents resulted in 68% dye removal. The Langmuir isotherm model was found to fit the adsorption of ENB dye on banana peel and sugarcane bagasse powders. The corresponding maximum adsorption capacities were equal to 24.09, 32.46, and 27.54 mg/g for banana peel powder, sugarcane bagasse powder, and the mixture of adsorbents, respectively.

1. INTRODUCTION

Reactive dyes are colorants commonly applied in the textile industry for dyeing pure cotton or cotton blend fabric. The color of aqueous solutions containing various reactive dyes usually ranges from 200 to 400 Hazen units. Reactive dyes are very toxic and harmful for living and aquatic life. They may cause cancer, skin diseases, and allergic reactions [1–3]. Besides the toxic, mutagenic, and carcinogenic effect, the presence of reactive dyes causes aesthetic damage to water bodies, increases water turbidity, and reduces the penetration of light through water.

Commonly used methods for treating dye-containing wastewater are coagulation and flocculation, electrocoagulation, activated carbon adsorption, and nanofiltration [4–6].

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These technologies sometimes do not show significant effectiveness or economic profitability for the removal of reactive dyestuffs. To solve this issue low-cost treatment methods such as adsorption techniques have been investigated and suggested by many researchers. Numerous non-conventional low-cost adsorbents have been proposed for dye removal [7–9]. The most frequently investigated adsorbents involve wood, China clay, Fuller's earth and fired clay, fly ash, wollastonite, Fe(III)/Cr(III) sludge, banana peel, and sugarcane bagasse [10–13].

Natural low-cost adsorbents are frequently modified physically or chemically to improve their sorption properties. Aziz et al. [2] presented a study on the removal of Eriochrome Black T (an azo anionic dye) using the powdered and calcined vegetable waste of *Persea americana* nuts as adsorbents. The experiments were performed in a batch mode with solutions containing 40–100 mg/dm^3 of dye at adsorbent doses in the range of 0.2–0.5 g/dm^3. The calculated adsorption capacities amounted to 120 mg/g for calcined vegetable waste, and 96.15 mg/g for powdered vegetable waste. The experimental equilibrium data showed that adsorption of Eriochrome Back T on vegetable waste derived from *Persea americana* nuts can be described by the Freundlich isotherm model. Gong et al. [10] treated basic dye solutions using rice straw modified with phosphoric acid. Several parameters such as temperature, adsorbent dosage, dye concentration, ionic strength, and pH were verified for the removal of two basic dyes (Basic Blue 9 and Basic Red 5). The study confirmed that the modified rice straw was an excellent adsorbent for the separation of basic dyes from aqueous solution. The dye removal efficiency for both dyes was above 96% at the adsorbent dosages of 1.5–2.0 g/dm^3. The increase in ionic strength of solution induced a decline of dye sorption efficiency. The experimental isothermal data fitted the Langmuir model. The sorption capacities for Basic Blue 9 and Basic Red 5 were 208.33 and 188.68 mg/g, respectively.

Industrial solid waste is often considered suitable adsorbent for dye removal. Namasivayam et al. [11] presented a study on the removal of Direct Red 12B and Methylene Blue onto Fe(III)/Cr(III) hydroxide. The study showed satisfactory results. Equilibrium adsorption data followed both Langmuir and Freundlich isotherms. The Langmuir adsorption capacity was found to be 5.0 and 22.8 mg/g for Direct Red 12B and Methylene Blue, respectively. The acidic solution was favorable for the adsorption of Direct Red 12B, whereas the basic one was beneficial for adsorption of Methylene Blue. Desorption studies showed that chemisorption was the major mode of adsorption.

Dye properties and their chemical structure can influence the sorption efficiency. Zhang et al. [12] presented a comparative study on the adsorption of two cationic dyes (Rhodamine B and Basic Blue 9) by milled sugarcane bagasse. They found that the increase in a specific surface area of sugarcane bagasse from 0.57 to 1.81 m^2/g improved Rhodamine B removal efficiency from 81.7 to 93.7%, whereas adsorption of Basic Blue 9 was not affected by variation in adsorbent specific surface area. The adsorption capacity of sugarcane bagasse towards Rhodamine B and Basic Blue 9 amounted to 65.5 and

30.7 mg/g, respectively. Application of linear and non-linear regression analysis of experimental data revealed that adsorption of Rhodamine on sugarcane bagasse can be described by the Freundlich model, whereas Basic Blue 9 adsorption was well fitted by the Langmuir model. The differences in adsorption performances observed for applied dyes were related to the dye molecular structure and the surface chemistry of sugarcane bagasse.

Water plants are also considered useful sorbents for various organic dyes. Waranusantigul et al. [13] conducted laboratory investigations on the potential use of dried giant duckweed (*Spirodela polyrrhiza*) biomass as an adsorbent for the removal of Methylene Blue (basic dye) from aqueous solutions. The results showed that upon increasing the amount of the dried *Spirodela polyrrhiza*, the percentage of dye sorption increased accordingly. At pH 2.0, the sorption of dye was not favorable, while the sorption at pH from 3.0 to 11.0 was remarkable. The adsorption of Methylene Blue on dried giant duckweed biomass followed the first-order rate kinetics. The determined maximum sorption capacity depended on the pH of the solution and amounted to 119 mg/g (at pH 7) and 145 mg/g (at pH 9). Since this aquatic plant (*Spirodela polyrrhiza*) is readily available in the environment, Waranusantigul et al. [13] recognized it as more economical than other sorbents.

Ahmed and Alam [3] presented a study on the adsorption of Eurozol Navy Blue (ENB) reactive dye using orange and lemon peel as biosorbents. Several process parameters such as adsorbent dosage, solution pH, dye concentration, agitation speed, and temperature were considered. The results of ENB removal were satisfactory. The removal efficiency varied from 81 to 91%, however the sorption capacity of tested biosorbents was not very high (0.162 mg/g and 0.174 mg/g for orange and lemon peel, respectively).

Banana peel and sugarcane bagasse are widely available and the cost of their getting and treatment is rather low. This waste biomass can be collected from fruit stores and juice factories and prepared for the removal of reactive dyes. Parameters that affect the adsorption of a reactive dye such as pH, contact time, agitation speed, temperature, and initial dye concentration, single and combined adsorbent dosage were taken under consideration in this study. The experimental data were analyzed using Freundlich and Langmuir isotherm models and the adsorption mechanism was identified.

2. MATERIALS AND METHODS

Preparation of banana peel and sugarcane bagasse powders. 85 pieces of banana were washed properly by distilled water after collection and their peels were taken out carefully. The peels were cut into small pieces and dried under sunlight for 15 days. After drying, the peels were crushed and sieved carefully through a sieve No. 100 (US sieve size) which corresponded to an opening size of 150 μm. 250 g of the banana peel powder was obtained. The powder was kept in an airtight jar.

For the preparation of sugarcane bagasse powder, 4 kg of sugarcane bagasse was washed properly by distilled water after collection, and then it was cut into small pieces and dried under sunlight for 15 days. After drying, the bagasse was crushed and sieved carefully through a sieve No. 60 (US sieve size) which corresponded to the opening size of 250 µm. The weight of the obtained sugarcane bagasse powder was 250 g. The powder was kept in an airtight jar.

Preparation of reactive dye solution. The Eurozol Navy Blue (ENB) reactive dye was obtained from a local dye-house. This dye belongs to a Remazol® group of reactive dyes, which are used for dyeing cotton, silk, and wool. In terms of chemical structure, the ENB dye is an anionic mono-azo dye containing two sulfonic acid groups and one vinyl group. The dye characteristics is given in Table 1. The stock solution of ENB dye was prepared by dissolving 1000 mg of dye in 1 dm^3 of distilled water. The dye stock solution was hold in a 2 dm^3 glass flask at room temperature.

Table 1

Properties of Eurozol Navy Blue reactive dye

Chemical formula	$C_{21}H_{24}N_8Na_2O_7S_2Cl$
Molar mass	645.4 g/mol
Maximum absorbance wavelength	556 nm
Solubility in water (25–40 °C)	85 g/dm^3
Fixation temperature	25–40 °C

Adsorption experiments. In the first stage of experiments, the adsorption process was carried out for model dye solution containing 25 mg/dm^3 of Eurozol Navy Blue. The temperature and pH were established at 25 °C and 7, respectively. Dye solutions were agitated in a laboratory shaker for 60 min at an agitation speed of 160 rpm. The adsorbent dosage amounted to 0.2 g/dm^3. The preliminary experiments were focused on the evaluation of bioadsorbents' usability in ENB dye removal.

In the next stage of experiments, banana peel and sugarcane bagasse powders were dosed individually into dye solutions at variable amounts (0.2, 0.4, 1.0, 1.6, and 2 g/dm^3). Finally, the simultaneous dosage of both biosorbents at a weight ratio of 1:1 was applied.

In the course of experiments, the dye removal efficiency was evaluated depending on adsorbent dosage, agitation speed (140, 160, 180, 200, and 240 rpm), contact time (45, 60, 80, and 110 min), initial dye concentration (15, 50, and 100 mg/dm^3), temperature (25, 30, 40, 45, and 50 °C), and pH (2–12). In each series of experiments, only one parameter was variable whereas other parameters were kept constant. The pH of dye solutions was adjusted with 0.1 M HCl solution or 0.1 M NaOH solution.

Dye concentration was determined before and after adsorption with the use of a spectrophotometer (model DR-2800). Absorbance measurements were performed at a wavelength of 560 nm. The biosorbent powder was separated before the spectrophotometric analysis by simple sedimentation (20 min) and filtration through Whatman filter paper. The efficiency of dye removal (*R*, %) was calculated according to equation:

$$R = \frac{C_0 - C_t}{C_0} \times 100\% \tag{1}$$

where: C_0 – initial dye concentration (mg/dm^3), C_t – dye concentration after the adsorption process lasting *t* min (mg/dm^3).

The amount of dye adsorbed at equilibrium conditions (q_e, mg/g) was calculated using the following equation:

$$q_e = \frac{(C_0 - C_e)V}{M} \tag{2}$$

where: C_0 – initial dye concentration (mg/dm^3), C_e – dye concentration at equilibrium (mg/dm^3), *V* – volume of sample (0.2 dm^3), *M* – mass of adsorbent used (g).

The amount of dye adsorbed after time *t* (q_t, mg/g) was calculated using the following equation:

$$q_t = \frac{(C_0 - C_t)V}{M} \tag{3}$$

Dye desorption. Dye desorption was conducted after adsorption of Eurozol Navy Blue when the dye concentration was equal to 50 mg/dm^3 and the adsorbent dose amounted to 1 g/dm^3. 500 mg of banana peel powder or sugarcane bagasse powder saturated with dye was mixed with 500 cm^3 of distilled water for the periods from 5 to 30 min at an agitation speed of 140 rpm at room temperature. Before the spectrophotometric analysis of the desorbed dye, the biosorbent powder was separated by simple sedimentation and filtration through filter paper. The dye desorption efficiency was calculated as a ratio of the amount of dye desorbed to the amount of dye adsorbed and expressed as percentage share.

Adsorption isotherms. There are several equations available for analyzing adsorption parameters at equilibrium. The Langmuir and Freundlich models are the most common. The Langmuir isotherm model is based on the assumption that there is a finite number of active sites which are homogeneously distributed over the surface of the adsorbent These active sites have the same affinity for adsorption of a monomolecular layer and there is no interaction between adsorbed molecules [2, 3]. The well-known linear form of the Langmuir equation can be expressed as [2]:

$$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{1}{q_m} C_e \tag{4}$$

where: q_e – the amount of dye adsorbed on the solid adsorbent at equilibrium conditions (mg/g), q_m – maximum adsorption capacity (mg/g), K_L – Langmuir equilibrium constant (dm^3/mg), C_e – ENB dye concentration at equilibrium conditions (mg/dm^3).

The essential characteristics of the Langmuir isotherm can be expressed by the dimensionless constant called equilibrium parameter R_L, defined by [2]:

$$R_L = \frac{1}{1 + K_L C_0} \tag{5}$$

where: C_0 – initial ENB reactive dye concentration (mg/dm^3).

The values of R_L indicate the possible type of the isotherm and the nature of the adsorption process as: unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$) or irreversible ($R_L = 0$). The values of the maximum adsorption capacity q_m and the adsorption constant K_L can be obtained by plotting C_e/q_e versus C_e.

The Freundlich isotherm model applies to adsorption on heterogeneous surfaces with the interaction between the adsorbed molecules, and it is not restricted to the formation of a monolayer. This model assumes that as the adsorbate concentration increases, the concentration of adsorbate on the adsorbent surface also increases [2, 3]. The well-known expression for the Freundlich model (linear form) is given as [2]:

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \tag{6}$$

where: K_f – Freundlich constant (dm^3/mg), n – heterogeneity factor.

The K_f value is related to the adsorption capacity, while the $1/n$ value is related to the adsorption intensity. The values of $1/n$ indicate the type of isotherm and the nature of adsorption process as following: irreversible $1/n > 1$, favorable $0 < 1/n < 1$, unfavorable $1/n > 1$. Therefore, a plot of $\log q_e$ versus $\log C_e$ should be a straight line of the slope $1/n$ and the intercept $\log K_f$.

3. RESULTS AND DISCUSSION

3.1. EFFECT OF CONTACT TIME ON DYE ADSORPTION EFFICIENCY

The preliminary experiments gave satisfactory results (data not shown), thus comprehensive experiments on ENB dye removal by biosorption were performed. The experiments involving variable contact time of dye particles with biosorbent powder are of primary importance because they help to establish the conditions of equilibrium state. The effect of contact time on dye removal efficiency and the amount of dye adsorbed is shown in Fig. 1.

The experiments were performed at constant dye concentration (50 mg/dm^3) and constant biosorbent dose (1 g/dm^3). The degree of dye removal increased rapidly during the first 60 min of adsorption reaching the equilibrium state. Further increase in contact time did not improve the dye removal efficiency and the amount of dye adsorbed remained almost unchanged due to the saturation of adsorbents by dye particles. It was assumed that for the investigated adsorption process the equilibrium state was achieved after 60 min for both biosorbents applied. The banana peel powder exhibited slightly better adsorption properties than sugarcane bagasse powder.

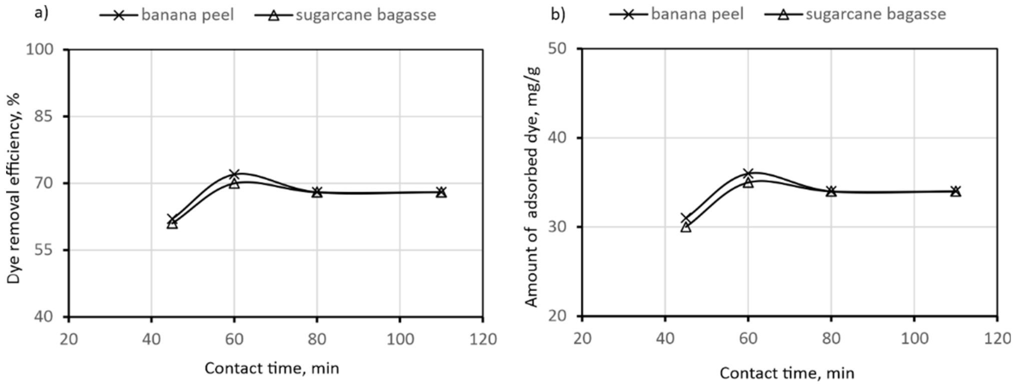

Fig. 1. Effect of contact time on dye removal efficiency (a), and amount of adsorbed dye (b); initial dye concentration 50 mg/dm^3, adsorbent dose 1 g/dm^3, agitation speed 160 rpm, temperature 25 °C, pH 7

3.2. EFFECT OF ADSORBENT DOSAGE ON DYE ADSORPTION EFFICIENCY

The applied doses of banana peel and sugarcane bagasse powders varied from 0.2 to 2 g/dm^3. These biopowders were added to the model dye solution (50 mg/dm^3) individually and as a mixture of both adsorbents (at a weight ratio of 1:1). It was found that the degree of dye removal increased with the increasing dose of adsorbent reaching maximum removal efficiency at the dose equal to 1.0 g/dm^3 (Fig. 2a). Further increase in the amount of adsorbent did not make any significant changes in the dye removal efficiency. This dependence was observed irrespectively of the applied adsorbent. The maximal degree of dye removal amounted to 72, 70, and 68% for banana peel powder, sugarcane bagasse powder, and the mixture of biosorbents, respectively. The adsorbent dose of 1 g/dm^3 was considered as the optimum value for both biosorbents and their mixture (when ENB dye concentration was equal to 50 mg/dm^3). The adsorption capacity towards reactive dye decreased with the increasing adsorbent dose for both biosorbents applied (Fig. 2b). A similar observation was noted by Mondal et al. [15] for the removal of Congo Red by banana peel dust. The decrease in the dye uptake with an increase in biosorbent dose can be explained by reducing the availability of active sites due to adsorbent aggregation.

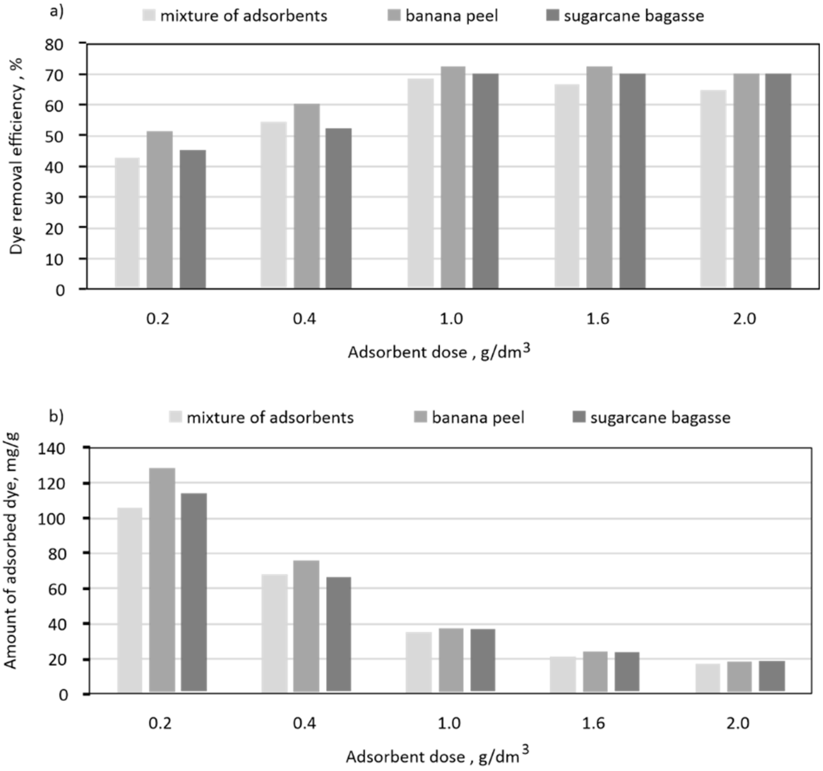

Fig. 2. Effect of adsorbent dose on dye removal efficiency (a), and dye uptake (b) at equilibrium; initial dye concentration 50 mg/dm^3, contact time 60 min, agitation speed 160 rpm, temperature 25 °C, pH 7

3.3. EFFECT OF INITIAL DYE CONCENTRATION ON ADSORPTION EFFICIENCY

Another parameter that influences the adsorption efficiency is the amount of dye in the treated solution. In the experiments, the following ENB dye concentrations were applied: 25, 50, and 100 mg/dm^3. The adsorbent dosage was constant and amounted to 1 g/dm^3. The initial dye concentration had a rather minor influence on the removal efficiency – a slight improvement in percentage dye removal was observed with the increasing dye amount in model solution (Fig. 3a). The maximal dye removal efficiency reached 73% (banana peel powder) and 70% (sugarcane bagasse powder). These results seemed to be somewhat contradictory with the observed improvement of adsorption capacity upon the increasing dye concentration (Fig. 3b). The adsorption capacity has almost doubled when the dye concentration was increased from 50 to 100 mg/dm^3, which could indicate that there were still free active sites available for dye particles in adsorbent powders of banana peel and sugarcane bagasse (for the adsorbent dose of 1 g/dm^3). Probably at the elevated dye concentration, the driving force (concentration gradient) was enhanced and the dye uptake was improved.

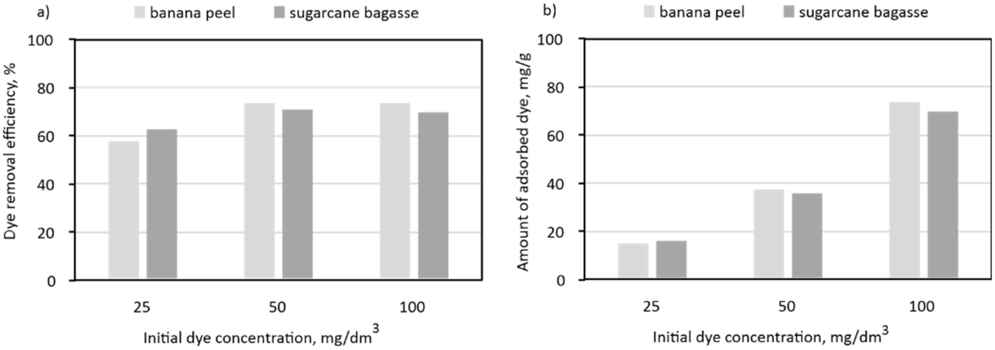

Fig. 3. Effect of initial ENB dye concentration on dye removal efficiency (a), and amount of dye adsorbed at equilibrium (b); contact time 60 min, adsorbent dose 1 g/dm^3, agitation speed 160 rpm, temperature 25 °C, pH 7

3.4. EFFECT OF AGITATION SPEED ON ADSORPTION EFFICIENCY

The adsorption process is controlled by diffusion, thus appropriate mixing speed will be beneficial in enhancing the diffusion rate of dye particles. To analyze the effect of mixing various agitation speeds were applied (140, 160, 180, 200, 240 rpm).

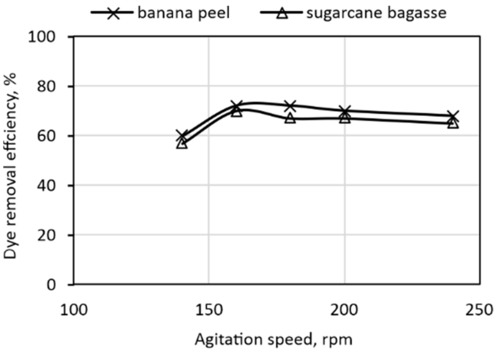

Fig. 4. Effect of agitation speed on dye removal efficiency; contact time 60 min, adsorbent dose 1 g/dm^3, dye concentration 50 mg/dm^3, temperature 25 °C, pH 7

A rapid improvement of dye removal efficiency from 60 to 72% (banana peel powder) and from 57 to 70% (sugarcane bagasse powder) was observed when the agitation speed was increased from 140 to 160 rpm (Fig. 4). Further increase of mixing intensity did not bring any improvement of the degree of dye separation and even a slight deterioration of dye removal percentage was detected. Thus, the agitation speed of 160 rpm was taken up as an optimal one for the analyzed adsorption process with the use of both powders.

3.5. EFFECT OF TEMPERATURE ON ADSORPTION EFFICIENCY

The adsorption of ENB dye was favored at the temperature range of 25–30 °C (Fig. 5). Further increase in temperature caused a slight deterioration of the degree of dye removal for both biosorbents applied. According to Ashour et al. [14], for conventional physisorption, an increase in temperature usually increases the rate of approaching the equilibrium state. On the other hand, when chemisorption is considered, it is known that temperature increase may cause weakening of sorptive force between the active sites of adsorbent and anionic dye molecules. It should be also pointed out that ENB dye belongs to cold brand reactive dyes. The dyes of this group become more active at low temperatures and their fixation to textile materials is more efficient at low temperatures (from 25 to 35 °C).

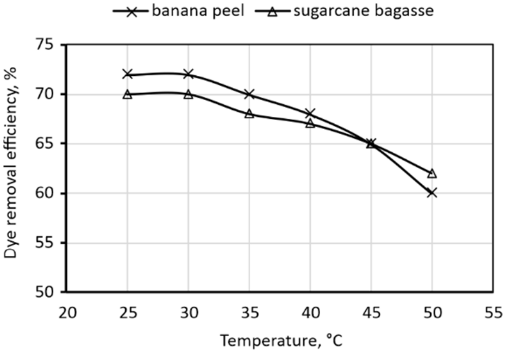

Fig. 5. Effect of temperature on the dye removal efficiency. Contact time 60 min, adsorbent dose 1 g/dm^3, dye concentration 50 mg/dm^3, agitation speed 160 rpm, pH 7

3.6. EFFECT OF pH ON DYE ADSORPTION EFFICIENCY

pH of the solution of adsorbate is fundamental in controlling the surface charge of adsorbent, the ionization degree of adsorbate, as well as the dissociation degree of various functional groups of the adsorbent. The effect of pH on the adsorption efficiency of Eurozol Navy Blue was verified in the series of experiments which were performed at variable pH (in the range of 2–12), whereas the other process parameters were kept constant (Fig. 6). It was found that the adsorption efficiency increased from 20–23% to 70–72% when pH increased from 2 to 7. However, a further increase in pH resulted in the worsening of dye removal efficacy, especially when pH was above 10. This relationship was observed for both biosorbents applied and the maximum degree of dye removal was recorded at a neutral solution.

The pH of the point of zero charge (pH$_{\mathrm{ZPC}}$) for banana peel and sugarcane bagasse powders was established as 5.9 [15] and 5.0 [12], respectively. Above these values, the surfaces of tested biosorbents are negatively charged. Thus, the worsening of dye removal with increasing pH (above 7) can be attributed to the weakness of electrostatic attraction between the anionic reactive dye and active sites of biosorbents. On the other hand, at low pH, the dye exists predominantly in the molecular form and the electrostatic attraction between positively charged surfaces of biosorbents and dye molecules will be also suppressed. As the solution pH increases, the share of dye particles in their dissociated form becomes higher and the removal efficiency improves. It seems that the adsorption of Eurozol Navy Blue dye on bio-waste was also affected by other interactions between functional groups of dye and biosorbents besides the electrostatic attraction. In the case of sugarcane bagasse, the sorption effect may be due to interactions between carbonyl and hydroxyl groups of sugarcane bagasse and the sulfonic acid groups of ENB dye [12]. For adsorption with the use of banana peel powder possible interaction may occur between amine, hydroxyl, and carboxyl functional groups of biosorbent and sulfonic functional groups of dye [15, 16].

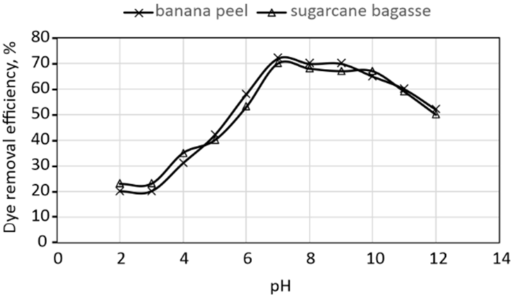

Fig. 6. Effect of pH on the dye removal efficiency. Contact time 60 min, adsorbent dose 1 g/dm^3, dye concentration 50 mg/dm^3, agitation speed 160 rpm, temperature 25 °C

3.7. DYE DESORPTION

The possibility of recovering both the dye and the adsorbent may be of key significance because of economic aspects and environmental protection. The desorption experiments for banana peel and sugarcane bagasse powders saturated with reactive dye were performed after adsorption of ENB from the solution containing 50 mg/dm^3 of dye. The time dependence of the desorption process is shown in Fig. 7. The maximal dye desorption efficiency reached 28 and 29% for banana peel and sugarcane bagasse

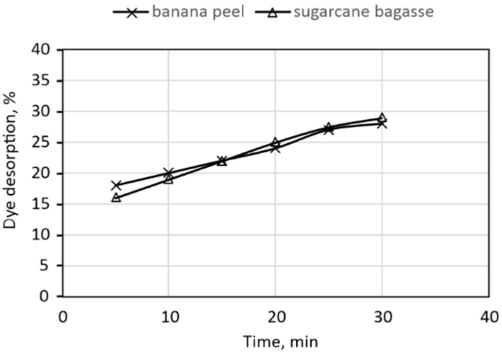

Fig. 7. Dye desorption from exhausted biosorbents after adsorption of ENB dye (C_0 = 50 mg/dm^3). Contact time 60 min, adsorbent dose 1 g/dm^3, dye concentration 50 mg/dm^3, agitation speed 160 rpm, temperature 25 °C

powders, respectively. It seems that besides reversal physisorption, chemisorption also took place in the adsorption of reactive dye on bio-waste. However, the proper selection of eluents for adsorbent and adsorbate recovery depends on the adsorption mechanism. Mondal et al. [15] found that by applying a 0.1 M solution of NaOH it was possible to recover 97% of Congo Red dye from banana peel dust.

3.8. ADSORPTION ISOTHERMS

The adsorption isotherms are very useful in understanding the mechanism of adsorption. The Langmuir and Freundlich isotherms are the most commonly used models in adsorption evaluation. The Langmuir isotherm enables estimation of the maximum adsorption capacity on the assumption that the surface of the adsorbent is covered with a monolayer of adsorbed molecules. By applying the Freundlich model, it is possible to estimate the adsorption intensity assuming that the adsorbent surface is heterogeneous and multilayer sorption occurs.

To describe possible interactions between the dye molecules and biosorbents, the adsorption isotherms of ENB dye on banana peel and sugarcane bagasse powders were fitted with Langmuir and Freundlich models according to equations (4) and (6) (Figs. 8, 9). The calculated isotherm constants together with correlation coefficients (R^2) for both models are presented in Table 2. Based on the R^2 values, it seems that the Langmuir model slightly better describes the sorption of ENB dye on biosorbents than the Freundlich model. The maximum monolayer adsorption capacities were 24.09, 32.46, and 27.54 mg/g for banana peel powder, sugarcane bagasse powder, and the mixture of adsorbents, respectively. The R_L and $1/n$ values given in Table 2 revealed favorable sorption of Eurozol Navy Blue on the tested bio-waste.

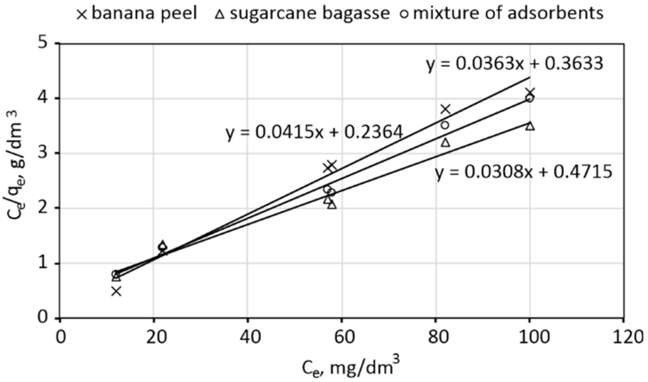

Fig. 8. Langmuir isotherm (linearized) for banana peel powder, sugarcane bagasse powder and the mixture of adsorbents

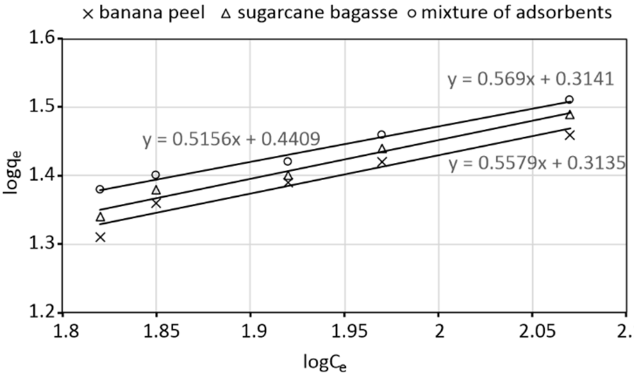

Fig. 9. Freundlich isotherm (linearized) for banana peel powder, sugarcane bagasse powder and the mixture of adsorbents

Table 2

Estimated values of isotherm parameters for Langmuir and Freundlich models

Adsorbent	Langmuir isotherm				Freundlich isotherm		
	q_m [mg/g]	K_L [dm^3/mg]	R_L	R^2	K_f [dm^3/mg]	$1/n$	R^2
Banana peel powder	24.09	0.175	0.10–0.36	0.979	2.06	0.56	0.945
Sugarcane bagasse powder	32.46	0.085	0.19–0.55	0.977	2.06	0.57	0.974
Mixture of adsorbents	27.54	0.077	0.34–0.59	0.988	2.08	0.52	0.985

The determined adsorption capacities for ENB dye onto banana peel and sugarcane bagasse are comparable or even higher than those of various biowaste towards reactive dyes reported in the literature. For example, Munagapati et al. [16] reported that adsorption capacity for Reactive Black 5 on unmodified banana peel powder amounted to 21.2 mg/g. Umar et al. [17] determined the adsorption capacity for Reactive Blue 19 onto modified coconut shell which was only 2.2–2.9 mg/g. An extensive study on textile dye adsorption on seed hulls of sunflower was made by Jóźwiak et al. [18]. They found that the amination of biowaste resulted in significant improvement of adsorption capacity of sunflower seed hulls against Reactive Black 5 and Reactive Yellow 84 dyes from 2.89 and 4.15 mg/g to 51.02 and 63.27 mg/g, respectively. It is worth mentioning that the biosorbents tested in this study can be used without any modification and could be recognized as low-cost materials for effective removal of Eurozol Navy Blue reactive dye by adsorption.

4. CONCLUSIONS

- Agricultural waste such as unmodified banana peel and sugarcane bagasse powders can be effectively used for the removal of reactive dye (Eurozol Navy Blue) by adsorption. The maximal dye removal efficiency amounted to 73% (for banana peel powder), 70% (for sugarcane bagasse powder), and 68% (for the mixture of both adsorbents) at the biosorbent dose of 1 g/dm^3 and initial dye concentration of 50 mg/dm^3.

- The adsorption efficiency of Eurozol Navy Blue on banana peel and sugarcane bagasse was dependent on the solution pH. The maximum dye removal efficiency was achieved at solution pH equal to 7 for both biosorbents.
- The adsorption mechanism of Eurozol Navy Blue onto bio-waste involved electrostatic interactions between dye molecules and charged biosorbent surfaces as well as interactions between dye sulfonic groups and functional groups of biosorbents (carbonyl, hydroxyl, carboxylic, amine).
- The Langmuir isotherm model was found to fit better the adsorption of Eurozol Navy Blue on banana peel and sugarcane bagasse powders than the Freundlich isotherm model. The corresponding maximum adsorption capacities were equal to 24.09, 32.46, and 27.54 mg/g for banana peel powder, sugarcane bagasse powder, and the mixture of adsorbents, respectively.

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