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Focusing on eco-friendly biosorption method: removal of reactive yellow-145 by natural ureolytic mixed culture

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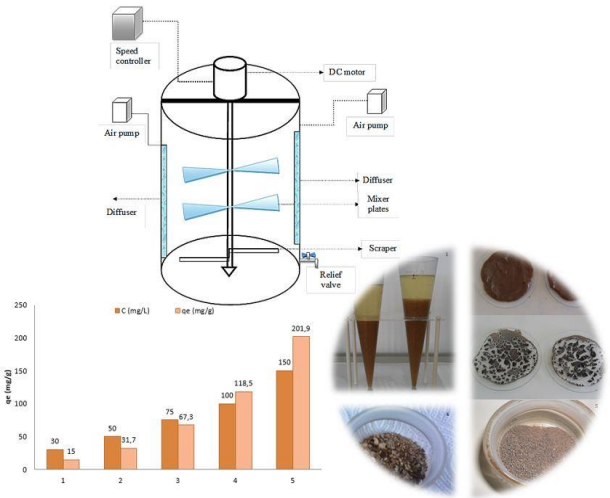
Graphical abstract



Abstract

In this study, removal of reactive yellow 145 (RY 145) dyestuff by dry biomass of Ureolytic mixed microorganism culture (UMC), existing in domestic wastewater and various industrial wastewater, was studied. Optimum conditions of adsorption efficiency were tested. For this purpose, studies were conducted on the effect of initial dye concentration (30-50-75-100-150 mg/L), UMC amount (0.2-0.5 -1.0-2.0 g), temperature (20-35-50 °C), pH (2-3-5-7-9) and contact time (1-5-10-20-30-60-120 min) on the efficiency of color removal. As a result of these studies, optimum conditions were revealed with 150 mg/L initial RY 145 concentration, 0.2 g dry UMC amount, 150 rpm agitation speed, 20 ^{0}C temperature, pH 2 and 30. minute contact time. After spectrophotometric calculations, according to Langmuir isotherm, it was found that 610.9 mg/g and the removal efficiency of tests was calculated as 84.5% under optimum conditions. It is seen that the process in which physisorption is at the forefront and single-layer adsorption occurs fits the Langmuir and pseudo-second order models. Thermodynamic data showed that the process occurred spontaneously and endothermically. The results support that UMC is both a promising and alternative environmentally friendly biosorbent for RY 145 removal.

Keywords: Biosorption, biosorbent, dyestuff, ureolytic microorganism, reactive yellow 145

1. Introduction

Many dyestuffs with various characteristics have been used in the dyeing process to colour fabric, yarn, fibre, etc. in the production system of the textile industry (Kanwal *et al.* 2023). Dyestuff is classified as anionic-direct, acid and reactive dyestuff, cationic-basic dyestuff, and non-ionic disperse dyestuff (Aksu *et al.* 2011). Dyestuff generally has synthetic origins and is comprised of complex aromatic molecular structures that are more stable and harder to separate (Aksu, 2001; Aksu, 2004). Artificial dyes have been developed in the industry to increase product quality by providing ease of use and long-lasting colour (Rose *et al.* 2023). Approximately 70% of the 800,000 tons of dyestuff produced internationally each year are reactive dyes (Hatimi *et al.* 2023). Although reactive dyes have complex aromatic structures, they are the most preferred group of hazardous dyes due to their covalent bonding effect (Altas *et al.* 2011; Clarke & Anliker, 1980). The wastes of these industries may contain dyed wastewater of undesired amounts which is why they need to be treated and discharged (Clarke & Anliker, 1980; Robinson *et al.* 2001). Reactive dyes have various structures due to the presence of various functional groups such as azo, anthraquinone, oxazine and phthalocyanine. In particular, azo groups (R_1-N=N-R_2) attached to aromatic rings in the structure of reactive azo dyes make them toxic and resistant (da Silva *et al.* 2023; Patel *et al.* 2023). They may also have amphoteric properties due to the presence of carboxyl, hydroxy, amino or sulfonyl functional groups (Barciela *et al.* 2023). Therefore, textile wastewater containing raw dyes poses a risk to humans and other organisms and biodiversity (El Messaoudi *et al.* 2024; Farajzadeh-Dehkordi *et al.* 2023). Coloured wastewater mixed into receiving water environments leads to a decrease in dissolved oxygen and inhibition of photosynthesis. Under anaerobic conditions, the decomposition of some types of dyes leads to the formation of intermediate compounds such as aromatic amines, which are potentially carcinogenic (Hatimi *et al.* 2023).

Azo dyes are resistant to conventional treatment processes due to their low degradability, resistance to degradation in sunlight and high-efficiency assimilation. Therefore, it is necessary to investigate creative and cost-effective methods to remove azo dyes from wastewater (Jinendra *et al.* 2019). These methods have disadvantages such as high cost, regular maintenance requirements, complex operation and secondary pollution (Fatima *et al.* 2023). Compared to different wastewater treatment methods, adsorption is a low-cost, easy to design, maintain and operate, insensitive to pollutant toxicity and reusable (desorption capacity) process. So far, a wide variety of adsorbents have been used for the removal of dyes from wastewater (Raji *et al.* 2023; Banat *et al.* 1996). In recent years, many researchers have focused on studies performed with microorganisms that can do biodegradation and bioaccumulation for the removal of reactive dyes in wastewater (Tripathi *et al.* 2023). Types of microorganisms that include bacteria, fungi and algae are used in studies for colour removal from dyestuff (Dönmez *et al.* 1999). Two approaches stand out in scientific literature regarding the usability of microorganisms in colour removal. The first one is the biodegradation of the dye with living cells of microorganisms such as fungus, yeast, algae and bacteria and the second one is the removal or the dye with inactive (dead) microbial mass through adsorption, that is, biosorption. There are important limitations in dye removal with living cells. Those are the differences between the environmental conditions under which the microorganisms reproduce and the conditions of removal, the need for nutrition for the microorganisms to sustain reproduction, inhibition of microorganism reproduction in high concentrations of dyes and the required time for total removal. Inactive (dead) cells have a higher biosorption capacity compared to living cells; they can achieve total removal in a short time as well as their storage and regeneration capacity (Aksu, 2004).

Scientific and environmentally friendly approaches are important for effective and widely used materials. In this context, UMC can be produced on a laboratory scale for biocatalytic calcium (Ca) removal. The production of UMC is based on the hydrolysis of urea by the enzyme urease into ammonium and carbon dioxide, as shown in the equations below (Maulas *et al.* 2024; Simsek *et al.* 2013). These products can then react to form ammonium and carbonate ions, which can react in the presence of soluble calcium ions and precipitate as $CaCO_3$ (Fıtrı *et al.* 2023).

In this study, the purification potential and biosorbent utility of inanimate UMC for RY 145 dye from an aqueous solution was investigated. Although it meets the criteria of an ideal biosorbent, the biosorption ability of UMC in terms of dye removal has only been tested to a limited extent in the literature. In addition, there is a relative lack of information on the potential use of waste sludge resulting from laboratory scale biocatalytic Ca removal. This study was prioritised in terms of both the beneficial product use of this sludge, namely the UMC containing sludge that is disposed of as waste, and the approach of removing the waste with the waste. Although there is previous research on ureolytic bacteria, no studies regarding the removal of dyes from wastewater have been observed. In this study, classical biosorption parameters such as initial RY 145 concentration, UMC amount, pH, and temperature and contact time were tested in a batch system. Optimal conditions for the biosorption capacity between UMC and RY 145 were determined. In addition, different isothermal and kinetic models were presented in the study using experimental data.

$$H_2N-CO-NH_2 + H_2O \xrightarrow{\text{Urease}} NH_2COOH + NH_3 \quad (1)$$

$$NH_2COOH + H_2O \rightarrow H_2CO_3 + NH_3 \quad (2)$$

$$NH_3 + H_2O \leftrightarrow OH^- + NH_4^+ \quad (3)$$

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+ \quad (4)$$

$$HCO_3^- + H^+ + 2OH^- \leftrightarrow CO_3^{-2} + 2H_2O \quad (5)$$

$$Ca^{+2} + H_2CO_3 \leftrightarrow CaCO_3 + 2H^+ \quad (6)$$

$$Ca^{+2} + HCO_3^- \leftrightarrow CaCO_3 + H^+ \quad (7)$$

$$Ca^{+2} + CO_3^{-2} \leftrightarrow CaCO_3 \quad (8)$$

2. Materials and methods

2.1. Dyestuff solution preparation and analytical measurement

The dye RY 145, which is widely used in the textile industry, is preferred because of its bright colour and its ability to be effectively applied to the fabric. The general properties and chemical structure of RY 145 are shown in **Table 1**. Sodium hydroxide (NaOH) and hydrochloric acid (37% HCl) used for pH adjustment with RY 145 were analytical grades from Merck KGaA, Darmstadt, Germany. All solutions were prepared with ultrapure water (*chemical resistance: 18 mΩ-cm*) obtained using a Millipore Elix Advantage 5-Synergy UV instrument. 1000 mg/L stock solution was used for working solutions with different concentrations of RY 145. As a result of wavelength scanning UV-Vis spectrophotometer (Shimadzu UV-1280) with dye solutions formed at different concentrations, the maximum wavelength for RY 145 was observed to be 420 nm. The calibration curve of RY 145 is shown in **Figure 1**.

Table 1. Specific properties of RY 145 dyestuff

Properties	RY 145 Dyestuff
Colour Index nomenclature	C.I. RY 145 dye
Molecule formula	$C_{28}H_{20}ClN_9Na_4O_{16}S_5$
Molecular Weight	1026.25 (g/mol)
Brand Name	Remazol Yellow 3RS
Chemical Structure	fx1

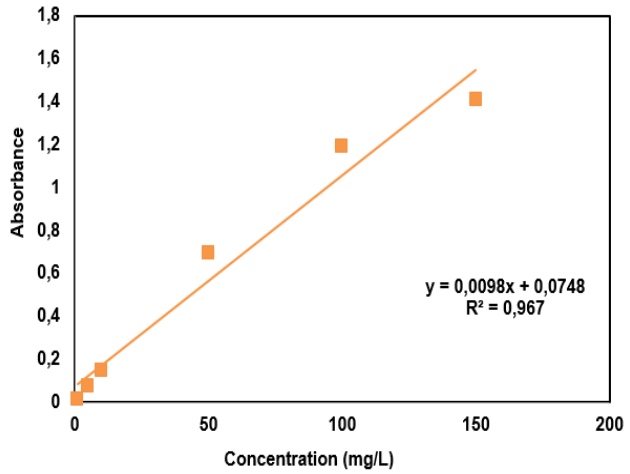


Figure 1. The Graph of RY 145 calibration curve

2.2. Preparation of conditions for producing UMC

UMC are a group of bacteria that hydrolyze the urea with urease enzyme. They exist in domestic wastewater and exit water of various industries. Urease is an enzyme quite commonly found in nature (Gibbon & Doetsch, 1959; Nuhoğlu *et al.* 2002). Researchers have shown that urea is decomposed into ammonia and carbon dioxide with the help of bacteria urease and that this ammonia meets the need of nitrogen in the formation of bacterial proteins. Many aerobic (*Proteus; Morganella; Serratia; Pseudomonas; Clostridium; Fusobacterium; Ureapalsma; Providencia; Sarcina etc.*) and anaerobic (*Neisseria vulvovaginitis, Catenabacterium cantortum, Cillobacterium sylvestris and Clostridium sordelli etc.*) bacteria species can decompose urea under aerobic/anaerobic conditions (White-Pettigrew *et al.* 2024; Huet & Aladame, 1952). For UMC production, aerobic conditions were provided by pumping air into the aerobic reactor system by a compressor. The operation sequence is shown in **Figure 2**.

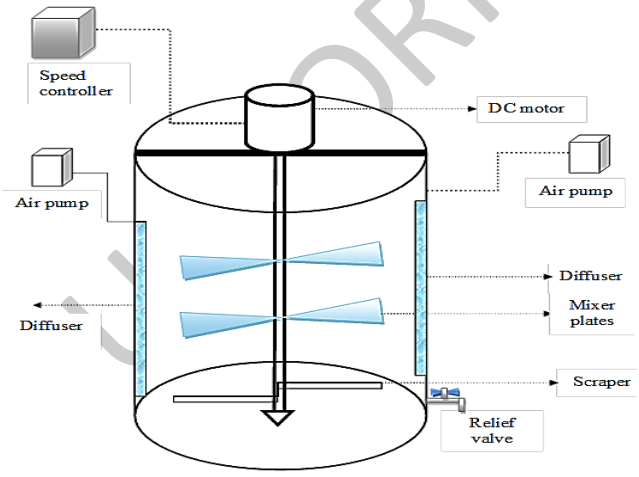


Figure 2. The aerobic reactor system

Under normal circumstances, reproduction temperature for UMC varies between T=20-30 °C and pH value varies between pH=6-9. The study was conducted under 25 °C of room temperature and pH=6-7 values. Agitation speed was managed by a speed controller device. The oxygen in the environment was ensured continually by air pumps and periodically by a compressor. UMC was grown in synthetic wastewater environment which involves urea, and which has been enriched with mineral compounds under aerobic conditions. UMC was grown in an enriched environment with constant mixture and ventilation. The compound of the synthetic wastewater that was used is given in **Table 2**.

Table 2. The constituents of synthetic wastewater

Compound	Concentration
Glucose	940 (mg/L)
Starch	60 (mg/L)
Ammonium Acetate	160 (mg/L)
Yeast Extract	80 (mg/L)
NH_4Cl	306 (80 mg N/L)
Urea	856 (400 mg N/L)
KH_2PO_4	112 (15 mg P/L)
$NaHCO_3$	600 (300 mg CaCO3/L)
$Cr(NO_3)_3.9H_2O$	0.770 (0.100 mg metal/L)
$CuCl_2.2H_2O$	0.536 (0.200 mg metal/L)
$MnSO_4.H_2O$	0.108 (0,035 mg metal/L)
$NiSO_4.6H_2O$	0.336 (0.075 mg metal/L)
$PbCl_2$	0.100 (0.075 mg metal/L)
$ZnCl_2$	0.208 (0.100 mg metal/L)

2.3. Preparation of biosorbent from UMC

The UMC produced in the aerobic reactor system during the first 6 days was transferred to Imhoff funnels and centrifuged at 3750 rpm for 2 min after a 30-minute waiting period. The centrifuged UMC was washed with ultrapure water and dried in a NUVE-brand oven at 60 °C for 24 hours. The dried UMC was granulated and stored. The images of the UMC biosorbent obtained are shown in **Figure 3**.

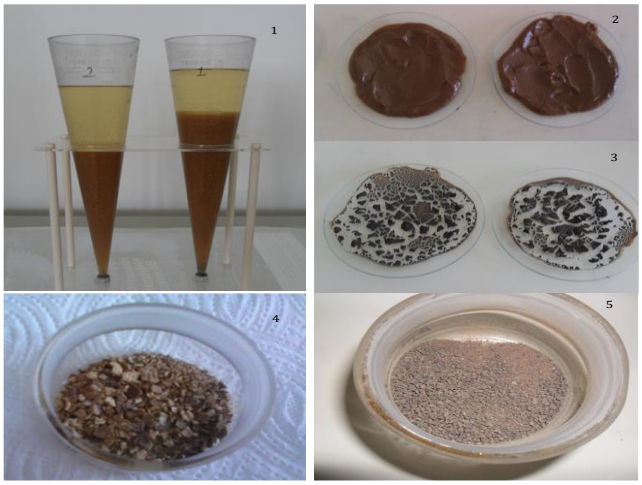


Figure 3. Culture of ureolytic microorganism produced for use in biosorption studies (1. Filtering through the imhoff funnels; 2. After centrifugation; 3. Dried in the oven; 4. Granule; 5. Powdered)

2.4. batch biosorption process

Batch biosorption experiments were conducted using Erlenmeyer flasks containing RY 145 solutions in a working volume of 500 mL. Homogeneous shaking was performed on a ZHICHENG brand platform shaker with a constant stirring speed of 150±5 rpm. To determine the efficiency of the basic adsorption parameters, UMC amount (0.2-2.0 g), pH (2-9), contact time (1-120 min), initial RY 145

concentration (30-150 mg/L) and temperature (20-50 °C) were applied at different values. In all experiments, the pH was monitored and adjusted using a HACH HQ440D multimeter. The study was carried out in two stages. The first stage was carried out in four series for different amounts of biomass in dye solutions of different concentrations. Based on the results of the first stage, the dye concentration, biomass amount and contact time produced the highest biosorption efficiency from the calculated q_e values. In the second step, a pH-temperature study was carried out on the aqueous solution with the previously determined dye concentration by adding the determined amount of biomass at the appropriate contact time. In this way, the most appropriate pH-temperature values at suitable contact times were determined.

After adsorption, UMC+RY 145 samples were centrifuged at 3000 rpm for 10 minutes to separate the UMC from the solution and make it ready for analysis. In batch experiments, the centrifuged samples were analysed using a Shimadzu UV-1280 spectrophotometer. Batch studies were performed in triplicate and at the 95% confidence limit (standard deviation ≤5%). The adsorption capacity (q_e) (mg/g) and removal efficiency (%) of RY 145 were determined using equations (9) and (10), respectively.

$$q_e = \frac{(C_0 - C_e) \times V}{1000 \times m} \quad (9)$$

$$\text{Yield}(\%) = \frac{C_0 - C_e}{C_0} \times 100 \quad (10)$$

Where C_0 and C_e (in mg/L) are the initial and final RY 145 concentrations respectively, V (L) is the volume of the solution and m (g) is the amount of UMC.

Table 3. Isotherm and kinetic model equations

Isotherms	Equations
Langmuir	$R_L = \frac{1}{1+K_L C_0}$ $\quad \frac{1}{q_e} = \frac{1}{q_m} + \left(\frac{1}{q_m K_L}\right)\frac{1}{C_e}$
Freundlich	$\log q_e = \log K_F + \frac{1}{n}\log C_e$
Kinetics	**Equations**
Pseudo-First Order	$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t$
Pseudo-Second Order	$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e}t$

K_L: Langmuir constant (L/mg), K_F: Freundlich constant (mg/g), n: Heterogeneity factor, R_L: equilibrium parameter k1: Pseudo-first-order kinetic constant (1/min), k2: Pseudo-second-order kinetic constant (1/min)

Isothermal and kinetic model evaluations were performed under optimal experimental conditions during the adsorption process. For q_e, Langmuir and Freundlich isotherm models describing the discrete experimental results and pseudo-first and pseudo-second-order kinetic models were used. The experimental data were evaluated according to the relevant adsorption models described in **Table 3.** In addition, the dimensionless separation factor R_L (R_L>1 unfavourable; R_L=1 linear; 0<R_L<1 favourable, R_L=0 irreversible) value related to Langmuir was also calculated.

3. Results and discussion

3.1. The effect of dye concentration on biosorption of RY 145

It was preferred to use the concentration values found in biosorption experiments published in the literature. The receiving environment was not exposed to significant dye concentrations. High concentrations were utilized, nevertheless, to more clearly assess the chosen biosorbent's efficacy in cases of severe contamination. Five distinct concentrations were chosen to serve as the variables. **Figure 4** illustrates how the biosorption process is impacted by the variation in the starting RY 145 concentration. The concentration of 150 mg/L RY 145 produced the greatest q_e value (201.9 mg/g) in all of the experiments that were undertaken. Numerous studies in the literature claim a direct relationship between the starting concentration and the biosorption capability (Huet and Aladame 1952).

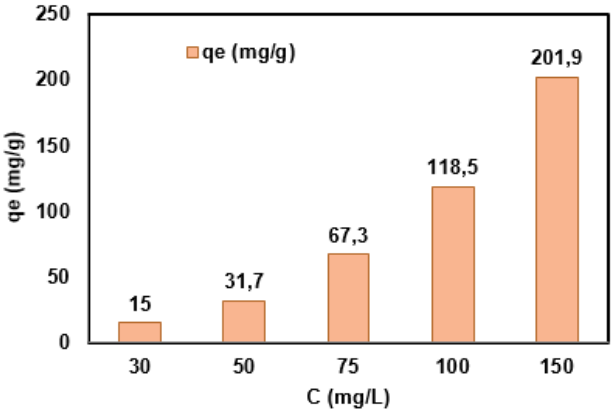


Figure 4. The qe values of initial dye concentration of aqueous RY 145 (Biomass amount, m: 0.2 g, contact time: 5 min, T: 20 °C)

3.2. The effect of umc amount and contact time on RY 145

Biosorbents are a key parameter in the adsorption process due to their nature (pore structure, surface area, etc.) and the effectiveness of the functional groups. As with the pH

factor, the optimum UMC dose must be determined to ensure both economical and efficient removal of RY 145 for the effectiveness of the process. The qe values of RY 145 were evaluated as shown in **Figure 4**, with an initial concentration of 150 mg/L, a stirring speed of 150 rpm and a constant temperature of 20 °C, while varying the UMC dose between 0.2 and 2 g. The results in **Figure 5** show that RY 145 was removed rapidly with the UMC dose until equilibrium conditions were reached. The reason for this is the presence of empty active sites on the UMC surface, which increases the amount of RY 145 retained per unit time (Ebrahim & El-Apasery, 2023). When the dose of UMC was 0.2 g, the qe value of the dye RY 145 was determined to be 201.9 mg/g. Starting from 0.5 g UMC dose, a decrease in the qe values of RY 145 was observed, which is due to the saturation of the active empty sites on the UMC surface. This behavior has also been observed in other adsorption studies (Brahimi-Horn et al. 1999; Zhou & Zimmermann, 1993).

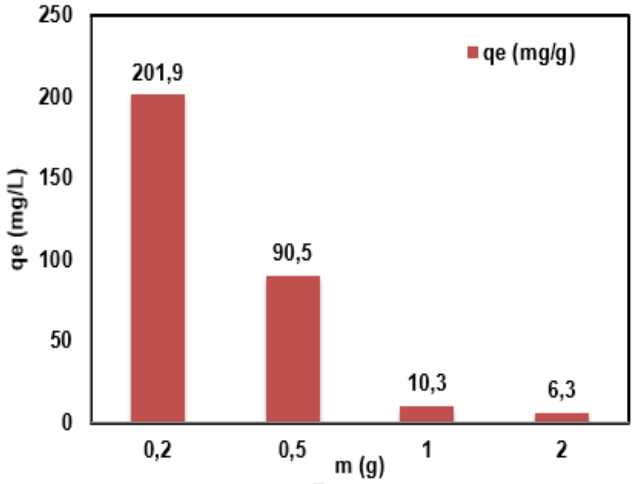


Figure 5. The qe values of different UMC amounts (Contact time, t: 5 min, T: 20 0C, initial dye concentration: 150 mg/L)

Figure 6 illustrates the role of contact time in the biosorption of RY 145 on the prepared UMC surface. According to the graph, the biosorption of RY 145 can occur in two stages: In the first stage, there is a rapid biosorption process that occurs in the first 30 min due to the available empty spaces on the surface of the UMC. In the second stage, a slow biosorption process occurs from the contact time of 60 min until equilibrium is reached. To determine the effect of contact time between RY 145 and UMC, a study was conducted at 20 °C, 150 rpm shaking speed, 150 mg/L RY 145 concentration and a range of 1-120 min. The biosorption capacity of RY 145 reached a maximum value of 610 mg/g at 30 min contact time. The maximum qe value reached in the first 30 min may be due to more active functional groups on the surface of the UMC, the density of active adsorption sites and the fact that RY 145 exceeds the liquid/solid mass transfer limit (Munagapati *et al.* 2022; Saravanan *et al.* 2020). As biosorption continues over time, the vacant sites decrease and a repulsive force is formed between the molecules retained on the UMC surface and those attempting to adsorb, and the biosorption rate slows. The findings of many studies in the literature are consistent with the results of this study (Aksu *et al.* 2011; Güngörmedi, 2009).

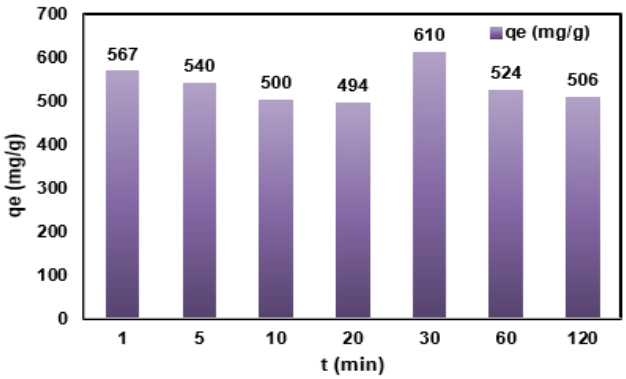


Figure 6. The qe values of different contact time (m= 0.2 g, T=20 °C, original pH, initial dye concentration: 150 mg/L)

3.3. The effect of pH on RY 145 biosorption

As pH is the most important parameter affecting not only the biosorption capacity but also the colour of the dye solution and the solubility of some dyes in biosorption systems, many researchers have analysed the effect of pH on colour removal (Gonzales *et al.* 2024). Changes in solution pH facilitate the dissociation of the biosorbent site and the chemistry of the pollutant, such as hydrolysis, surface complexation, redox reactions and precipitation (Sen, 2023). The effects of UMC on RY 145 molecules at pHs ranging from acidic (pH = 2-5) to basic (pH = 7-9) are shown in **Figure 7**. The results obtained show that RY 145 was rapidly biosorbed by UMC at pH 2. The qe for RY 145 at pH 2 was found to be 610.9 mg/g. RY 145, due to the high protonation of functional groups at pH≤2, causes electrostatic attraction between UMC and RY 145, which increases the removal of RY 145. As RY 145 is an anionic dye, a positively charged biosorbent surface supports a good biosorption process at acidic pH values.

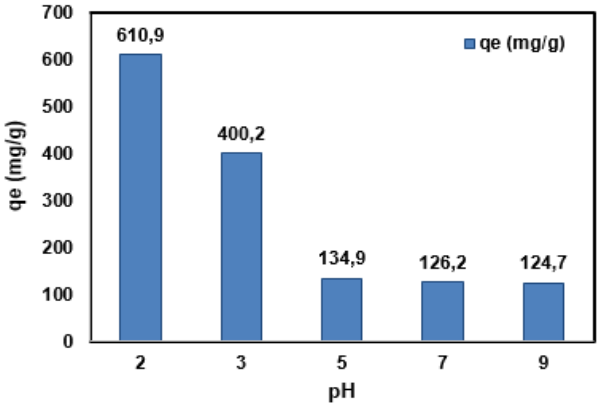


Figure 7. The variation of biosorption efficiency with different pH values at constant temperature (T=20 °C, m=0.2 g, t= 30 min, RY145 =150 mg/L)

3.4. The effect of temperature on dye biosorption with umc biomass

Temperature is a key parameter that explains the thermodynamics and interactions of molecules in the adsorption process (Altas *et al.* 2011; Banat *et al.* 1996; Fu & Virarahavan, 2001). Temperature is an important

indicator of the exothermic or endothermic nature of the adsorption reaction process (Mondal *et al.* 2019). The biosorbability of RY 145 on UMC was carried out in a thermally controlled shaker according to the temperature values varying in the range of 20 °C ≤ RY 145 ≤ 50 °C. According to the results obtained in **Figure 8**, the decrease in efficiency and qe value of RY 145 as the temperature increases above 20 °C may be due to the decrease in affinity of the dye for UMC. The high retention rate at 20 °C (q_e=7.5 mg/g) may be the result of the rapid diffusion and spreading rate of the dye in the biosorbent (Yadav and Dasgupta, 2022). Silva et al. (2020) stated that the weakening of the bonds between the target dye and the adsorbent surface depends on the high temperature. **Figure 6** shows that the optimum temperature is 20 °C. However, the partial decrease in QE with increasing temperature may indicate that the reaction becomes exothermic, which is due to the change in the interaction bonds between the pollutant and the adsorbent with temperature (Sen, 2023). In addition, the effect of temperature on QE can also be attributed to surface functional groups.

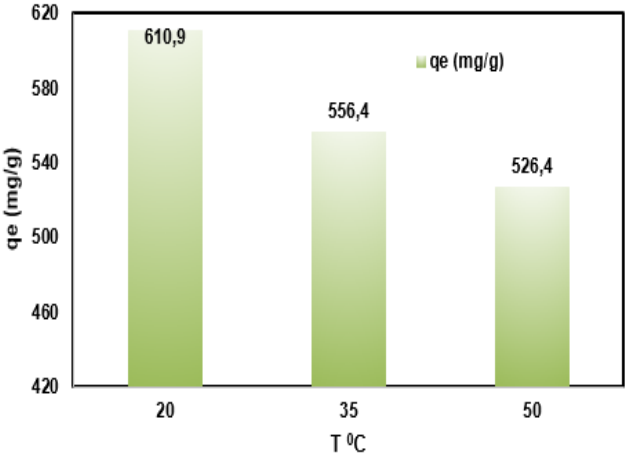


Figure 8. The effect of temperature on RY 145 biosorption with UMC (pH:2, m=0.2 g, RY145 =150 mg/L)

Table 4. Best-fit parameters for isotherm and kinetic models

Models	Equations	Factor -1	Factor -2	Factor-3	R^2
Langmuir	$q_e = \frac{q_m K_L C_e}{1 + K_L C_e}$	a= 1.000	K_L= 44.52	q_e=605.75/q_m=609.48	0.8894
Freundlich	$q_e = K_F \sqrt[n]{C_e}$	K_F= 74.40	n= 2.944	-	0.6386
Pseudo First Order	$In(q_e - q_t) = Inq_e - k_1 t$	k_1= 0.0366	-	-	0.8344
Pseudo Second Order	$\frac{t}{q_t} = \frac{1}{k_2 \times q_e^2} + \frac{1}{q_w}$	k_2= 0.00015	-	q_e= 600.95	0.8673

Table 5. Similar methods at various operating parameters.

Pollutant	Treatment method (Biosorption)	Amount (g)	Time (min)	q_e (mg/g)	References
Diuron	*sphaerica*	1	80	26.43	(Azza *et al.* 2015)
Acid Orange 7	*Ceratophylum demersum*	1	20	64.67	(Daneshvar *et al.* 2013)
RM 19	UMC	0.2	20	620	(Koçyiğit & Manav, 2018)
2,4-dichlorophenoxy acetic acid	*Anoxybacillus flavithermus*	0.05	60	24.15	(Ozdemir *et al.* 2012)
Methylene Blue	Modified Chitosan	2.81	120	392.16	(Xing & Li, 2014)
Basic Red 46	*Spirulina Platensis*	0.05	60	25.46	(Deniz & Kepekci, 2015)
Basic Red 46	Alga Enriched in Phenolic Compounds	0.05	-	33.33	(Deniz & Kepekci, 2016)
Acid Blue 25	Kenaf core fiber	0.1	180	303.03	(Intidhar *et al.* 2018)
Acid Green 25				344.83	
Reactive Black 5	Chitosan powder (CP)	0.5	-	654.3	Jaqueline *et al.* 2016)
	Chitosan films (CF)	0.5	-	589.5	
RY 145	UMC	0.2	30	610.9	This study

3.5. Biosorption Kinetic and Isotherm

The adsorption isotherm is characterized by certain constants that compare the surface properties, sorbent similarities and adsorption capacity of the biomass for different dyes (Clarke *et al.* 1980). These types of dyes are azo group chromophores combined with various types of reactive groups that typically interact with active groups in the cell surface such as surface adsorption, ion exchange, complexation, chelation and micro-sedimentation. Langmuir and Freundlich equations are commonly used to define adsorption equilibrium in wastewater practice. In this study the plots for Freundlich and Langmuir adsorption isotherms are shown in **Figure 9** and **Figure 10** respectively. In this study, the biosorption behavior between UMC surface and RY 145 was explained by using Langmuir and Freundlich models to determine the amount of RY 145 biosorbed on the selected UMC surface. The calculated parameters of the applied isotherms are detailed in **Table 4**. In these equations, q_m (mg/g) indicates the maximum biosorption capacity and the K_L constant (L/mg) indicates the affinity of the contaminant to the binding sites on the UMC. At 150 rpm,

20°C, 30 min contact time for RY 145 and 150 mg/L initial concentration, q_m was determined to be 609.48 mg/g. The separation factor (R_L) determines the suitability of the adsorption process, where $0 < R_L < 1.0$ indicates favourable adsorption, $R_L > 1.0$ indicates unfavourable adsorption, $R_L = 1.0$ indicates linear adsorption and $R_L = 0$ indicates irreversible adsorption (Munagapati *et al.* 2022). In this study, the value of R_L was found to be between 0 and 1.0, confirming the favourable nature of the biosorption of RY 145 on UMC. The Freundlich model describes adsorption on a reversible and non-ideal heterogeneous surface. The value of 'n', where n > 1.0 represents physical adsorption, n < 1.0 represents chemisorption and n = 1.0 represents linear adsorption (Khalid *et al.* 2021). In this study, the 'n' value for RY 145 was found to be greater than 1.0 (see **Table 4**), indicating physical adhesion of RY 145 to UMC. According to the available R2 values, the isothermal order is Langmuir>Freundlich.

k_1 (1/min) and k_2 (g/mg/min) are the pseudo first order and pseudo second order apparent adsorption rate constants; q_e adsorption capacity of adsorbate (mg/g); q_m maximum adsorption capacity of adsorbate (mg/g); K_L (L/mg) Langmuir constant related to the energy of adsorption; C_e is the equilibrium solution concentration (mg/L); K_F (L/mg) Freundlich constant related to the sorption capacity of adsorbent; a adsorption per molecule of the adsorbate

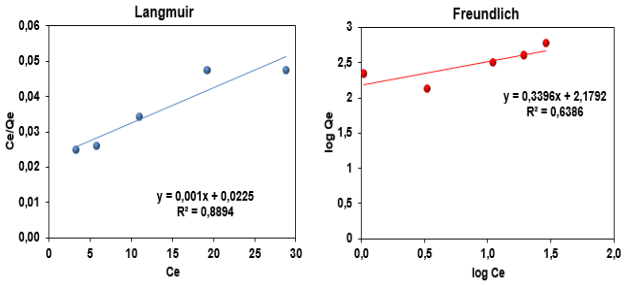


Figure 9. The Langmuir and Freundlich Isotherm Graph for RY 145

To evaluate the biosorption performance of UMC against RY 145, studies conducted by different researchers were compared as summarized in **Table 5**. The comparison of UMC with different biosorbents shows that UMC can be considered as a potential biosorbent for the removal of cationic and anionic dyes.

Pseudo-first order and pseudo-second order models were tested to determine the retention rate of the process. PFO can estimate the equilibrium time and the amount of adsorbed pollutant by determining the contact time (Grigoraș *et al.* 2023). PSO can explain the potential chemical relationships between the pollutant and the adsorbent surface. **Figure 10** and **Table 4** show the model plots and coefficients obtained from the kinetic equations. At high and low dye concentrations, the pseudo-first and pseudo-second order models produce more suitable profiles (Grigoraș *et al.* 2023). While PFO and PSO data are very close to each other, experimental data showed that PSO is one step ahead for the study. The results show the suitability of pseudo-second order kinetics in terms of R^2 values. The graphical distribution shows that the order pseudo-second > pseudo-first can be established for RY 145.

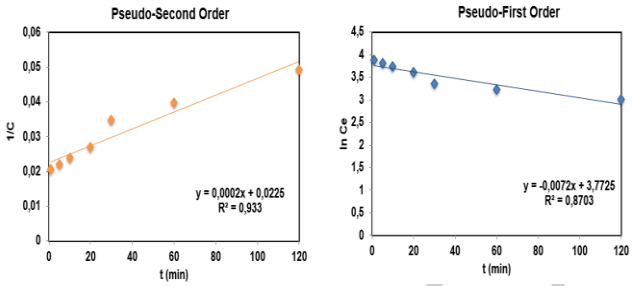


Figure 10. The PFO and PSO Order Reaction Graph for RY 145

4. Conclusion

The biosorption capacity of the biosorbent obtained from the ureolytic microorganism culture which was used for RY 145 removal and which involves reaction kinetic and isotherm studies was examined. The experiments were continued as a function of initial pH and initial dye concentration. The results that were obtained showed that ureolytic microorganism culture has a high sorption capacity in dye removal. Data from the literature regarding the studies using different biosorbents in the sorption of reactive yellow dye were compared to the sorption capacity of the ureolytic microorganism culture, and the result showed that it is an alternative and effective method that can be used for the biosorption of the reactive dyestuff of ureolytic microorganism culture. The results of the study obtained under the most favorable conditions suggest that RY 145 has a biosorption efficiency of 84.5 % and biosorption capacity qe of 610 mg/g in 150 mg/L initial dye concentration by adding 0.2 g/L biosorbent with pH=2 and T=20 °C temperature after 30 minutes contact time in aqueous solution and it was calculated that the biosorption kinetic is compatible with second order adsorption kinetic. According to the R^2 correlation coefficients calculated in the isotherm studies where adsorption isotherm constants are found, the biosorption of RY 145 dyestuff is in accordance with Langmuir isotherm in this study. The ureolytic microorganism culture biomass is cost-efficient, natural, abundant and easily available, therefore, it can be used in the removal of reactive dyes as an alternative to more expensive methods such as active carbon. With the study we present alternative way of employing waste waters which is important for water management.

Conflict of interest

The authors declare no conflicts of interest.

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