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Original Research Paper

# Application of residual brewery yeast for adsorption removal of Reactive Orange 16 from aqueous solution

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ABSTRACT

The adsorption characteristics of C.I. Reactive Orange 16 (RO 16) from aqueous solution onto residual brewery yeast were investigated under various experimental conditions. At pH 3.0 and 308 K, the adsorption capacity of RO 16 onto residual brewery yeast was found to be 0.56 mol/kg. Experimental data indicated that the adsorption capacity of residual brewery yeast for the dye was higher in acidic, than in neutral or basic solutions. The adsorption equilibrium data showed good correlation with the Langmuir isotherm models. The estimated values for the free energy of adsorption ($\Delta G^o$) were −6.661, −4.812 and −3.929 kJ/mol at 288, 298 and 308 K, respectively, which indicated that a spontaneous process had occurred. The negative values of enthalpy ($\Delta H^o$) and entropy ($\Delta S^o$) indicated the exothermic nature of the adsorption of RO 16 onto residual brewery yeast. Kinetic studies showed that the biosorption of RO 16 onto residual brewery yeast in the system followed pseudo-second order kinetics.



## 1. Introduction

Dye pollutants from the textile industry are an important source of environment contamination, and pose serious environmental problems because of their color, low biochemical oxygen demand and high chemical oxygen demand. Vinyl sulfone and chlorotriazine dyes constitute the largest and most important class of commercial dyes in wastewater. These dyes can be used for cotton, silk, wool, rayon, paper and wood, but not for synthetic fibers [1–4]. These dyes are difficult to remove from effluents since they are stable to light, heat and oxidizing agents as well as being biologically non-degradable. Although some existing technologies, such as conventional chemical coagulation/flocculation, ozonation, oxidation and ion exchange may have certain efficiency in the removal of reactive dyes, their initial and operational costs inhibiti their use in the dyeing and finishing industries. However, the adsorption process is one of the effective techniques that have been successfully employed for color removal from wastewater. Many adsorbents have been tested for the possibility the removal of dyes from aqueous solutions, such as activated carbon [5–7], sewage sludge [8], chitin/chitosan [9,10], bacteria [11], fungus [12] and others [13,14].

Activated carbon is the most widely used adsorbent for the removal of color and treatment of textile effluents, but is not widely used, due to its high price. Also, living or dead biomass can be used to remove dyes, but maintaining a living biomass during this biosorption is difficult as a continuous supply of nutrients is required and the dyes may be toxic towards the microorganisms. Conversely, the use of dead biosorbent can avoid these problems and the used cells can easily be regenerated [15]. Yeasts are a better raw biosorbent material for the removal of reactive dyes due to their unicellular nature and high growth rate [16]. Yeast cells can be easily cultivated in inexpensive growth media, and are a readily available source of biomass that possesses potential for the bioremediation of wastes at low pH values. The binding mechanisms of dyes via biosorption can be explained by the physical and chemical interactions between cell wall ligands and the adsorbates due to ion exchange, complexation, coordination and microprecipitation.

The objectives of this study were to examine the feasibility of residual brewery yeast as a novel type of biosorbent for the removal of C.I. Reactive Orange 16 (RO 16) from aqueous solution.

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## 2. Materials and methods

### 2.1. Materials

Residual brewery yeast, collected from a brewery plant in Korea, was washed several times with distilled water, and then dried in a vacuum drying oven at 353 K for 48 h. The dried yeast was ground with a mortar and pestle. The particles were separated using the US standard testing sieve (No. 100–120) and stored in a sealed bottle with a silica gel to prevent the re-adsorption of moisture. The buffer solution for adjusting the pH of the aqueous solutions contained sodium hydroxide (Sigma, USA) and acetic acid (Yakuri Co., Japan). A reactive dye with wide industrial applications was selected, namely Reactive Orange 16 dye (C.I. No. 17757, Aldrich Chemical). The chemical structure and its absorption maxima are given in Table 1. All solutions were prepared with deionized water. All reagents used were of analytical grade.

### 2.2. Biosorption equilibrium and kinetics

The RO 16 was dissolved in deionized water to the required concentration, and the pH adjusted to 3, 7 and 10 using 1 M HCl or NaOH. For the adsorption equilibrium experiments, residual brewery yeast (0–0.7 g) and the dye solution (200 $cm^3$) were placed in a 300 $cm^3$ flask and shaken for 2 days in a shaking incubator. The dye concentration of the solutions was analyzed using UV–VIS spectrophotometry (UV-1601, Shimadzu) at 492 nm. The amount of adsorption at equilibrium, $q_e$ (mol/kg), was obtained as follows:

$$q_e = (c_i - c_e)V/W \quad (1)$$

Here $q_e$ is the equilibrium amount adsorbed onto the biosorbent (mol/kg), $c_i$ and $c_e$ are the initial and equilibrium solution concentrations (mol/$m^3$), respectively, $V$ is the solution volume ($m^3$) and $W$ is the weight of the biosorbent (kg).

Batch adsorption experiments were conducted in a Carberry-type batch adsorber. The effects of the residual brewery yeast concentration and initial pH of the RO 16 solution on the biosorption were studied. The temperature of the solution mixture was kept at 298 K, with the experiments conducted at approximately 400 rpm, since the film mass transfer coefficient, $k_f$, was reasonably constant under this condition. Samples were withdrawn at predetermined time intervals, centrifuged and the residual RO 16 concentration then analyzed.

## 3. Results and discussion

### 3.1. Characterization of residual brewery yeast

The functional groups on the surface of the residual brewery yeast were analyzed using FT-IR spectrophotometry (300E, JASCO, Japan) and the Bohem method. Fig. 1 shows the main frequencies and functional groups of residual brewery yeast for before and after the adsorption experiments. As shown in Fig. 1, the amide A and amide B absorption bands, which are located at 3280 and 3070 $cm^{-1}$, respectively [17], are mainly related to the NH stretching modes in Fermi resonance with overtones or combinations of amide I and amide II modes [18]. The typical CH group mode, observed at 2924 $cm^{-1}$ is not significantly altered by removal of the dye by the biomass. The amide and amine bands are more significant to the understanding of the dye sorption mechanisms. In the 1500–1700 $cm^{-1}$ range, two bands are identified. The so-called amide I band, a CO stretching mode conjugated to a NH deformation mode, is located around 1646 $cm^{-1}$ [18]. The NH deformation mode conjugated to a C=N deformation mode, the so-called amide II band, is located between 1550 and 1590 $cm^{-1}$, depending on possible protonation and on the degree of acetylation [18,19]. The other typical amide band (amide III), whose frequency is 1377 $cm^{-1}$, is identified as the NH deformation mode conjugated with a C=O and a C=N stretching mode (the double link C=N is possibly related to a delocalization of the C=O link in the amide) [19]. The presence of phosphate groups was indicated by the presence of a weak band within the 950–990 $cm^{-1}$ range. Fig. 1 also shows the IR spectrum of residual brewery yeast saturated with RO 16 dye. The peaks were substantially lower than those for the raw residual brewery yeast. This change in the peak intensities can be interpreted as the result of the weakened bond structure of residual brewery yeast due to the reaction between RO 16 dye and the functional groups on the yeast. From these results, the functional groups potentially involved in the adsorption of RO 16 dye included phosphate, carboxyl, amine and amide groups.

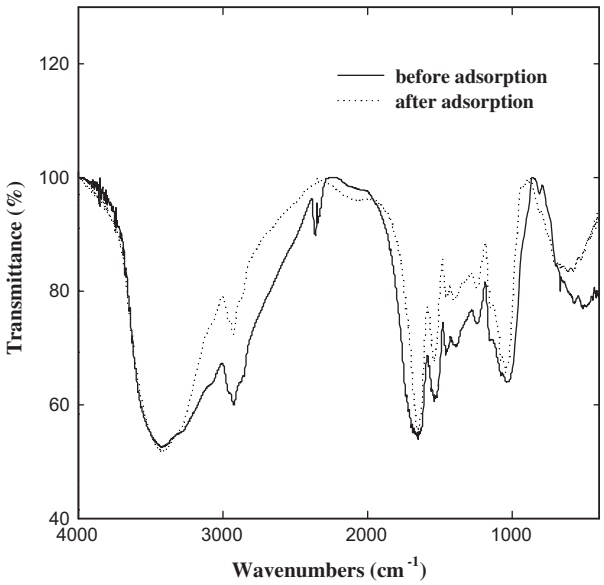
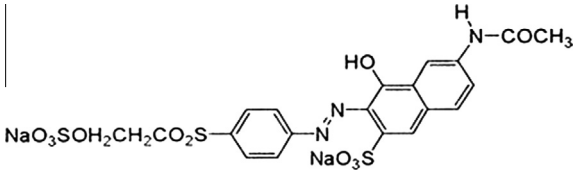



**Fig. 1.** FT-IR spectra of brewery yeast for before and after the adsorption of RO 16.

Table 2 lists the physical properties of residual brewery yeast, which were measured using $N_2$ adsorption (Autosorb-1, Quantachrome Co., USA) at 77 K. The specific surface area of residual brewery yeast (13.15 $m^2/g$) was much smaller than that of activated carbon (696–1950 $m^2/g$), but larger than that of the biosorbent

**Table 1**
Chemical structure and absorbance maximum of dye.

| Name | Chemical structure | $\lambda_{max}$ (nm) |
|---|---|---|
| Reactive Orange 16 |  | 492 |