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Application of response surface methodology to optimize the process variables for Reactive Red and Acid Brown dye removal using a novel adsorbent

K. Ravikumar [a], S. Ramalingam [b], S. Krishnan [c], K. Balu [c,*]

[a] Department of Chemical Engineering, Sri Venkateswara College of Engineering, Sriperumpudur, Chennai 602 105, India
[b] Department of Chemical Engineering, Sri Sivasubramaniya Nadar College of Engineering, Kalavakkam, Chennai 603 110, India
[c] Department of Chemical Engineering, Alagappa College of Technology, Anna University, Chennai 600 025, India

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Abstract

Decolourization of Verofix Red (Reactive Red 3GL) and Lanasyam brown Grl (Acid Brown 29) from aqueous solution was studied by adsorption technique using a hybrid adsorbent that was prepared by pyrolysing a mixture of carbon and flyash at 1:1 ratio. A 2^4 full factorial central composite design was successfully employed for experimental design and analysis of the results. The combined effect of pH, temperature, particle size and time on the dye adsorption was investigated and optimized using response surface methodology. The optimum pH, temperature, particle size and time were found to be 10.8, 59.25 °C, 0.0525 mm and 395 min, respectively, for Reactive Red 3GL and those for Acid Brown 29 were 1.4, 27.5 °C, 0.0515 mm and 285 min, respectively. Complete removal (100%) was observed for both the dyes using the hybrid adsorbent.

Keywords: Adsorption; Hybrid adsorbent; Dye removal; Response surface methodology; Statistical analysis

1. Introduction

The coloured dye effluents are considered to be highly toxic to the aquatic biota and affect the symbiotic process by disturbing the natural equilibrium by reducing photosynthetic activity and primary production due to the colourization of the water [1]. Effluents contain significant level of organic contaminants, which are toxic as they create odour, bad taste, unsightly colour, foaming, etc. These substances are often resistant to degradation by biological methods and are not removed effectively by conventional physico-chemical treatment methods [2]. Removal of dyes from effluents in an economic fashion remains a major problem for textile industries. Adsorption technique has been proved to be an excellent way to treat effluents, offering advantages over conventional process, especially from the environmental point of view [2]. Weber and Morris [2] had identified many advantages of adsorption over several other conventional treatment methods. Carbon is being used as a potential adsorbent because of its high efficiency [3]. Enhancement of the price of activated carbon results in economic difficulties for developing countries like India. Hence, alternate adsorbents with an equivalent potential of activated carbon are current thrust area of research.

The adsorption of dyes on various types of materials has been studied in detail. These include: activated carbon [4], peat [5], chitin [6], silica [7], hardwood sawdust [8], hardwood [9], bagasse pith [10], flyash

* Corresponding author. Tel.: +91 44 22203522; fax: +91 44 22352642.
E-mail address: kbalu@annauniv.edu (K. Balu).

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Nomenclature

C_0	initial concentration of dye solution (mg/l)
C_t	concentration of dye solution at the desired time, t (mg/l)
x_i	dimensionless coded value of the variable, X_i
X_0	value of the X_i at the center point
δX	step change
Y	predicted response
X_1	pH
X_2	temperature (°C)
X_3	particle size (mm)
X_4	time (min)
Exp.	experimental value
Pred.	predicted value

Greek letters

β_0	offset term
β_i	linear effect
β_{ii}	squared effect
β_{ij}	interaction effect
η	removal efficiency (%)

[11,12], mixture of flyash and coal [13], chitosan fibre [14], paddy straw [15], rice husk [16], slag [17], chitosan [18], acid treated spent bleaching earth [19], palm fruit bunch [20] and bone char [21].

Conventional and classical methods of studying a process by maintaining other factors involved at an unspecified constant level does not depict the combined effect of all the factors involved.

This method is also time consuming and requires large number of experiments to determine optimum levels, which are unreliable. These limitations of a classical method can be eliminated by optimizing all the affecting parameters collectively by statistical experimental design such as Response Surface Methodology (RSM) [22]. RSM is a collection of mathematical and statistical techniques useful for developing, improving and optimizing processes and can be used to evaluate the relative significance of several affecting factors even in the presence of complex interactions. The main objective of RSM is to determine the optimum operational conditions for the system or to determine a region that satisfies the operating specifications [23]. The application of statistical experimental design techniques in adsorption process development can result in improved product yields, reduced process variability, closer confirmation of the output response to nominal and target requirements and reduced development time and overall costs [24].

For any batch adsorption process, the main parameters to be considered are pH, temperature, particle size and time [25]. Hence it is necessary to investigate

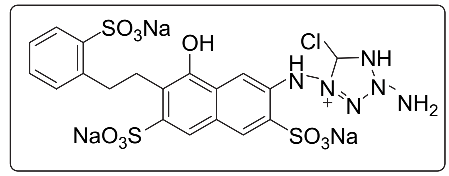

Fig. 1. Structure of Verofix Red (Reactive Red 3GL).

extensively on the relationship between adsorption efficiency and the parameters affecting it. Owing to high cost of activated carbon, an adsorbent that is cheap and easily available would be a better alternative. In the present study, a novel adsorbent consisting of 1:1 mixture of carbon and flyash was investigated for its efficiency to remove two classes of dyes namely Reactive Red 3GL ($C_{19}H_{17}ClN_6Na_3O_{10}S_3^+$) and Acid Brown 29 ($C_{16}H_{11}N_3O_4$) from aqueous solution. Their chemical structures are shown in Figs. 1 and 2. The interaction between the parameters was studied and optimized using response surface methodology.

2. Materials and methods

2.1. Preparation of hybrid adsorbent

Flyash, obtained from Ennore Thermal Power Plant, Chennai, Tamilnadu was washed with distilled water, dried under sunlight and subsequently in hot air oven at 60 °C. Hybrid adsorbent was prepared by mixing carbon (supplied by SD Fine Chemicals) with flyash at 1:1 ratio by pyrolysing in an isothermal reactor powered by an electric furnace. High purity nitrogen was used as the purging gas. The isothermal reactor was heated to the desired temperature of 650 °C at a heating rate of 15 °C/min, and a holding time of 3 h. After pyrolysis, the product was activated at the same temperature for 3 h using CO_2 as oxidizing agent and subsequently used as adsorbent. The SEM (Scanning Electron Micrograph) image (Fig. 3) shows irregular and porous structure of the hybrid adsorbent, owing to their exposure to a combustion environment, which indicates very high surface area. Chemical analysis of the hybrid adsorbent showed that carbon was the major constituent along with silica, lime and alumina. The origin of carbon constituents could be reasoned by analyzing the process and material used for carbon manufacture.

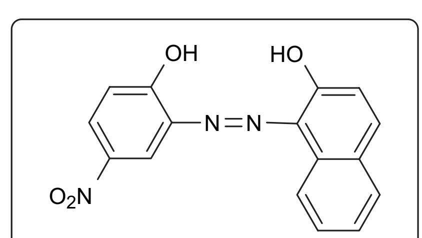

Fig. 2. Structure of Lanasyam Brown Grl (Acid Brown 29).