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Study on Treated Fly Ash and Cladodes of *Opuntia ficus indica* as Low-Cost Dye Adsorbents

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ABSTRACT

Textile industries discharge wastewater containing harmful dyes into the environment, causing pollution. The conventional methods for treating dye-containing wastewater are expensive and beyond the financial reach of small-scale textile industries. This study explores the use of two low-cost adsorbents, namely fly ash and *Opuntia ficus indica* , as alternatives to conventional methods. The adsorption efficiency of these adsorbents, both individually and in combination, was evaluated against crystal violet and malachite green in aqueous solution. Fly ash was treated with HCl and microwave irradiation, and *Opuntia ficus indica* was activated chemically using NaOH and NaClO. The adsorption capacity of the adsorbents varied with the preparation conditions and the type of dye. Microwave-treated fly ash exhibited the highest adsorption capacity, achieving a 95.2% reduction in 0.05% crystal violet. However, it only showed a 19% reduction in 0.05% malachite green. *Opuntia ficus indica* activated with NaOH exhibited the highest adsorption capacity for both crystal violet and malachite green, achieving 50.8% and 44.5% reductions, respectively. The combination of treated fly ash and treated *Opuntia ficus indica* exhibited the highest reduction in 0.5% crystal violet (40.5%) and 0.02% malachite green (93.52%). The adsorption capacity of the combination was better than the individual samples of treated fly ash and treated *Opuntia ficus indica* for malachite green. These findings suggest that the combination of treated fly ash and treated *Opuntia ficus indica* could be a promising low-cost alternative for treating dye-containing wastewater in small-scale textile industries.

Key words: *Fly ash, Adsorbent, Wastewater, Adsorption, Opuntia ficus indica, Textile dyes*

Introduction

Water scarcity is becoming an increasing concern due to population growth, urbanization, agriculture, and industrialization. The textile dyeing industry, which produces wastewater with high concentrations of pollutants such as BOD, COD, and uncooperative organic molecules, is one of the most significant contributors to water pollution (Mittal, *et al.,* 2017). The use of fly ash, which is a potential low-cost and effective adsorbent for the removal of various pollutants from water and wastewater, including heavy metals, organic compounds, and dyes, has been extensively researched for environmental remediation (Singh, Singh, Singh, & Singh, 2013). Fly ash is a solid waste generated mainly from power generation, and its high content of silicate and aluminate minerals has been found to possess excellent adsorption properties. Fly ash has unique physico-chemical properties, such as surface area, pore size distribution, and surface charge, which enable it to absorb a wide range of contaminants (Mittal *et al.,* 2017). *Opuntia ficus indica*, also known as the prickly pear tree, has been identified as a promising natural adsorbent for dye removal due to its high-water holding capacity (Hou, Wang, Liang,

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and Li, 2015). The mucilage present in the plant's tissues has remarkable adsorption properties, allowing it to bind to heavy metals and other pollutants in water (Hou *et al*., 2015). *Opuntia ficus indica* is a plant that generates significant waste due to the high percentage of discarded fruit, and its stems, called cladodes, are cooked and consumed as a vegetable. The use of *Opuntia ficus indica* and fly ash as natural adsorbents for the removal of pollutants from water and wastewater has the potential to be applied in various industries, including textile, printing, and dyeing (Mittal *et al*., 2017). The exploration of low-cost, sustainable materials for adsorption processes is crucial for reducing costs and minimizing environmental impact in industrial applications (Erdem, Karapinar and Donat, 2004).

Materials and Method

Fly ash Sample

To prepare Fly ash samples, mix **10 g of fly ash** with **20 ml of 1 M HCl solution**. Two samples of fly ash treated with HCl were prepared under conditions: one at room temperature (FA-RT) and the other at **100 °C for 24 hours** (FA-100). The other two samples of fly ash treated with HCl were prepared using microwave for **1 and 2 minutes**, respectively labelled as FA-M1 and FA-M2. All the samples are filtered, washed, and dried at **100 °C overnight**. Then, **1 g of each sample** is added to **50 ml of 0.05% standard dyes** (Crystal Violet and Malachite Green). The mixture is shaken for **72 hours (about 3 days)** in a shaker at **100 rpm**. Finally, the optical density (O.D.) is measured spectrophotometrically at **590 nm and 617 nm** for Crystal Violet and Malachite Green, respectively.

Opuntia Ficus Sample

Three different protocols for sample preparation. The first protocol, untreated sample preparation (OP), involved collecting cladodes of O. Ficus-indica, washing and cutting them into small pieces. The second protocol, for sample OP-NaClO, involved washing and cutting cladode waste, immersing it in **12% sodium hypochlorite solution**, heating it in a hot air oven at **50°C for 30 mins** and neutralizing the pH with distilled water. The third protocol, for sample OP-NaOH, involved washing and cutting cladode waste, immersing it in industrial-grade **25% sodium hydroxide solution**, heating it in a hot air oven at **50 °C for 30 mins** and neutralizing the pH with distilled water. All these prepared samples were sun-dried, stove-dried until they lost 88% of their weight, grinding and sieving to obtain particles with a size between 1mm and 2 mm and then, **1 g of each sample** is added to **50 ml of 0.05% standard dyes** (Crystal Violet and Malachite Green) and then incubated for 72 hours (about 3 days) at 30 °C and 100 RPM. Further, Optical density was measured spectrophotometrically at **590 nm and 617 nm** for Crystal Violet and Malachite Green, respectively, after centrifuging the mixture at **3000 rpm for 10 minutes**.

Flash adsorber (FA-M2 + OP-NaOH)

The Flash adsorber was prepared using FA-M2 and OP-NaOH, as these combinations gave the highest individual reductions against standard dyes. To prepare the mixture, combine equal amounts of OP-NaOH and FA-M2. Take 1 g of the mixture and add it to varying concentrations of malachite green (0.05%, 0.02%) and crystal violet (0.1%, 0.05%). Thoroughly mix the resulting solutions and place them in a shaker at 30 °C with a speed of 100 rpm for 72 hours (about 3 days). After 72 hours (about 3 days), centrifuge the samples at 3000 rpm for 10 minutes, and measure their optical densities at **590nm and 617nm** using a spectrophotometer.

Results and Discussion

Table 1. Activity of fly ash against Crystal violet and Malachite green

HCl treated Fly ash samples	%Reduction against standard dyes (DAY 3)	
	0.05 % Malachite green	0.05% Crystal violet
FA-RT	7.34%	69.28%
FA-100	10.74%	87.48%
FA-M1	23.72%	94.88%
FA-M2	**25.43%**	**95.22%**

Table 2. Activity of treated Opuntia ficus indica against crystal violet and malachite green

Treated opuntia Ficus-indica samples	%Reduction against standard dyes (DAY 3)	
	0.05 % Malachite green	0.05% crystal violet
OP	0%	0%
OP- NaOH	44.53%	50.85%
OP-NaClO	0%	0%

Table 3 Combined activity of FA-M2 and OP-NaOH against Crystal violet and Malachite green:

FA-M2 + OP-NaOH	%Reduction against standard dyes (DAY 3)			
	0.02% Malachite green	0.05% Malachite green	0.05% Crystal violet	0.1% Crystal Violet
	93.52%	89.43%	40.50%	8.64%

Fly ash and *Opuntia ficus indica* have been found to be effective adsorbents for dye removal due to their unique properties. Fly ash, which is a waste product of coal combustion, has a rough surface area and pores that make it an effective adsorbent for dyes. Acidic treatment of fly ash with HCL increases its adsorption capacity, while microwave treatment enhances its pore volume, resulting in the highest adsorption capacity of 95.22% for crystal violet and 25.43% for malachite green.

Opuntia ficus indica, a type of cactus, possesses mucilage, flavonoids, tannins, and phenols in its cladodes that make it an effective adsorbent for dyes. Chemical treatments using NaOH and NaClO were applied to Opuntia to increase its adsorption capacity. The highest reduction in crystal violet and malachite green was observed with Opuntia treated with NaOH, achieving an adsorption capacity of 50.85% and 44.53%, respectively.

When a combination of fly ash treated with HCL under microwave and Opuntia treated with NaOH was used for dye adsorption, a reduction of 89.43% against Malachite Green and 40.50% against crystal violet was observed. This suggests that the interaction between these two treated materials may have led to changes in the chemical properties and structure of the dye molecules.

In conclusion, fly ash and *Opuntia ficus indica* have shown potential to be effective adsorbents for dye removal. Chemical treatments can be applied to both materials to increase their adsorption capacity, and a combination of the two can lead to even higher dye removal rates. Further research is needed to fully understand the mechanisms behind these interactions and optimize their use for various dye removal applications.

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Conflict of Interest None

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