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# Adsorptive Removal of Synozol Red Dye from Aqueous Solutions Using Potato Peel and CuO/Potato Peel Nanocomposite

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## ABSTRACT

There is a threat to the environment and the health of people due to the pollution of water bodies with synthetic dyes emitted by textile plants. Potato peel (PP) and copper oxide-modified potato peel nanocomposite (CuO/PPNPs) were examined in the given study as low-cost biosorbents in the removal of Synozol Red (SR) dye in aqueous solutions. Fourier Transform Infrared spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Energy Dispersive X-ray spectroscopy (EDX), and X-ray Diffraction (XRD) methods were used to characterize the prepared adsorbents. Experiments on batch adsorption were carried out to investigate the influence of pH, contact time, adsorbent dosage, and initial dye concentration on the adsorption efficiency. The experimental findings pointed out that the process of removal of dye was very sensitive to solution pH and the dosage of adsorbent. The highest removal was recorded under acidic conditions (pH 2), whereby the removal efficiency of the CuO/PPNPs was about 72.6%. The maximum adsorption capacity was increased with the contact time and the dye concentration. Kinetic modeling demonstrated that the adsorption process was governed by the pseudo-second-order kinetic model, which indicated that the adsorption process was chemisorption in nature. The Langmuir isotherm model was the best fit to the equilibrium data, so it indicates monolayer adsorption of dye molecules to the adsorbent surface. The findings indicate that CuO/PPNPs has a better adsorption capacity than raw potato peel and is an efficient and non-polluting adsorbent to obtain the cost and to treat the dye-impure wastewater.

**Keywords:** Synozol Red, Biosorption, Potato Peel Adsorbent, Copper Oxide Nanocomposite, Textile Wastewater

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## Introduction

The high rate of industrialization has led to discharging of huge amounts of pollutants into the water bodies. Synthetic dyes are one of the most troublesome contaminants that fall under this category of pollutants, owing to their complex chemical structures as well as their inability to decompose (Slama et al., 2021). The textile industries are the main cause of contamination of dyes in the water systems because large amounts of colored wastewater are released during the process of dyeing and finishing (Maheshwari, Agrawal, & Gupta, 2021).

Synthetic dyes have been made stable to light, temperature, and microbial degradation. Although these properties are beneficial in industrial usage, they render the process of removing the dyes in wastewater extremely difficult (Jamee & Siddique, 2019). Even the traces of dyes can lead to a tremendous discoloration in water bodies to the extent of diminishing the penetration of light in the water mass and disrupting the photosynthesis in aquatic plants (Mehta, Sharma, Pathania, Jena, & Bhushan, 2021).

The Synozol Red dye finds extensive use in textile processing and other industrial processes because it has high coloring strength and chemical stability (Khan, Mehmood, Iqbal, & Hamayun, 2020). Nonetheless, exposure to contaminated water that contains dye has been reported to have adverse impacts on aquatic organisms and human beings. Certain dyes can be mutagenic, carcinogenic, and toxic, and bring in serious environmental impacts (Ramírez-Revilla, Ollancaya, Condori, & Ortiz-Romero, 2025).

There are various methods that have been invented to eliminate dyes in wastewater, which include coagulation, oxidation, membrane filtration, and biological treatment (Kasperchik, Yaskevich, & Bil'Dyukevich, 2012). Nonetheless, most of these methods are costly, have complicated apparatus, or create as a by-product, secondary pollution. Adsorption has proved to be one of the most viable and popular methods of dye removal because of its simplicity, high efficiency, and comparatively low cost (Bhatia, Sharma, Singh, & Kanwar, 2017).

There has been interest in using Agricultural waste materials as sustainable adsorbents in the treatment of wastewater (Steiger, Zhou, Anisimov, Evitts, & Wilson, 2023). These materials are cheap, very easy to access, and consist of natural functional groups that can bind pollutant molecules. One of the agricultural wastes that is generated in great amounts as a result of food processing industries is potato peel. It is composed of cellulose, hemicellulose, and lignin that offer active adsorption sites (Sen, 2023).

Metal oxide nanoparticles can also be added to the natural bio sorbents in order to enhance their adsorption efficiency(Ghosh, Das, Biswas, & Haldar, 2022). Copper oxide nanoparticles have a high surface area with good adsorption capacity, and hence they have the potential to enhance the performance of pollutant removal. The biomass substances combined with the metal oxide nanoparticles lead to the generation of nanocomposites with improved adsorption characteristics (Alprol, Mansour, Abdelwahab, & Ashour, 2023).

The objective of the current research was to compare the adsorption efficiency of potato peel and CuO-modified potato peel nanocomposite in the removal of the Synozol Red dye in aqueous solutions. The impact of operational factors, including

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pH, contact time, adsorbent dosage, and initial concentration of the dye, was examined to find out the adsorption behavior of the adsorbents prepared.

## Materials and Methods

### Preparation of Biosorbent

Potato peels were gathered in the local restaurants and washed thoroughly by distilled water to get dust and impurities out. The peels were dried in an ambient environment under small pieces. The peels after air drying were then dried in an oven at 80 °C till the sample had a constant weight. This was dried and ground in a laboratory grinder to fine powder. The airtight containers containing the powdered material were used as the biosorbent in the adsorption experiments.

### Preparation of CuO/Potato Peel Nanocomposite

The synthesis of copper oxide nanoparticles was done on the surface of potato peel powder through a precipitation process. A solution of copper precursor was added to the biosorbent powder, and stirring was continued until copper oxide nanoparticles were formed. The resulting mixture was then filtered and washed repeatedly using distilled water in order to clean it of any remnant impurities. To acquire the final CuO/PPNP nanocomposite, the composite material was dried in an oven.

### Preparation of Dye Solutions

An appropriate amount of dye was dissolved in distilled water to form a stock solution of Synozol Red dye that had a concentration of 1000 mg/L. The stock solution was diluted with distilled water to working solutions with a concentration of 25 to 200 mg/L. The pH of the dye solutions was changed with the help of sodium hydroxide (NaOH) or the hydrochloric acid (HCl) according to the requirements of the experiment.

### Characterization of Adsorbents

The morphology and structure of the adsorbents prepared were examined by applying varied methods of analysis. The functional groups that existed in the biosorbent and nanocomposite materials were identified by FTIR spectroscopy. SEM was conducted to trace the surface morphology and the pore structure of the adsorbents. The elemental composition of materials was identified with the help of EDX spectroscopy. To ascertain the crystalline nature of copper oxide nanoparticles used in the nanocomposite, XRD analysis was done.

### Batch Adsorption Experiments

Batch adsorption experiments were carried out in 250 mL conical flasks containing 25 mL of dye solution. The adsorption process was studied under different experimental conditions including pH, contact time, adsorbent dose, and initial dye concentration. The flasks were agitated to ensure proper mixing between the dye solution and adsorbent particles. After the desired contact time, the samples were filtered using filter paper to remove the adsorbent. The remaining dye concentration in the solution was determined using a UV-Visible spectrophotometer at the maximum absorption wavelength of the dye. All experiments were conducted in duplicate, and the average

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values were used for further analysis.

## Results and Discussion

### Effect of pH on Synozol Red Removal

The pH of the solution is important in the adsorption process by determining the ionization state of dye molecules as well as the charge of the surface of the adsorbent. The adsorption of Synozol Red was also examined in a range of pH of 2 to 8. The findings showed that the efficiency of dye removal declined with a rise in pH. The potato peel and CuO/PPNPs had removal efficacy of 69.9% and 72.6% at pH 2, respectively. But with increasing pH to 8, the potato peel removal rate decreased to 29.6% and CuO/PPNPs to 35.4%.

Higher adsorption observed in the conditions with acidic conditions may be explained by the protonation of functional groups on the adsorbent surface (Danish, Hashim, Ibrahim, & Sulaiman, 2013). When the pH involves a lower value, the adsorbent surface becomes positively charged, and this promotes the electrostatic attraction of the adsorbent and the negatively charged dye molecules. With the increase in the pH, the adsorption sites with a positive charge become minimized, which leads to low adsorption (Yan, Yang, Li, & Cheng, 2016).

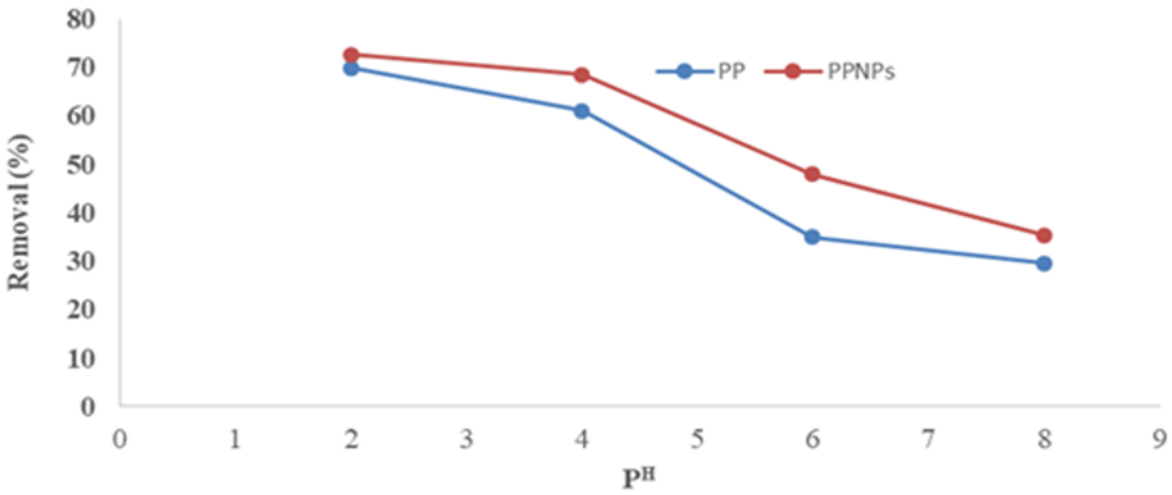


Figure 1: Effect of pH on SR removal

### Effect of Contact Time

An important parameter is the contact time, which defines the time taken to achieve adsorption equilibrium. It experimented with the adsorption of Synozol Red with a contact time between 1 hour and 24 hours. The findings showed that both adsorbents took a long time to remove the dye, and the contact time was also increasing. In the case of potato peel, the removal efficiency at 1 hour stood at 22.7%, and at 24 hours, 61.1%. In the case of the CuO/PPNP nanocomposite, the removal efficiency rose to 68.5% with time as compared to 34.5%. First, the adsorption took place very fast since numerous active adsorption sites were present on the adsorbent surface. The time of adsorption decreased with the adsorption process as the adsorption sites

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available were occupied. At a certain point, a balance was achieved, and no more adsorption could be attained (Hoseinzadeh, Samarghandi, McKay, Rahimi, & Jafari, 2014).

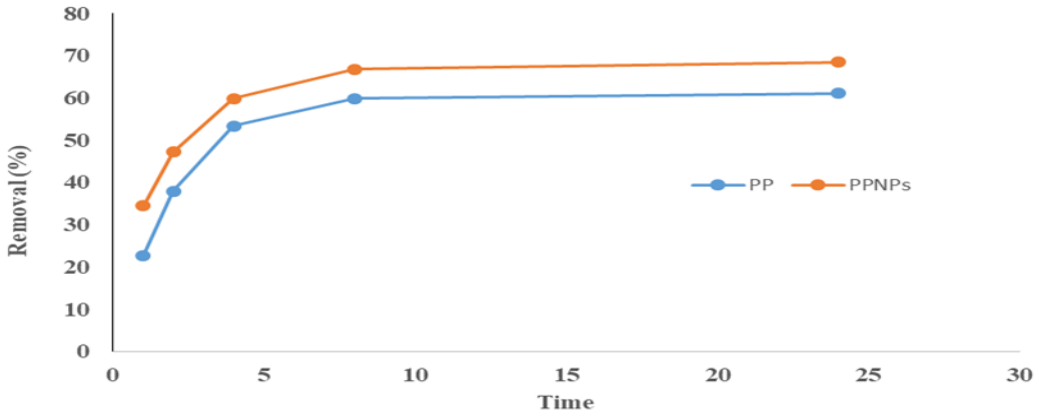


**Figure 2:** Effect of contact time

**Effect of Adsorbent Dose**

Dosage effect of adsorbent on the removal of the dye - The dosage of adsorbent was kept constant to 25 mg and the adsorbent dosage was varied between 25mg and 200mg added to the 25 mL solution. Experimental findings indicated that the removal of dye was better when the dose of adsorbent was increased. In the case of potato peel, the peel removal efficiency rose with peel concentration 14.9% at 25mg and 68.8% at 200mg. In the same way, the removal efficiency of the CuO/PPNP nanocomposite grew to 76.4% as compared to 32.8%. This could be attributed to the fact that as the adsorbent dosage increases, there is an increase in the dye removal capacity due to the availability of more adsorption sites and greater surface area to adsorb the dye. The high the concentration of adsorbent, the more available binding sites the dye molecules have, leading to high removal efficiency (Assefa et al., 2024).

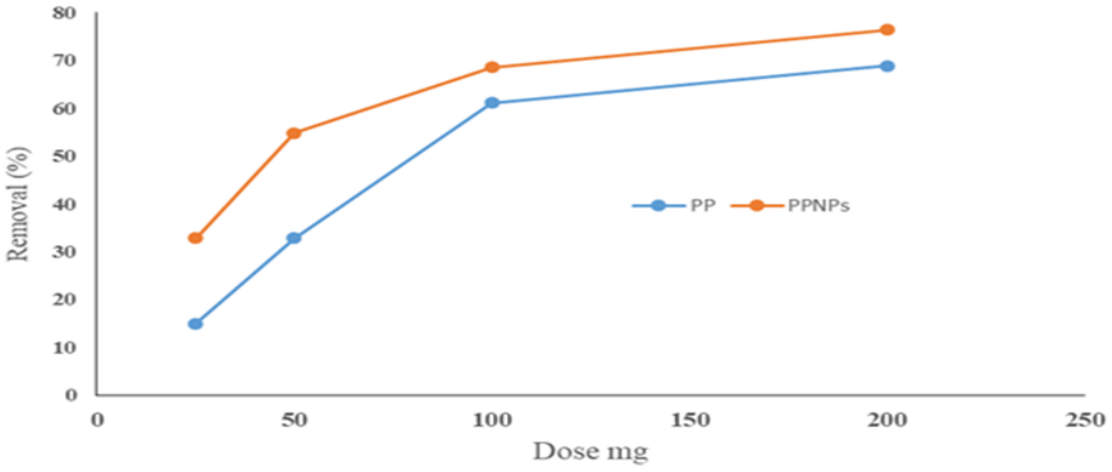


**Figure 3:** Effect of dose

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**Effect of Initial Dye Concentration**

Initial concentration of dye on adsorption, was determined by changing the concentration of dye, 25 ppm to 200 ppm. Both adsorbents had an increasing adsorption capacity with a rise in concentration of dye. In the case of potato peel, the adsorption capacity was found to go up with the concentration of the solution, which is 4.35 mg/g at 25 ppm and 25.35 mg/g at 200 ppm. For CuO/PPNP nanocomposite, adsorption capacity increased from 5.22 mg/g to 29.7 mg/g. Higher dye concentrations provide a stronger driving force for mass transfer between dye molecules and the adsorbent surface. This results in increased adsorption capacity at higher concentrations (Mary Ealias & Saravanakumar, 2019; Toor & Jin, 2012).

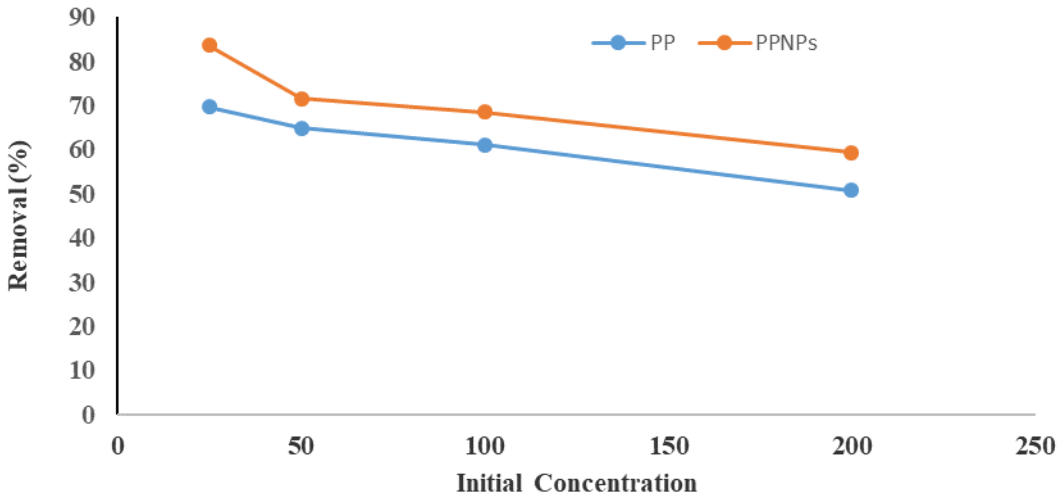


**Figure 4:** Effect of concentration

**Adsorption Kinetics**

The kinetics of the adsorption process were analyzed using pseudo-first-order and pseudo-second-order kinetic models. These models were applied to understand the mechanism and rate-controlling steps involved in the adsorption process. The experimental results showed that the adsorption data fitted better with the pseudo-second-order kinetic model compared to the pseudo-first-order model. This indicates that the adsorption process is primarily controlled by chemisorption, involving chemical interactions between dye molecules and functional groups present on the adsorbent surface. The pseudo-second-order model assumes that the adsorption rate depends on the availability of active adsorption sites and the interaction between adsorbate and adsorbent (Chowdhury & Saha, 2011; Lin & Wang, 2009).

**Adsorption Isotherm Analysis**

Adsorption isotherm models were applied to describe the equilibrium relationship between dye concentration in the solution and the amount of dye adsorbed on the adsorbent surface. The experimental data were analyzed using Langmuir and Freundlich isotherm models. The results showed that the adsorption data were better

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described by the Langmuir isotherm model, indicating monolayer adsorption on a homogeneous adsorbent surface. According to the Langmuir model, adsorption occurs at specific homogeneous sites within the adsorbent, and once these sites are occupied, no further adsorption occurs at that location. This suggests that the adsorption of Synozol Red onto the adsorbent surface takes place as a monolayer (Jeppu & Clement, 2012; Khayyun & Mseer, 2019).

## Conclusion

The current research has shown that potato peel, as well as CuO-modified potato peel nanocomposite, can be effectively utilized as the biosorbent in the knowledge of removing the Synozol Red dye in an aqueous solution. Several parameters governing the adsorption process, such as the pH, contact time, dosage of adsorbent, and the initial concentration of dye, were found to affect the adsorption process. The highest dye removal was obtained at acidic conditions and at pH 2 specifically, the adsorption efficiency of CuO/PPNPs was found to be 72.6%.

The contact time and the dosage of the adsorbent increased the adsorption capacity. The nanocomposite adsorbent displayed more adsorption efficiency than the use of potato peel wastes because the nanocomposite had copper oxide nanoparticles that enhanced the number of active adsorption sites. The kinetic analysis indicated that the adsorption process was best described using the pseudo-second-order model indicating that chemisorption was the dominant adsorption mechanism used. The Langmuir isotherm model was the most appropriate to illustrate equilibrium data, which showed that dye molecules were monolayered adsorbed onto the surface.

CuO/PPNP nanocomposite using potato peel waste, in general, is a cheap, eco-friendly, and effective adsorbent in the purification of dye wastewater. The possible future research can be based on regenerating the adsorbent and testing its effectiveness in the real systems of wastewater treatment in industries.

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