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Facile Synthesis of Carbon Dots from Chicken Feathers via Catalytic Hydrothermal Method for Photodegradation of Methylene Blue

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Abstract. Chicken feathers have a high keratin content and have the potential to be used to create novel materials, such as Carbon dots (C-dots). C-dots are zero-dimensional carbon materials that can cause fluorescence, making them useful as photocatalysts. A hydrothermal technique using hydrochloric acid as catalysis with various concentrations (2, 4, and 6 M) was designed to synthesize C-dots from chicken feathers to generate a crystalline carbon core. The C-dots show that the functional groups C-O, C=C, and O-H are present in the FTIR data, and the functional group C-H increases with acid content. UV-Vis results reveal an absorbance peak at 270 and 380 nm, indicating the presence of a C-dot core. The photoluminescence measurement results, which show a cyan luminescence emission intensity peak at 430 and 460 nm, strengthen the indication of C-dots formation. According to the photodegradation results, the C-dots sample reduced the methylene blue content at the CD-2 sample by up to 80%. The synthesized C-dots derived from chicken feathers are efficient and eco-friendly materials with the potential for wastewater treatment and environmental sustainability.

Keywords: Carbon dots, Catalytic hydrothermal, Chicken feather, Photodegradation

1. Introduction

Textile industries are key drivers of economic growth in many countries, including Indonesia, but they significantly contribute to environmental pollution. Textile industries produce highly colored effluent with hazardous pollutants discharged into aquatic resources [1]. Many synthetic dyes used in the dyeing process do not fully stick to textile Fiber and are released into rivers, lakes, and seas through wastewater. Dyes harm both the environment and human health. Heavy metals in textile dyes create pollutants that are portable with wastewater, persist in water and soil, and pose serious health risks to living organisms [2]. Dyes also reduce soil fertility and hinder photosynthesis in aquatic plants, creating toxic conditions for aquatic life [3]. Therefore, developing cost-effective and eco-friendly treatment methods for these pollutants is urgently needed.

On the other hand, poultry farm waste is becoming a big problem as the poultry industry grows and becomes a major contributor to economic prosperity. If handled inadequately, poultry waste can negatively affect the environment and human health [4]. The Indonesian poultry industry produces millions of tonnes of waste annually, making a sustainable management system necessary to turn waste into wealth [5]. Millions of tons of farm waste are created worldwide by the poultry industry, including feather waste. In addition to mitigating harmful environmental effects, a sustainable strategy for managing the waste from chicken farms opens up exciting business potential through waste processing and recycling [6]. Feather waste has a high carbon, nitrogen, sulphur, and lipid content, allowing further processing to create carbon sources like carbon dots [7]. Carbon dots can be employed as photodegradation material to remove textile contaminants. Figure 1 depicts a sustainable method of waste utilization and environmental remediation that includes transforming waste materials into useful resources while addressing environmental contamination.

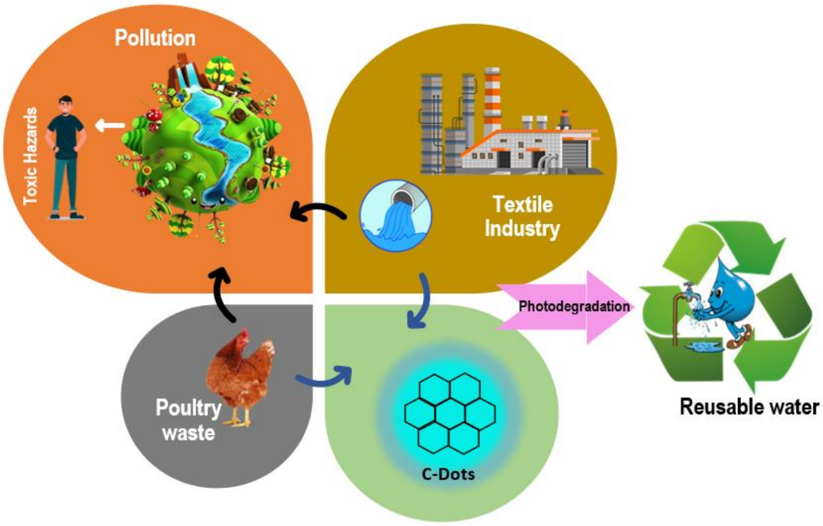

Figure 1. Sustainable method to waste utilization and environmental remediation

The development of high-performance carbon dots (C-dots) has attracted attention because of their possible use in several applications, including sensors, bioimaging, and photocatalysis [8]. With their unique electrical structure and tuneable bandgap, carbon dots are particularly useful for photocatalytic reactions. Various biomass sources can be used to synthesize carbon dots, providing a sustainable and environmentally beneficial method [9].

Recent research has shown that the optical characteristics of carbon dots can be tuned by varying the synthesis conditions. The hydrothermal synthesis of carbon dots from biomass and hydrochloric acid is a promising approach to developing high-performance C-dots [10]. The optical properties of the resulting carbon dots can be tailored to maximize the photocatalytic efficiency by optimizing the synthesis conditions, such as temperature, reaction time, and acid concentration [11]. Therefore, this study synthesized carbon dots from poultry feather biomass waste using the hydrothermal method. We investigated different concentrations of acid chloride (2, 4, and 6 M) to analyze the effect of the process on the properties of C-dots. These carbon dots were then applied to degrade methylene blue (MB) dye waste. The objective was to explore an efficient and eco-friendly way to degrade dye waste using waste-derived carbon dots, contributing to better wastewater treatment and environmental sustainability.

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2. Material and Methods

Green synthesis of C-Dots material from chicken feathers via catalytic hydrothermal method. Chicken feather waste was collected from a local poultry market (Malang, Indonesia) and washed with distilled water to remove contaminants. 1 gram of chicken feather powder was combined with 40 ml of distilled water and 20 ml of HCl at various concentrations of 2, 4, and 6 M. The solution was placed in a Teflon line autoclave and processed at 200°C for 6 hours. The collected materials were then centrifuged and filtered using a 0.22 micro membrane. FTIR, UV-Vis spectrometry, photoluminescence, and UV light were used to characterize C-dot samples. The methylene blue (MB) degradation test was performed using a homemade photocatalyst reactor, and the decrease in sample degradation concentration was measured using a UV spectrophotometer.

3. Results and Discussion

3.1 Structural Properties

Figure 2 displays the FTIR spectra of C-dots from chicken feathers. The absorbance peak at 670 cm^{-1} indicates C=N bonding. The C-O stretching vibrations, associated, were expected to be in the 1122-1250 cm^{-1} range. The C = C vibration causes the strong bands at 1449-1505 cm^{-1}. The occurrence of a C = C peak implies that the C-dots are graphitic. The strong C = O bond can be found around 1690 cm^{-1}. This study suggests that C-dots have a lot of oxygen on their surface and are particularly soluble in water. The peak at 3470-3483 cm^{-1} is related to O-H bonding, representing the hydroxyl group on the surface of C-dots. Its hydroxyl group can increase the hydrophilicity of dots. Additionally, the HCl concentration increased C-H vibration at 1402 cm^{-1}. Functional group C=C is the composer of $\pi \rightarrow \pi$ * (core). While for function group O-H, C=O, and C-O are the composers of $n \rightarrow \pi^*$ (surface state). The typical CDs are formed by the atomic bonds C, O, and H of various functional groups, following the general chemical structure of CDs [12].

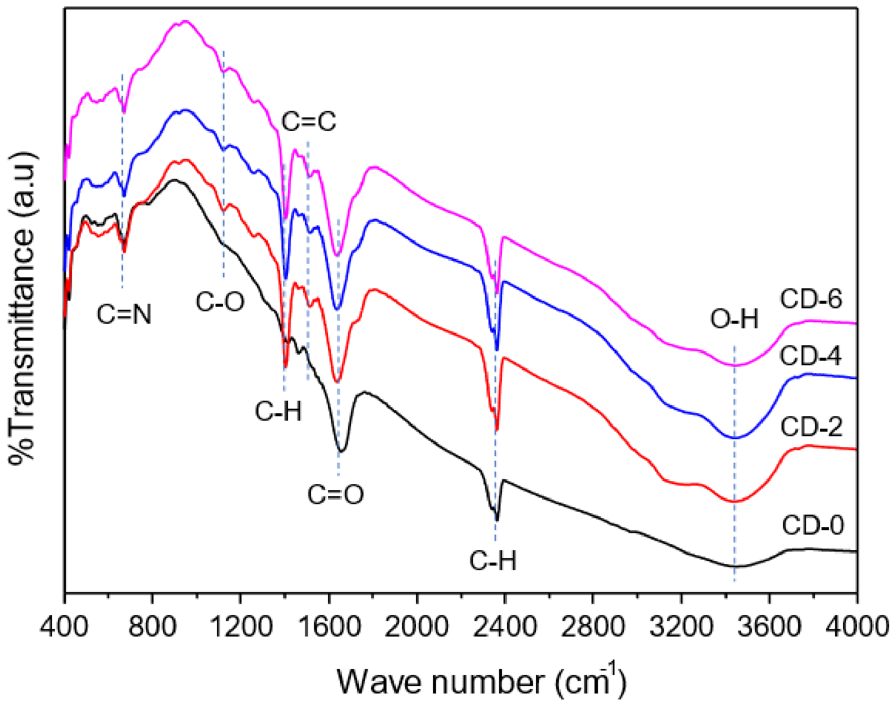

Figure 2. FTIR spectra of C-dots

3.2 Optical Properties

The optical characterization of C-dot after catalytic hydrothermal used UV-Vis spectroscopy and photoluminescence. Optical qualities play an important role in determining C-dot fluorescence properties. The UV-vis absorption spectra (Fig. 3a) of biomass C-dot in aqueous solution indicated a prominent peak in the UV region (~230 and ~280 nm), which corresponds to the transitional bond n→π* of the C-O band and the π→π* transition of the conjugated C-C band, that could be the mechanism of electron transition within the aromatic π orbital. These findings are similar to previous studies [13,14]. The increase in HCl content in hydrothermal processes impacts energy gap values. Figure 3b demonstrates that the energy gap reduces as the concentration of HCl increases, resulting in varying energy gaps of 3.25, 2.88, 2.82, and 2.80 for samples CD-0, CD-2, CD-4, and CD-6, respectively.

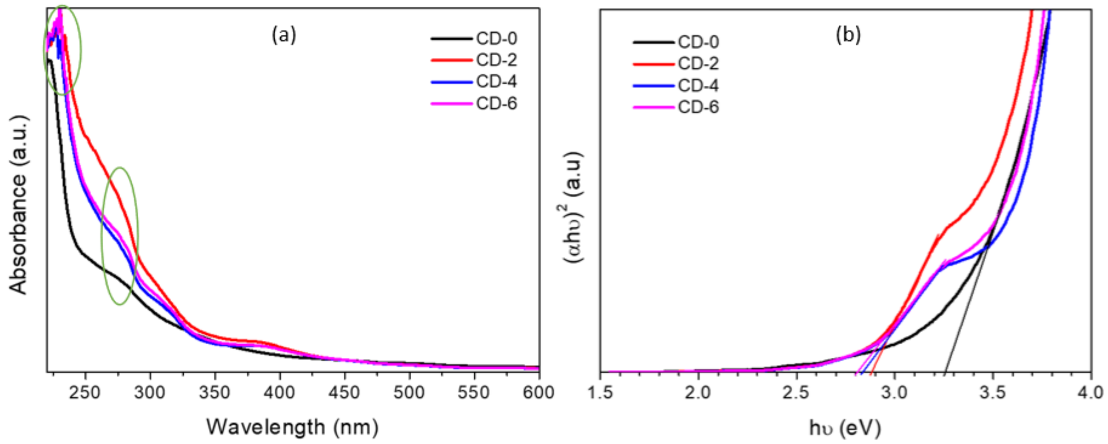

Figure 3. (a) Absorbance spectra; (b) energy gap of C-dots

In Fig. 4, photoluminescence plots were used to analyze the fluorescence properties of carbon dots generated using a catalytic hydrothermal process at 200 °C for various HCl concentrations. Regardless of reaction circumstances, all water dispersions after hydrothermal processes show a blue emission centered at around 400 nm, with a single excitation band at 365 nm. The emission spectrum of the C-Dots also indicates that the energy shift of the C-Dots gap to the region of the light spectrum appears to affect various photocatalytic applications positively. This shift means C-Dots may successfully absorb and utilize visible light, making them appropriate for pollutant degradation, water splitting, and other environmental cleanup operations. The ability to modify the photoluminescent features of C-Dots by varying HCl concentrations enhances their flexibility and potential in advanced photocatalytic systems.

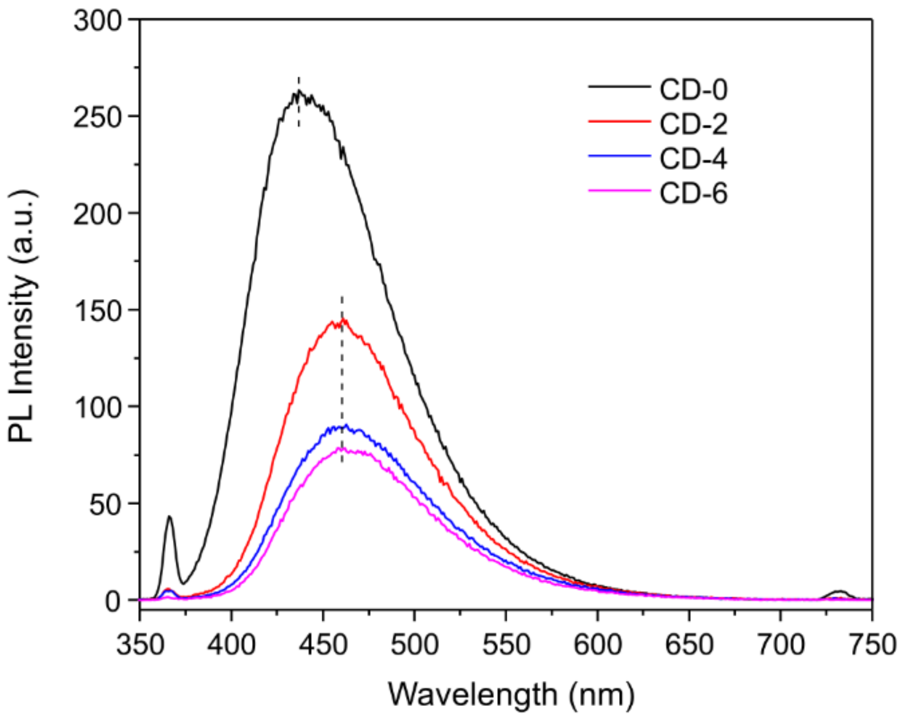

Figure 4. Photoluminescent spectra of C-dots

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3.3 Photocatalytic degradation of Methylene Blue (MB)

The photocatalytic activity tests were designed to evaluate the performance of C-Dots in degrading methylene blue under different conditions, as shown in Fig. 5. Photos of MB dyes before and after adding C-Dots and UV light clearly show the transformation from their original state to a colourless one under the catalyst and light. In just 30 minutes, the absorption peaks of the dyes significantly decreased. This research demonstrates that C-dots synthesized with HCl and UV light can break down MB dyes, making this process important for wastewater treatment and environmental cleanup.

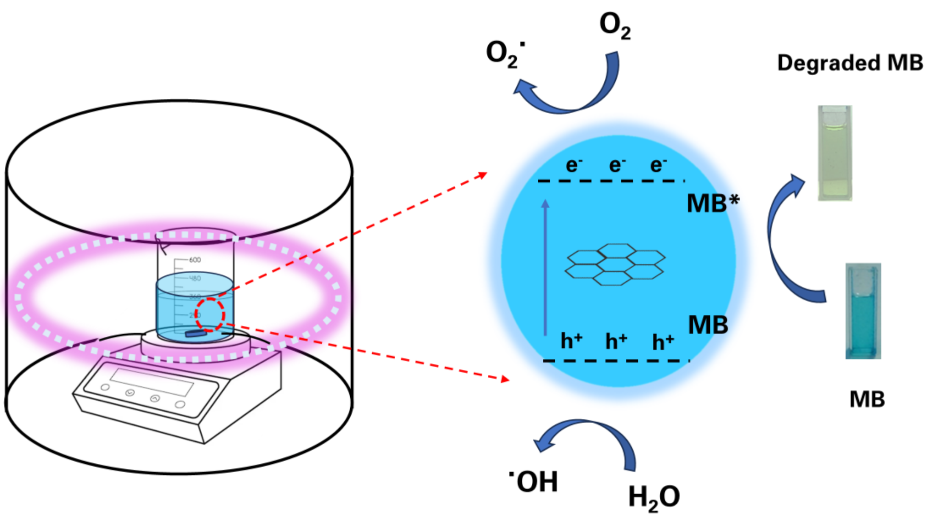

Figure 5. Scheme of Photocatalytic process

The light stage involved irradiating the samples with UV light, which activates the photocatalytic properties of the C-Dots. In contrast, MB served as a control to measure the baseline degradation without C-dots as catalysts. The degradation efficiency of MB dyes was evaluated by the peak absorbance intensity at different time intervals while keeping the concentration of the MB and C-dots constant. The results in Figure 6 demonstrated that adding C-dots gradually decreases MB concentration with time. It was observed that CD-2 significantly enhanced the photocatalytic efficiency of the C-Dots under UV light, achieving an impressive efficiency of 80.93% within 105 minutes.

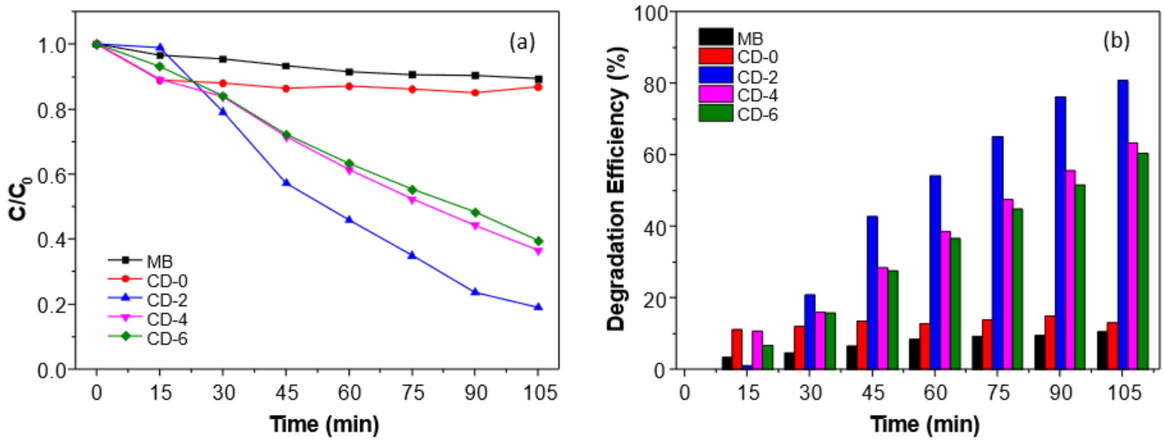

Figure 6. The degradation efficiency of MB

C-Dots' high photocatalytic efficiency is due to their ability to absorb UV light and many active centres. Enhanced light absorption excites electrons in C-Dots and creates electron-hole pairs (e^--h^+). Surface defects on C-Dots capture electrons, preventing recombination and allowing efficient photoreaction charge transfer [15]. Fast electron transfer between CQDs and surface-adsorbed MB improves e^--h^+ separation. Others are taken by dissolved oxygen, forming superoxide radicals ($^{\bullet}O_2^-$), that degrade MB. Photosensitized h^+ reacts with surface-adsorbed water to produce hydroxyl radicals ($^{\bullet}OH$) or directly interact with dye molecules to form organic radicals. Surface groups like -OH and -COOH are active sites for photocatalytic reactions through H-bonding with MB dye [16].

4. Conclusion

In this study, hydrochloric acid was used as a catalytic agent in the hydrothermal method to promote the synthesis of carbonization. The hydrothermal technique with varying concentrations of hydrochloric acid (2, 4, and 6 M) effectively produces C-dots. FTIR analysis confirms the presence of functional groups C-O, C=C, and O-H, with increased C-H groups at higher acid concentrations. UV-Vis spectroscopy reveals 270 and 380 nm absorbance peaks, indicating C-dots formation. Photoluminescence measurements show cyan emission peaks at 430 and 460 nm, further validating C-dots formation. The C-dots, particularly the CD-2 sample, demonstrate significant photocatalytic activity, reducing methylene blue content by up to 80%. This research highlights a sustainable approach to converting chicken feathers into useful nanomaterials, reducing waste, and promoting recycling. The synthesized C-dots show promising potential in environmental applications, particularly in the photodegradation of methylene blue.

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