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Textile Wastewater Treatment Using Ultrasonication Based Catalytic Treatment

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Textile Wastewater treatment using ultrasonication based catalytic treatment

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***Abstract*— Managing wastewater from textile industries presents a formidable challenge due to its intricate makeup and harmful effects on the environment. In this study, we address this challenge by employing ultrasonication-based catalytic treatment processes to treat synthetic textile wastewater. Through optimization using Central Composite Design (CCD), we have identified crucial factors for maximizing pollutant removal. These include maintaining a pH of 5.8, utilizing a catalyst dosage of 735.12 mg/L, starting with an initial pollutant concentration of 20.56 mg/L, treating for 65.83 minutes, and achieving a predicted removal percentage of 64.44%. This analysis emphasizes the importance of these parameters in achieving efficient wastewater treatment in textile industries.**

Keywords— Textile wastewater treatment, Ultrasonication, Catalysis, Catalyst dosage, Treatment duration

Introduction

Textile wastewater management stands as a pivotal challenge in contemporary industrial practices, necessitating a comprehensive understanding of its profound environmental impact and intricate composition. The present landscape underscores the exigent demand for efficacious treatment methodologies to ameliorate the deleterious repercussions of textile effluents on aquatic ecosystems, soil quality, and public health. Within textile wastewater, a plethora of pollutants originating from various stages of textile production, encompassing dyeing, finishing, and washing processes, intertwines to create a complex mixture. These pollutants span a spectrum, encompassing organic dyes, heavy metals, suspended solids, and chemical additives, each bearing the potential to permeate natural water bodies and soil, thereby posing considerable risks to aquatic organisms and human well-being alike. Rhodamine G, a commonly used fluorescent dye in textile processes, is among the organic dyes contributing to the complexity of textile wastewater pollution [1].

It is within this context that innovative treatment methodologies, such as the sol-gel method for catalyst preparation and ultrasonication for wastewater treatment, have emerged as promising avenues, offering the potential to augment the efficiency and sustainability of textile wastewater treatment processes [1]. The sol-gel method stands as a versatile approach, heralding a paradigm shift in the synthesis of catalysts endowed with tailored properties, thereby facilitating the degradation of organic pollutants and the removal of heavy metals from textile effluents through advanced oxidation processes. Through the sol-gel process, catalysts are meticulously crafted, leveraging the manipulation of precursor materials and reaction conditions to yield catalysts characterized by high catalytic activity and stability. These catalysts, meticulously synthesized through the sol-gel method, serve as potent agents in advanced oxidation processes, paving the path for the degradation of recalcitrant organic pollutants encountered within textile wastewater. Furthermore, the versatile nature of the sol-gel method enables the precise engineering of catalysts, ensuring optimal performance and compatibility with diverse textile wastewater compositions. As such, the sol-gel method emerges as a pivotal tool in the arsenal of textile wastewater treatment, offering a sustainable and efficient pathway towards environmental remediation [2].

In tandem with the sol-gel method, ultrasonication emerges as a complementary treatment technique, harnessing the power of high-frequency sound waves to induce physical and chemical effects within wastewater. Ultrasonication represents a non-invasive and energy-efficient approach, fostering the disruption of suspended solids and the degradation of organic pollutants within textile wastewater. The application of ultrasonication initiates a cascade of physical and chemical processes, instigating the cavitation phenomenon wherein the formation and subsequent collapse of microbubbles generate intense local pressures and temperatures. This phenomenon, in turn, precipitates the disintegration of suspended solids and the fragmentation of organic pollutants, thereby enhancing their susceptibility to subsequent treatment processes. Moreover, ultrasonication engenders a reduction in particle size and an increase in surface area, facilitating the interaction between pollutants and treatment agents. Thus, ultrasonication emerges as a versatile and eco-friendly tool in the arsenal of textile wastewater treatment, offering a viable pathway towards enhanced pollutant removal and environmental remediation [3].

In essence, the integration of the sol-gel method for catalyst preparation and ultrasonication for wastewater treatment signifies a transformative approach towards textile wastewater management, encapsulating the synergistic amalgamation of cutting-edge technologies. Through the strategic utilization of these innovative treatment methodologies, sustainable solutions can be cultivated, effectively addressing the multifaceted challenges inherent in textile wastewater treatment. Furthermore, the adoption of these advanced treatment techniques not only underscores a commitment to environmental stewardship but also heralds a paradigm shift towards the realization of a circular economy within the textile industry. As such, the confluence of the sol-gel method and ultrasonication represents a testament to the inexorable march towards sustainable industrial practices, fostering the preservation of environmental resources and the cultivation of a harmonious coexistence between industry and nature [4].

I. MATERIAL AND METHODOLOGY

A. *Materials*

The materials utilized in the research include marble waste powder obtained from the marble industry, along with chemical reagents required for catalyst synthesis and wastewater characterization. These reagents include hydrochloric acid (HCl), calcium chloride ($CaCl_2$), sodium hydroxide (NaOH), and distilled water. we have prepared textile wastewater with the help of Rhodamine G.

B. *Methodology*

The sol-gel process is a versatile method for synthesizing nanocomposite materials with precise control over their properties and structures at the nanoscale. It involves hydrolysis of metal alkoxides or metal salts to form metal hydroxides or metal oxide clusters, followed by polycondensation to form longer chains or networks. Gelation transforms the solution into a gel-like state with a three-dimensional network, and aging stabilizes the gel through condensation reactions.

Marble waste, a byproduct of the marble industry, is utilized in the waste powder which undergoes thorough cleaning to remove impurities, first rinsed with tap water and filtered to remove solid particles, then purified with Demineralized Water to eliminate remaining impurities. After purification, the powder is filtered again to obtain a refined product. Drying is conducted in a hot air oven at 120°C for 2 hours to evaporate moisture, yielding dry powdered marble waste. This prepared material is then ready for further experimentation and analysis.

Chemical reaction:

(I) $CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$

(II) $CaCl_2 + 2NaOH = Ca(OH)_2 + NaCl$

(III) $Ca(OH)_2 + Heat = CaO + H_2O$

These reactions involve calcium compounds: In the first reaction, calcium carbonate ($CaCO_3$) reacts with hydrochloric acid (HCl) to produce calcium chloride ($CaCl_2$), water (H_2O), and carbon dioxide (CO_2). The second reaction involves calcium chloride ($CaCl_2$) reacting with sodium hydroxide (NaOH) to form calcium hydroxide ($Ca(OH)_2$) and sodium chloride (NaCl). Lastly, in the third reaction, calcium hydroxide ($Ca(OH)_2$) undergoes thermal decomposition when heated, resulting in the formation of calcium oxide (CaO) and water (H_2O).

C. *Experimental Step up*

The preparation procedure, depicted in Figure 1, involves several steps Solid $CaCO_3$ is dissolved in dilute HCl and dried at 120°C for 2 hours. The resulting solid is then powdered and sieved using a 100µm sieve size. Marble waste powder (MWP) is dissolved in 1M HCl, and 1M NaOH is slowly added to the mixture. After filtration, the filtrate is cleaned with distilled water. The filtered precipitate is dried at 60°C for 24 hours, followed by calcination at 900°C for 1 hour to obtain crystalline CaO (shown in figure 2).

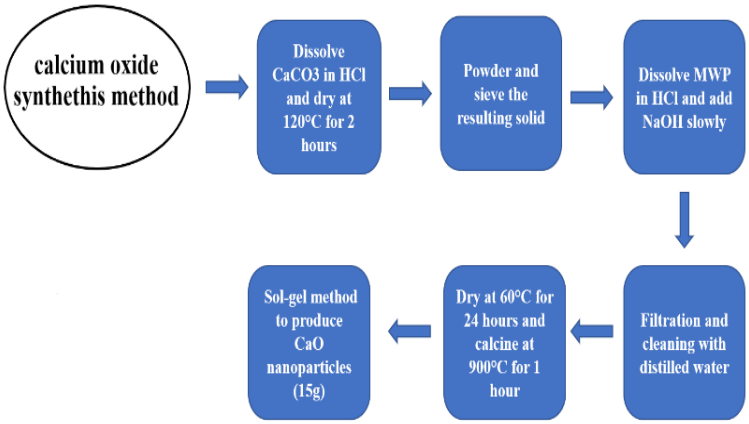


Figure 1Experiment procedure

Figure 2 Methodology

D. *Characterization of Catalyst and textile wastewater*

Characterization techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD) analysis will be employed to analyze the morphology, crystal structure, surface

chemistry, and specific surface area of the catalysts. The experimental wastewater sample was sourced from the textile wastewater system. Initial characterization involved measuring with the help of UV spectrophotometer to find Rhodamine G of this sample. Prior to commencing the studies, the samples were allowed to equilibrate to room temperature, and pH levels were carefully maintained.

E. Experimental Design Using CCD tool For Catalytic Treatment of Textile water

The various operating parameters such as pH (2-10), time (40-100min), Catalyst dosages of CaO (200-1000 mg/L) and Initial concentration (10-30 mg/L) are optimized during the catalytic treatment of treated textile water as shown in Table 1 By systematically varying the parameters, we can gain insights into the relationship between these variables and the behavior of the chemical reaction or process.

Table 1: Parameters during Catalytic Treatment

Parameter			
X_1	X_2	X_3	X_4
pH	Catalyst dosage (mg/L)	Initial concentration (mg/L)	Time (minute)
2	200	10	20
4	400	15	40
6	600	20	60
8	800	25	80
10	1000	30	100

II. Result and Discussion

A. Characterization of CaO

Characterization study such as XRD and SEM of synthesized Cao was performed

a. XRD analysis

X-ray diffraction (XRD) analysis characterized the crystallographic structure of the nano-catalyst designed for enhanced catalytic (shown in figure 3) [5]. Utilizing a high-resolution X-ray diffractometer with Cu Kα radiation, operating at 40 kV and 30 mA, XRD patterns were obtained in the 2θ range of 10° to 80°. The step size was 0.02°, and scanning occurred at a speed of 2° per minute [6]. The analysis, facilitated by appropriate software, identified crystalline phases, determined lattice parameters, and elucidated the crystal structure and phase composition. Rietveld refinement analysis can further refine the crystal structure and provide accurate information on lattice parameters and crystallite sizes. These XRD insights are crucial for understanding the structural properties of the nano-catalyst, optimizing its performance, and informing its application in catalysis, wastewater treatment, and environmental [7].

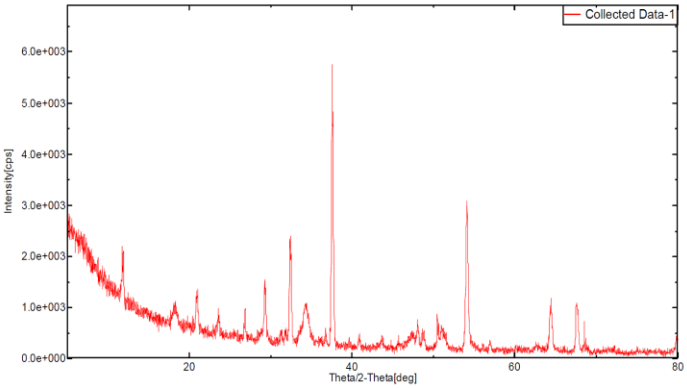


Figure 3 XRD Analysis

b. SEM Analysis

Scanning Electron Microscopy (SEM) analysis was conducted to investigate the morphology and surface characteristics of the developed nano-catalyst (shown in figure 4) [8]. The SEM images were obtained using a high-resolution scanning electron microscope operated at an accelerating voltage typically ranging from 5 kV to 30 kV [9]. Prior to imaging, the nano-catalyst samples were prepared by depositing a thin layer of the powdered material onto a conductive substrate, such as a carbon tape or a silicon wafer, followed by sputter-coating with a thin layer of conductive material, typically gold or platinum, to enhance sample conductivity and minimize charging effects during imaging [10].

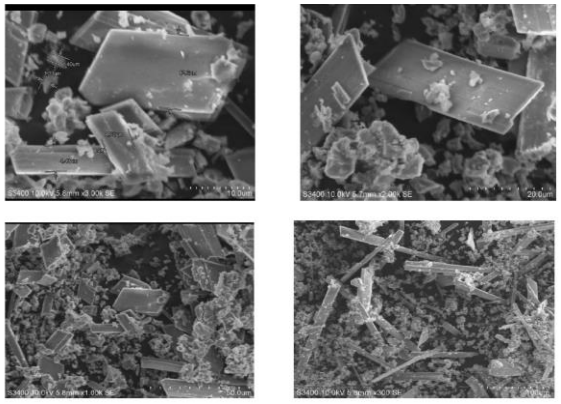
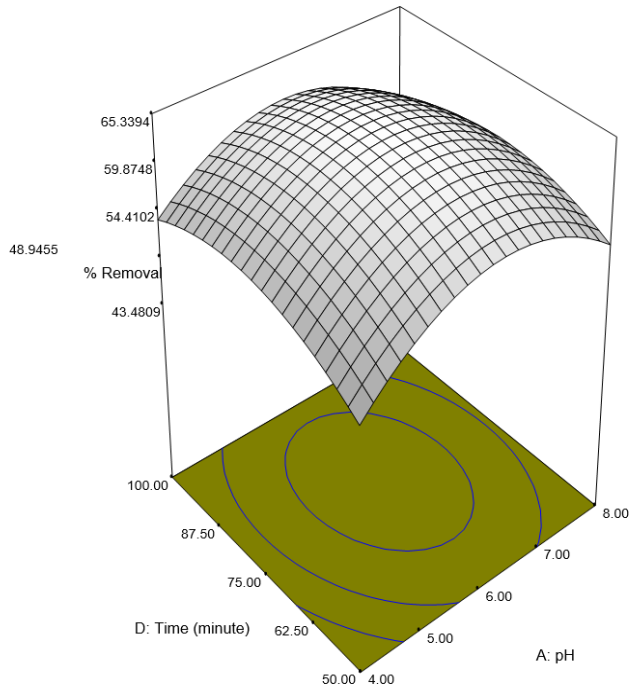


Figure 4 SEM Analysis

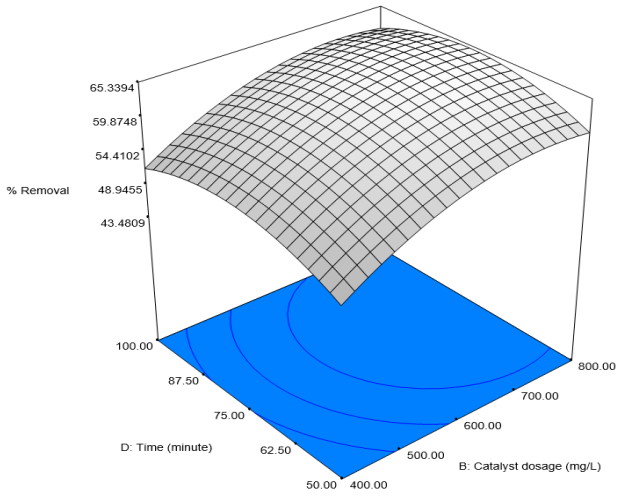
B. Effect of pH, time and dosage of CaO % Dye removal

The effect of pH (2-10), time (20-100), and dosage (200-1000 mg/L) during catalytic treatment was investigated for %Dye removal as shown in figure 5(a, b & c). Maximum %Dye removal was observed 64.44% at optimum operating conditions

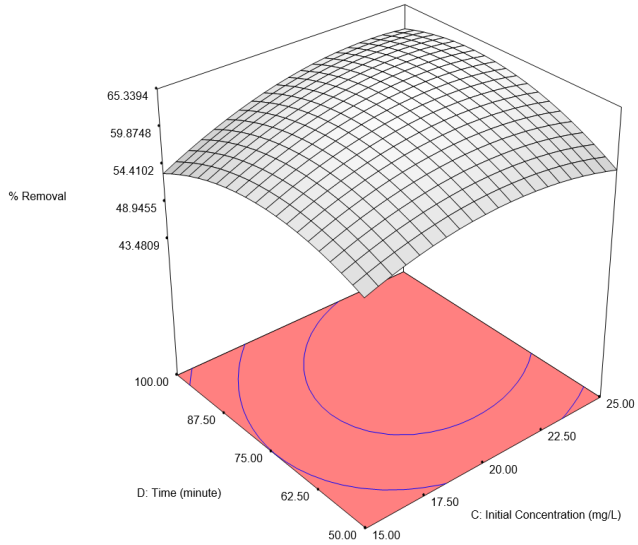
as mentioned in Table 2. Optimum amount of catalyst gives maximum removal efficiency as shown in figure



(a)



(b)



(c)

Figure 5 (a) Effect of pH and time duration on Dye removal (b) Effect of time and catalyst dosage on Dye removal (c) Effect of time and Initial Concentration on Dye removal

C. Optimization

The Table 2 outlines optimal conditions for a catalytic treatment process, as determined through software prediction. Catalytic treatments utilize specialized catalysts to expedite chemical reactions, typically aimed at mitigating pollutants or transforming them into less harmful forms. Key factors highlighted include pH, representing the solution's acidity or alkalinity, which significantly influences catalyst performance; catalyst dosage per liter of solution; initial concentration of the pollutant; treatment duration; and the percentage of pollutant removal. Analysis of the data indicates optimal conditions for maximum pollutant removal, including a pH of 5.8, catalyst dosage of 735.12 mg/L, initial concentration of 20.56 mg/L, treatment duration of 65.83 minutes, and a predicted removal percentage of 64.44%, with a slight variance observed in the test run at 62.1%.

It's noted that software predictions may slightly differ from actual results due to real-world variations. Additional information required for a comprehensive understanding includes the specific pollutant targeted and the type of catalyst employed, as different pollutants respond diversely to catalytic processes, and catalysts can be customized for specific pollutants. Further details on the treatment process would facilitate a more refined explanation.

Table 2: Predicted optimum values during Catalytic Treatment

pH	Catalyst dosage (mg/L)	Initial concentration (mg/L)	Time (min)	% Removal	
				CCD (Pre.)	Test Run
5.8	735.12	20.56	65.83	64.44	62.1

III. Conclusion

In conclusion, catalytic treatments play a crucial role in accelerating chemical reactions, specifically targeting the mitigation of pollutants or their conversion into less harmful forms through the application of specialized catalysts. The factors identified in this study, such as pH, catalyst dosage, initial pollutant concentration, treatment duration, and pollutant removal percentage, are integral in determining the optimal conditions for maximizing pollutant removal efficiency. The analysis of the presented data underscores the significance of these factors, highlighting specific conditions conducive to achieving maximum pollutant removal, notably a pH of 5.8, catalyst dosage of 735.12 mg/L, initial pollutant concentration of 20.56 mg/L, treatment duration of 65.83 minutes, and a predicted removal percentage of 64.44%. However, a slight variance between predicted and actual removal percentages, as observed in the test run at 62.1%, emphasizes the importance of further research to elucidate the underlying factors contributing to this deviation. Such insights will be instrumental in refining catalytic treatment processes and optimizing their effectiveness in addressing environmental pollution challenges.

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