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(Reconciliation with the Environment)

Sirte, October, 14, 2025

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Environmental Pollution and Challenges of Environmental Sustainability (EPESC),
Oct. 14, 2025

Highly Green Synthesis of Pure ZnO Nanoparticles as a Solid Oxidant for Enhanced Photodegradation of MB as Organic Contaminants

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***Abstract*:** This study synthesized ZnO NP powder using a straightforward, cost-effective, safe, green synthetic approach. The purpose of synthesizing ZnO NPs using plant extracts was to study their morphology, size of nanoparticles, and photodegradation activity of these nanomaterials in Methylene Blue (MB) dye under solar energy. The EDX analysis of nanoparticle powder was prepared to reveal the existence of Zn and O elements. The FESEM experiment has shown that the ZnO nanoparticles have an approximately circular structure with a size of 15.51 nm. Also, the shapes of those nanoparticles shield particles of varying shapes. Such semiconductor oxide nanoparticles possess unique properties to break down a water pollutant, specifically MB with ZnO nanoparticles.

Introduction

Water is one of the worthiest sources, so water plays an essential role in sustaining life and keeping the environment safe. Water sustains ecosystems by providing critical habitats for aquatic and terrestrial species, supporting biodiversity (Asefa et al., 2024). It plays a key role in nutrient cycling and soil health, which promotes plant growth and sustains food webs (Karelitz, 2020). Effective water management practices, including conservation and pollution control, are crucial for preserving clean water resources for both human use and ecological balance (Bartram et al., 2014). Recognising the imminent threat to our health and aquatic environments is vital. Introducing organic or inorganic chemicals, including heavy metals and organometallic compounds, has become rampant in our water bodies. Our marine ecosystems are seriously jeopardised due to various industries' discharge of hazardous chemicals. One of the most essential and dangerous water pollutants, Chemical dyes and

aromatic compounds utilised in producing goods such as paper, textiles, plastics, cosmetics, and leather, are regrettably not only harmful to humans but also infiltrate natural ecosystems when not managed properly (Tkaczyk et al., 2020). Organic dyes present significant environmental risks due to their stability, rendering them non-biodegradable. Research indicates that more than 10% of organic dyes persist in wastewater when not entirely bonded with the intended fibres, substantially contributing to pollution (Al-Tohamy et al., 2022). Their widespread application across multiple sectors, including food, cosmetics, pharmaceuticals, and printing ink, exacerbates this problem.

Different approaches like filtration, absorption, ion exchange, and photodegradation remove organic dyes from polluted water. Photocatalysis, on the other hand, is a more efficient way to remove organic pigments (Tkaczyk et al., 2020; Al-Tohamy et al., 2022). Photocatalysis uses a photocatalyst, for instance, ZnO, which releases reactive species that can attack the organic dyes, thus aiding in their degradation. The benefit of this method is that it can produce the conversion of dyes to harmless substances, like CO2 and H_2O, as byproducts (Yadeta Gemachu & Lealem Birhanu, 2024). Applying plant extracts for different purposes has numerous benefits, such as being readily available, simple to process, and possessing many interlocutors. Despite having a range of secondary polls with a specific ability to reduce, plant extracts can be effectively utilised as reducers and installers of environment-friendly nanoparticles (NPS) (Nemma & Sadeq, 2023). These characteristics make plant extracts a favourable option compared to the other vital approaches (Bitwell et al., 2023).

The goal of this work is to green synthesise ZnO Nanoparticles Using the plant extracts and study the photodegradation efficiency of photocatalyst in an aqueous solution under sunlight irradiation to remove the methylene blue dye as an organic pollutant (Tkaczyk et al., 2020).

Experimental

Experimental site

The photocatalyst was synthesized in the Biochemistry Laboratory, Faculty of Medicine, University of Sirte. The USAINS Biomics Laboratory studied chemical composition determination and exploration, and the Nano-Optoelectronics Research Laboratory, USM Penang, Malaysia, studied surface morphology.

Chemicals

All chemicals in this thesis from Chemical companies were used in pure form without further purification.

99% ethanol, Zinc Acetate, sodium hydroxide, and Technical Methylene blue dye (MB). Wild *Thymeala Hirsuta* leaves were gathered from the Dhehir region in Sirte City. All the glass apparatus to be used in the experiment was cleaned thoroughly; for example, it was rinsed with distilled water (DW) and ethanol twice and oven-dried before use.

Thymeala hirsute - Extract Preparation

It initially produced the Thymeala hirsute extract by washing and cutting the leaves and roots, and blending them after drying them with a mixer into small pieces. Then, 5 g of Thymeala hirsute powder was mixed with 100 ml of DI water, boiled for 30 min at 50 °C, and placed on a magnetic stirrer. After that, the mixture was cooled to room temperature, and the extract,

connected to the vacuum pump device, was filtered with Whatman No. 1 filter paper (Bitwell et al., 2023; Bordbar & Mortazavimanesh, 2017; Nemma & Sadeq, 2023).

Green synthesis of pure ZnO nanoparticles

Synthesis of ZnO NPs through the green method, with some modifications. 50 mL of $Zn(CH_3CO_2)_2 \cdot 2H_2O$ solution (0.5 M) was measured and poured into a 500 mL beaker. A 50 ml of *Thymeala hirsuta* extract (light green) was incorporated into the Zinc acetate solution at room temperature, a drop at a time. The pH was adjusted to 12 by adding a sufficient 1M NaOH solution. The solution was stirred for four hours at 50°C to obtain a deep yellow paste solution, followed by filtration. Meanwhile, the colour changes of the aqueous solution from light yellow to pale white indicated the reduction of zinc salt to ZnO NPs.

The resulting filtrate was washed with distilled water and ethanol and then dried in the oven (100°C) for two hours. The obtained paste was further transformed in the ceramic crucible and annealed at 700°C for six hours, resulting in a light white powder. Lastly, the resulting samples were ground down into fine white powders with a mortar and stored for characterisation (Bordbar & Mortazavimanesh, 2017; An et al., 2024; Dulta et al., 2022).

Characterisation Methods:

Study the nanoparticle powder's morphology, shape, size, and Elemental Composition. They were examined using field emission electron microscopy SUPRA55 (CARL ZEISS, Germany). EDAX analysis of nanoparticle powder was performed on a SUPRA55 (CARL ZEISS, Germany) using FESEM equipped with an EDAX attachment (Mourdikoudis, Pallares, & Thanh, 2018; Lin et al., 2014).

Study of Photocatalytic Degradation of Organic Pollutants

The performance of the photocatalyst was estimated by measuring the photodegradation of methylene blue dye, an organic contaminant in water. The test work was carried out under direct sunlight in sunny weather conditions using a modified procedure as per reference (Samadi et al., 2016).

Dissolve 10 mg of methylene blue dye in 1 litre of distilled water. The transfer of 100 ml of the dissolved dye solution to 250 ml was done. 60 mg of the photocatalyst was added to it.

The pH of the mixture was adjusted to 12 by stirring for 30 min in the dark condition at room temperature until the adsorption-desorption equilibrium was achieved. Before being exposed to sunlight, the photocatalytic activity of ZnO NP powder was tested in dark conditions using UV-vis spectrophotometry and recorded at zero min. When the solution was exposed to sunlight for 140 minutes, the dye degradation efficiency was calculated by the relation in the equation below:

Degradation Efficiency (%) = $(A_o - A_t)/A_o * 100$

Where A_o and A_t are the absorbance of the dye solution before and after photocatalytic activity (Bartram et al., 2014).

Results and discussion

EDAX Study

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The EDX study shows that the prepared sample through green synthesis contains oxygen and zinc. EDX The obtained spectrum indicated the presence of oxygen and zinc in the prepared sample, whereas the sharp peaks of the EDX studies show crystalline structures of the synthesised nanoparticles. The vigorous intensity and narrow width of the ZnO diffraction peaks indicate that the prepared materials are highly crystalline with few differences resulting from the divergence in the chemical contents, as shown in Fig. 1, and the atomic% % of the elements present in the sample is summarised in Table 1; such results are in good agreement with the previous literature (Yadeta Gemachu & Lealem Birhanu, 2024; Bitwell et al., 2023).

Table 1. The atomic% of the elements present in the sample.

Element	Atomic%
O	44.3
C	2.25
Zn	53.45
Total	100

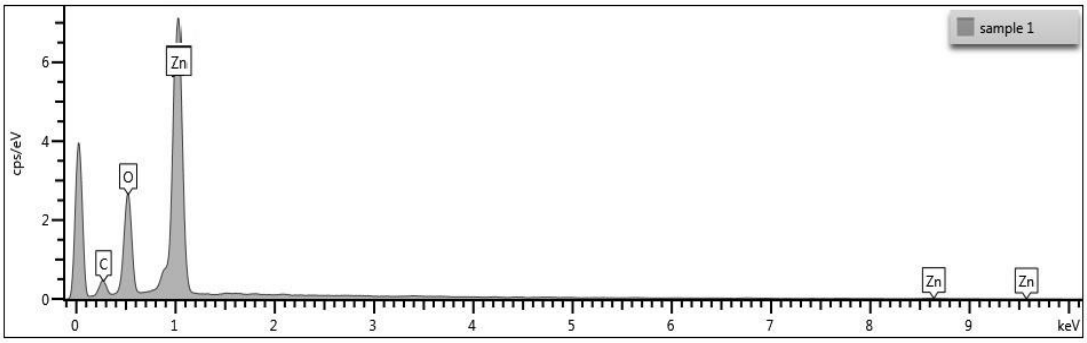

Figure 1. EDX spectrum of green synthesis of ZnO NPs.

FESEM Analysis

Figure 2a show the surface morphology (top view), shape, and size of nanoparticles; in this study, the particle size of ZnO prepared is 15.51nm, and the FESEM images exhibit growth up to the nano-sized range. A homogenous distribution of spherical-shaped of ZnO nanoparticles has similar results in studies (Abdulqudos & Abdulrahman, 2022; Rabbani et al., 2021).

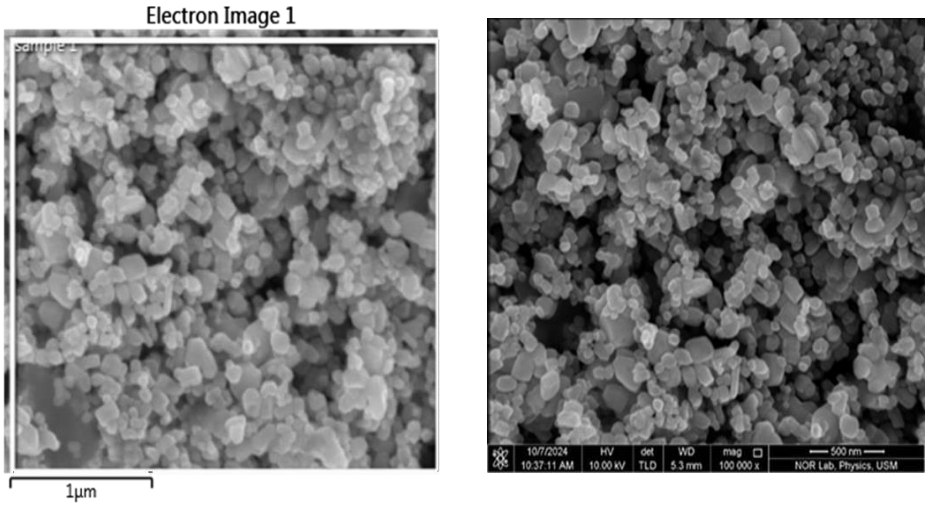

Fig 2a. FESEM images of green synthesis ZnO NPs at 1µm and 500nm.

Photocatalytic Activity of ZnO NPs

The photocatalytic degradation of methylene blue (MB) under sunlight irradiation was used to demonstrate the photocatalytic efficiency of the synthesized ZnO NPs. Figure 3 shows the photocatalytic degradation of hazardous pollutants with ZnO NPs. Very low degradation occurred without sunlight for the Nanocatalyst, about 26.34%.

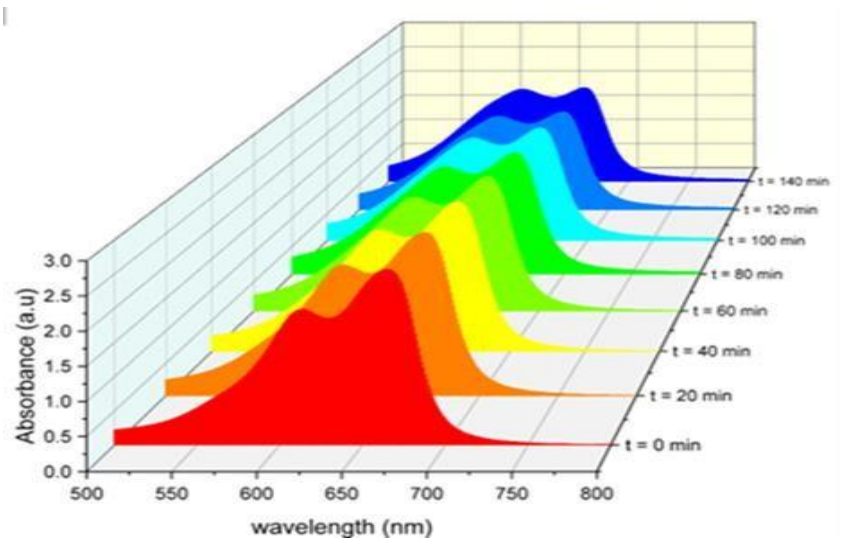

Figure 3. Photodegradation of MB dye in the dark using ZnO NPs.

Under sunlight irradiation, the photocatalytic degradation of methylene blue was 98.8% degraded at 140 min of reaction using pure ZnO nanoparticles. The decrease in the absorption curve indicates the decomposition of methyl bromide dye by the photocatalyst

(zinc nanoparticles) under solar energy. The relationship between the reduction of the absorption curve and the irradiation time is clear. The longer the aqueous solution of the dye is exposed to sunlight, the higher the rate of decomposition of the dye by the photocatalyst. The results are shown in Figures 3 and 4. These values were much higher than those reported in other studies (Al-Tohamy et al., 2022; Yadeta & Lealem, 2024; Abdulqudos & Abdulrahman, 2022).

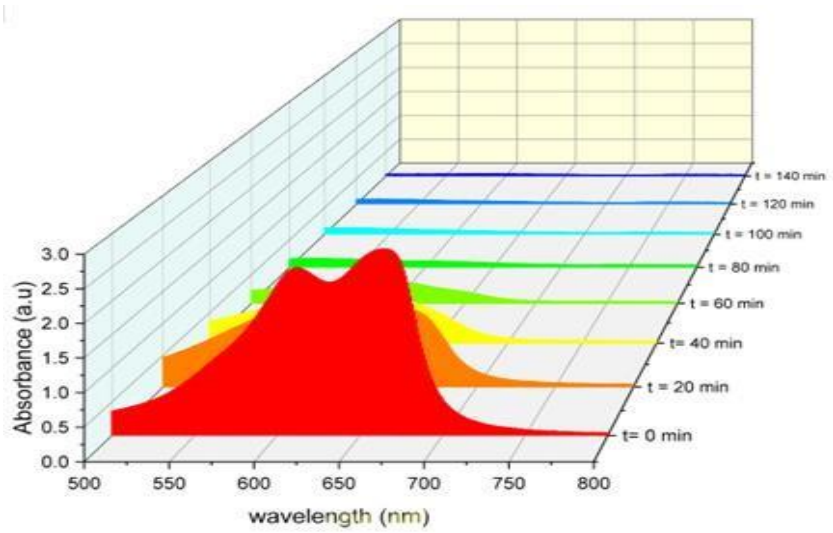

Figure 4. Photodegradation of MB dye under solar irradiation using ZnO NPs.

Similarly, Figure 4 shows the increase in the duration of irradiation leading to an increase in the degradation of MB due to its properties having many active sites. The superoxide anion radicals (O^{2-}) can be formed. At the same time, the valence band gaps (VB) can come into contact with H_2O to produce hydroxyl radicals (•OH) when the electrons from the conduction band (CB) come into contact. These hydroxyl radicals are essential factors in facilitating the degradation processes of MB. The chemical reactions can be combined into the following relationships (Viswanatha et al., 2012; Iqbal et al., 2015; Samadi et al., 2016).

The proposal of photocatalytic degradation of methylene blue (MB) under sunlight irradiation by pure ZnO NPs.

$$ZnO + Photon\ energy \rightarrow e^{-}(CB) + h^{+}(VB)$$

$$e^{-}(CB) + O_2(\text{adsorbed}) \rightarrow 2O^{-}$$

$$h^{+}(VB) + H_2O \rightarrow \cdot OH + H^{+}$$

$$h^{+}(VB) + \cdot OH \rightarrow OH^{-}$$

$$2O^{-} + \text{MB dye} \rightarrow \text{degradation}$$

$$\cdot OH + MB \rightarrow \text{degradation}$$

Conclusions

In this study, nanoparticles were prepared from ZnO by Thymeala hirsute Extract, and their morphology, size, and chemical composition were characterised using FESEM and EDX. The FESEM images show that the prepared ZnO nanoparticles are agglomerated with spherical grains with an average size of 15.51nm. The elemental composition analysis confirms the presence of zinc and oxygen in the hexagonal wurtzite phase of ZnO NPs. ZnO NPs showed vigorous photocatalytic activity against MB, utterly decolourised as a water pollutant.

Using plant extracts as cost-effective and environmentally friendly additives significantly impacts organic dyes as water treatment pollutants. Green synthesis based on indicators is a relatively straightforward process that can be easily scaled up for the large-scale production of nanoparticles.

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Conflict of interest: The authors declare that there are no conflicts of interest.

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