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Abstract

In this research, the biomaterial was synthesized using the medicinal plant *Amaranthus viridis* extract in combination with 1-ethyl-3-methylimidazolium acetate and microwave irradiation. The extract was characterized using gas chromatography mass spectrometry and used to reduce nickel salt to nanomaterials. The synthesis of these nanomaterials was determined by UV/Visible spectroscopy. X-ray diffraction, attenuated total reflectance, and thermogravimetric analysis were used to analyze their structural and compositional properties. The dynamic light scattering measurements were presented with a view to an assessment of the size distribution and surface charge, whereas the morphological appearances were analyzed with the help of field emission scanning electron microscopy. Further, the antibacterial activity of the synthesized nickel oxide nanoparticles and their performance in textile wastewater treatment were tested.

Keywords: Nickel oxide nanomaterial, ionic liquid, Microwave heating, cytotoxicity, Textile wastewater

1. Introduction

Nanomaterials have seen a tremendous growth in research due to the growing relevance of nanotechnology in biomedicine and the environment. Nickel oxide nanoparticles (NiO NPs) are one of these materials that have received significant attention due to their convenient physicochemical features. The above property of NiO NPs makes them focused on diverse uses, including polymer surface engineering, creation of magnetic fluids, catalysis, and research on their anticancer properties [1]. Most of the standard methods of NiO NPs synthesis apply to

various physical and chemical methods, and these include radiation-assisted methods, chemical reduction of metal precursors, electrochemical methods, and the evaporation condensation processes [2]. Although the synthesis techniques prove efficient, they most likely consume a lot of energy, demand long synthesis times, and produce byproducts that are both detrimental and undesirable, which makes the need to develop more environmentally compatible nanoparticle production techniques imminent. To meet such problems, microwave-assisted extraction has as one the solution to emerging challenges. When applied to ionic liquid (IL) media, this technique enables the conversion of metal ions to nanomaterials with ease and at a fast rate. ILs are organic cation or organic and inorganic anion complexes with unusual physicochemical properties, such as high thermal stability, low vapor pressure, and adjustable solvation characteristics [3]. Due to these characteristics, ILs have been well studied as possible solvent systems to extract and separate bioactive compounds in plant materials. This fact is further enhanced by the combination of microwave irradiation, which results in additional efficiency in extraction due to the formation of thermal, pressure, and mechanical interaction effects, leading to the high rate of volumetric heating and excellent process of mass transfer.

The *Amaranthus viridis* is an herbaceous plant that is familiar due to the value of medicinal uses. It is a member of the family Amaranthaceae, to which approximately 900 species belong, located in temperate, tropical, and subtropical regions. It has a wide range of bioactive products and exhibits powerful antioxidant, antibacterial, and anticancer properties. *Amaranthus viridis* is an important biological source for the synthesis of nanoparticles that is eco-friendly [4]. Such a sudden appearance of microorganisms, including those resistant to the use of conventional antibiotics, is a critical worldwide health challenge that needs new and efficient methods of antibacterial measures [5]. Along with medical considerations, the pollution of the environment caused by synthetic dyes has risen to become one of the biggest concerns. Many industrial colorants are already inherently toxic and are highly resistant to normal degradation mechanisms [6]. Methyl orange, methyl red, and methylene blue are colorants used widely in a variety of industries, including textile fabrication, printing, papermaking, and the formulation of cosmetics.

The common use of these dyes is a major contributor to the pollution of industrial wastewater [7]. The nanoparticles have demonstrated ability in the degradation of the dyes, and this is mostly as a result of their nanoscale size, which has left a high surface to volume ratio and

a significant amount of unoccupied active sites accessible as a result of adsorbent and catalytic reactions. This augmented solute availability to enrichment interactions dye molecules and the catalyst permits regal exchange of charge and accelerates the dismantling of retainable dye molecule structures to less harmful intermediates or mineralized products entirely.

This research aims to investigate whether metal nanoparticles can generate reactive species when light is obtained, which will further contribute to the degradation of persistent organic contaminants that are normally found in textile wastewater. In this context, plant extract-synthesized NiO NPs by IL is a better alternative to catalysts obtained using conventional methods. This environmentally friendly method not only uses less hazardous chemicals, but it also uses naturally occurring capping agents to increase the stability and catalytic activity of the particles. Therefore, the bio-fabricated NiO NPs have multifunctional property, which allows them to be used in both the negation of bacteria and the degradation of textile wastewater. This two-fold use brings out their capability of reducing environmental pollution and microbial contamination by an environmentally friendly approach.

2. Materials and Methods

The 1-butyle-3-methylimidazolium chloride [C₄Mim][Cl] and nickel nitrate (Ni(NO₃)₂) were obtained at Merck. Amaranthus plant material was purchased in the local markets, and distilled water was used in all the experiments.

2.2 Gas chromatography mass spectrometry (GC-MS)

The GC-MS analysis was accomplished using Agilent Technologies equipment that had a nonpolar HP-5MS capillary column (30 m, 0.25 mm i.d., 0.25 mm film thickness). The injector temperature was maintained at 220 °C, and the MS transfer line was maintained at 280 °C. The oven temperature schedule was preceded by a 50 °C temperature hold of 3 minutes, then ramped to 100 °C at 2 min to 1 minute at a 3-minute hold. The temperature was further applied to 250 °C with the rate of 30°C min⁻¹ and maintained for another 3 minutes. Helium was used as the carrier gas under a constant flow rate of 1.3 mL min⁻¹. A 1-2 7 split (100-fold) of samples (1 2L) was injected. Electron ionization at 70eV mass spectrometers was acquired over the mass range of 35-400 amu on a quadrupole mass analyzer. The separation of compounds was studied

with the help of total ion chromatograms, and the determination of the constituents was supported by having calculated the retention indices according to the Kovats procedure [8].

2.3 Identification of compounds

The analysis had been performed by matching the identified components of the essential oil with those of the standard reference libraries (NIST 98 and MassFinder). Further, GC-MS retention indices were obtained using a non-polar column. These retention indices have been obtained through the Kovats method through the study of a series of n-alkanes, which were identified as homologous, and performed by studying them on an HP-5 non-polar column.

2.4 Production of nickel nanoparticles

Amaranthus viridis plant material was completely washed with distilled water to get rid of surface impurities and dried in an oven at 40 °C. The dried biomass was used to form a fine powder by grinding and sieving to make an equal-sized particle with a 60-80 mesh size. To prepare the extract, 5 g of the powdered material was weighed with an aqueous IL (5:1 mL) solution and subjected to a microwave arrangement, comprising a Clevenger apparatus. Microwave irradiation of the mixture at 40 W at temperatures of 60 °C at 20 min was followed by the separation of the essential oil fraction in a flask.

To synthesize nickel nanoparticles, 4 mL of the biomass extract was mixed with an aqueous nickel nitrate solution (0.01 mM). This combination was heated by microwave radiation at a temperature of 80 °C for 30 minutes with a power frequency of 50W. After completion of the reaction, the resultant solid was collected and washed three times to remove unreacted species and then centrifuged at a rate of 4000 rpm for 5 minutes. Vacuum drying at 60 °C, and the obtained NiO NPs were further utilized in their work.

2.5 Characterizations

NiO NPs were examined under the UV/visible spectroscopy on a Shimadzu UV-2401 double beam spectrophotometer, and the spectrum was taken with the range between 200 and 800 nm.

Fourier transform infrared analysis was done with a Nicolet 5700 spectrometer (USA) coupled with an attenuated total reflectance (ATR) accessory.

The phase as well as the crystalline structure of the samples was determined through X-ray diffraction with an XPERT-PRO diffractometer, which used an Ni-filtered Cu K alpha radiation.

The interrogations were conducted at ambient conditions at a 2 theta of 1080 in an accelerating voltage of 40 kV and a divergence slit of 0.47 °. The average size of the crystallites was obtained through the broadening of the diffraction peaks with the aid of the Scherrer equation.

To assess the thermal stability of NiO NPs and discuss their rate of decomposition, thermogravimetric analysis of the sample was performed using a Mettler Toledo SDTA 10000 TG analyzer. Under controlled experimental conditions, the samples were heated at a steady rate of 10°C min⁻¹ at temperatures between 50 and 900 °C.

Scanning electron microscopy to examine the surface morphology of the samples was done with a Zeiss Supra 55VP field-emission scanning electron microscope that was fitted with a 5 kV acceleration voltage. To enhance the electrical conductivity of the specimens, a gold layer was coated on them before the analysis. To measure the elemental composition, an integrated energy-dispersive X-ray (EDX) detector was used.

The Malvern instrument (DKSH) that was used in the dynamic light scattering analysis was used to establish the surface charge and hydrodynamic size distribution of the particles.

2.6 Cytotoxicity

NiO NPs synthesized were tested using the agar well diffusion method to test their antibacterial properties against *Aeromonas hydrophila*, *Staphylococcus aureus*, and *Escherichia coli*. Agar refinements: bacterial cultures were incubated for 24 hours in nutrient broth at 37 °C and evenly inoculated onto nutrient agar plates. Agar wells that were aseptically made, and different volumes of the Ni NP suspension were put in each well. The plates were further incubated at 37 °C across the next 24 hours. The antibacterial efficacy was also monitored by estimating the size of the inhibition zones formed around the wells in the case of each of the test organisms.

2.7 Photo-degradation of dyes

The photocatalytic activity of the prepared NiO NPs in the degradation of textile wastewater was tested on exposure to UV light. According to the experimental technique, 0.5 mg of NiO NPs was introduced to 10 mL of the wastewater sample. The solution was agitated for predefined reaction durations to ensure proper interaction between the catalyst and the impurities. After each reaction interval, centrifugation was used to remove the catalyst from the mixture. The clear supernatant was then examined using UV-visible spectroscopy to determine concentration changes and monitor treatment efficiency [9].

3. Result and discussions

3.1 Composition of bioactive compounds

The analysis of the bioactive compounds was done by use of GC-MS, with 20 components being detected. The identification of compounds was done by comparing their calculated retention indices through the Kovats method against isolation through the ionic liquid using microwave-assisted extraction (ILMAE) as presented in Table 1.

Table 1: Bioactive compounds extracted from *Amaranthus viridis*

Peak No.	tR ¹ /min	Compounds	RI ²	RA ³
1	32.82	1-Hexanol	867	1.61
2	34.48	α -Pinene	931	1.16
3	34.81	undecane	1100	2.46
4	35.84	undecanal	1213	1.35
5	35.89	α -Sinensal	1357	2.45
6	35.97	Nonanal	1405	1.87
7	36.31	Trans- α -Bergamotene	1415	1.13
8	37.57	Farnesene	1452	0.06
9	38.11	Alloaromadendrene	1458	0.71

10	38.61	Valencene	1489	0.63
11	38.67	β -Himachalene	1474	0.58
12	38.85	Tetradecanal	1495	1.50
13	39.65	Nerolidol	1531	5.40
14	39.87	α - Bisabolol	1683	0.70
15	40.18	α - Bisabolol	1683	0.70
16	40.28	Farnesol	1744	0.90
17	40.30	cis -Lanceol	1765	2.02
18	40.58	iso-Caryophyllene	1737	3.02
19	41.12	Drimenol	1770	0.69
20	41.34	Drimenin	1941	1.14

The research revealed that 2-caryophyllene oxide was the most abundant ingredient, accounting for 42.51% of the total extract. Other significant elements included α -panasinsene (6.83%), n-decanoic acid (5.72%), and pinocarveol (4.19%). In addition to these primary components, additional alkanes, terpenoids, and alcohols were identified. The essential oil prepared using the ionic liquid-microwave aided extraction (ILMAE) technique included a total of 20 constituents (Figure 1). The extraction method had a considerable impact on the relative abundance of the principal ingredients. The greater amounts of terpenoids, alkanes, and alcohols in the ILMAE extract may be due to reduced hydrolytic and thermal breakdown during processing. Furthermore, sesquiterpenes with larger dipole moments interact more efficiently with microwave radiation, resulting in better extraction than terpene hydrocarbons with lower dipole values. Overall, this extraction approach shows great promise for producing high quantities of bioactive chemicals suited for a variety of applications.

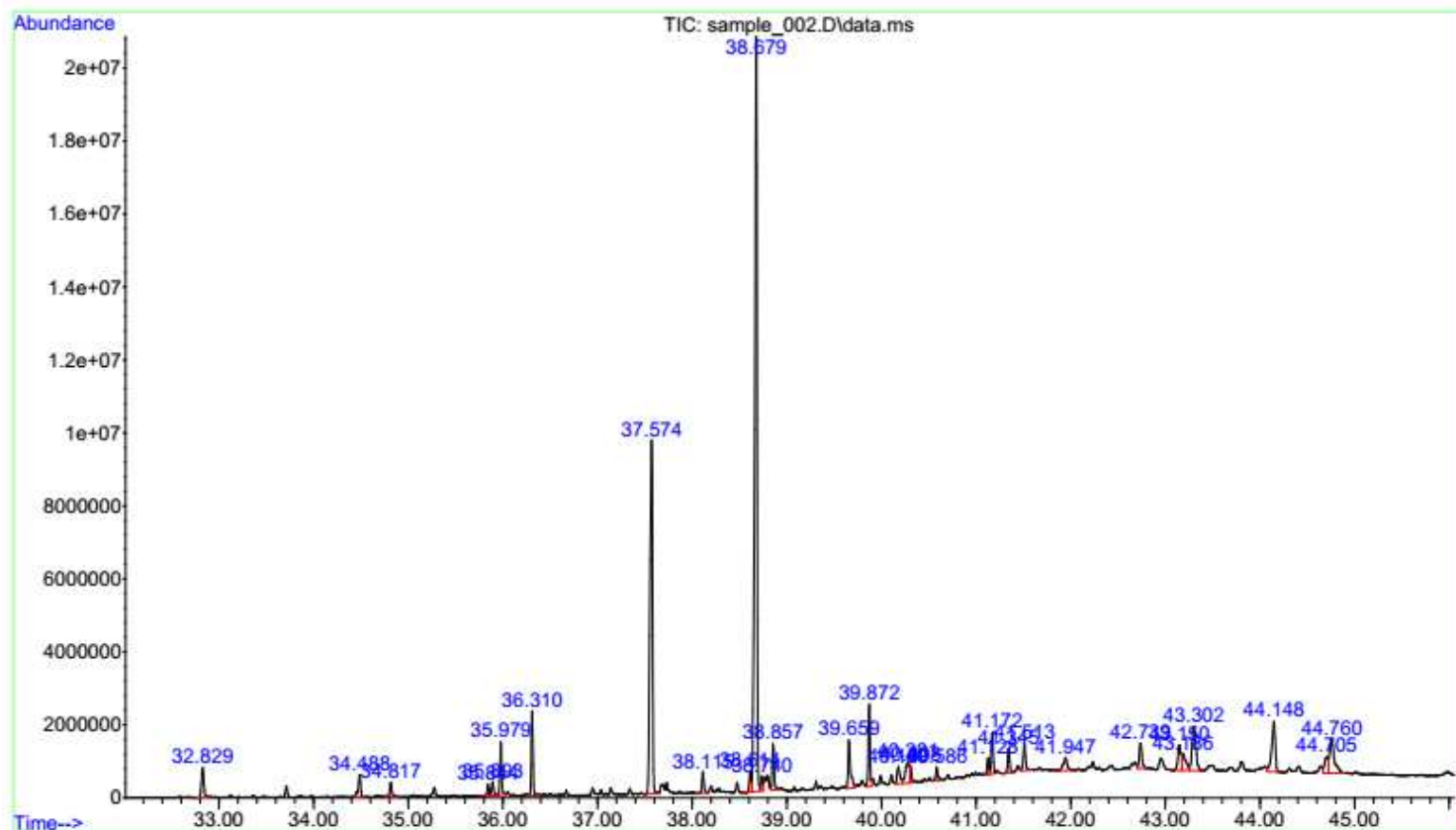


Figure 1. GC-MS Chromatogram of compounds

3.2 UV/Vis of the synthesized nickel nanoparticles

The synthesized NiO NPs using the ILMAE technique were initially signaled by the change of a deep green to a light green color of the reaction mixture. Through this change, the reduction of Ni^{2+} ions is indicated, and then the nanosized nickel is formed from metallic nickel. To prove this transformation, UV/visible spectroscopy was used to determine the production of the synthesized product.

Figure 2 shows that the UV/Vis spectrum of the NPs obtained after the formation of NiO NPs has a distinct absorption peak at 276 nm. This wavelength compares well with literature values of NiO NPs, in which absorption characteristics are generally observed in the range of 270-280 nm [10]. The profile of the observed band is strongly broadened, which could suggest the probable existence of mostly small nanoparticles with a not very broad size distribution. Such

spectral broadening is commonly associated with those of a nanoscale, including an increased surface interaction and size-dependent effects.

Moreover, the width of the absorption band is strongly dependent on the characteristics of the nanoparticles, their size, and shape. Apparently, therefore, the formation of small NiO NPs with a high surface-to-volume ratio was further supported by a broad absorption as represented in Figure 2. The results show that microwave-assisted extraction is a viable and feasible approach for the regulated production of NiO NPs.

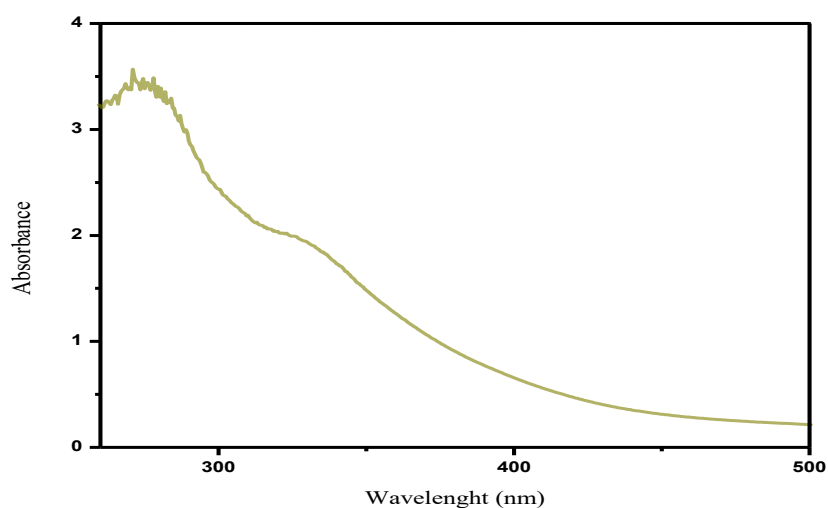


Figure 2: UV/Vis of the synthesized NiO NPs

3.2 Attenuated Total Reflectance (ATR)

The ATR spectrum confirms the formation of NiO NPs, which give useful information about the functional groups that contributed to the formation and stabilization of the nanoparticles. OH stretching vibrations are the origin of the high absorption band at 3420 cm^{-1} , the highest point is near 1635 cm^{-1} , and is associated with hydroxyl bending vibrations. These properties are indicative that there are alcoholic and phenolic groups of the bioactive constituents of the plant extract. The other absorption bands emerging at 2930 cm^{-1} and 1377 cm^{-1} are attributed to the stretching and bending vibration of aliphatic C-H functional groups, which indicate the existence of an alkyl group. Near the 1080 cm^{-1} signal, the band is found to be C-N

stretching vibrations, which are identified with aliphatic amines; the low frequency signal is close to C-C aromatic structures, providing 611 cm^{-1} of the C-C vibrations.

All of them indicate the existence of various phytochemicals in the extract, such as flavonoids, aldehydes, amines, and alkanes. The biomolecules play a major role in the green synthesis pathway, acting as reducing agents as well as stabilizing agents. Those few compounds with hydroxyl groups facilitate the reduction of Ni^{2+} ions to metallic nickel, and in addition, they adsorb onto the surface of the nanoparticles. The drastic expansion of the O-H stretching band suggests that the hydrogen bonding interactions between the phytochemicals and the NiO NPs are strong, which promote the surface stabilization and prevent the agglomeration of particles. Therefore, the obtained ATR results support the idea that the plant extract not only contributes to the manufacturing of the nanoparticles but also significantly improves the stability of manufacturing NiO NPs [11].

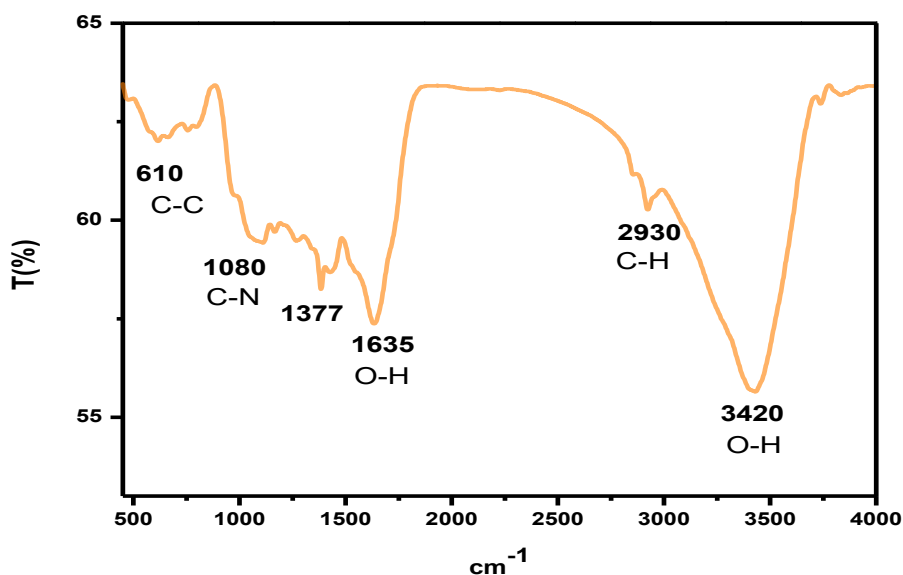


Figure 3. ATR spectrum of the synthesized NiO NPs

3.3 Analysis of X-ray diffraction (XRD)

The crystal structure of the NiO NPs synthesized was determined using XRD, and the diffraction pattern is shown in Figure 4. Clearly defined diffraction peaks are seen to exist at 2

theta angles of 33.3, 36.5, and 57.5 degrees, which are the (100), (101), and (110) crystallographic planes of nickel, respectively. These diffraction features are a confirmation that the NiO NPs synthesized have a face-centered cubic (fcc) crystal structure. When the experimental XRD pattern is compared to the standard reference data of metallic nickel (JCPDS No. 04-0835), it is evident that the pattern of the experiment succeeds in showing the high level of consistency and proves the production of phase-pure NiO NPs with no crystalline impurities detected. The intense and sharp nature of the diffraction peaks and the clarity of the diffraction peaks indicate a high level of crystallinity.

Based on the Debye Scherrer equation, the average size of crystallites of the NiO NPs was found to be 15-23 nm. This size range is very much comparable to the result of UV/visible spectroscopic analysis, which supports the evidence of well-dispersed nanoparticles. The reduction in crystallite size was probably attributed to the rapid nucleation and growth of the crystallite by the microwave irradiation, as well as the capping effect of phytochemical compounds in the plant extract, which inhibits the coalescence of particles and practically prevents agglomeration [12].

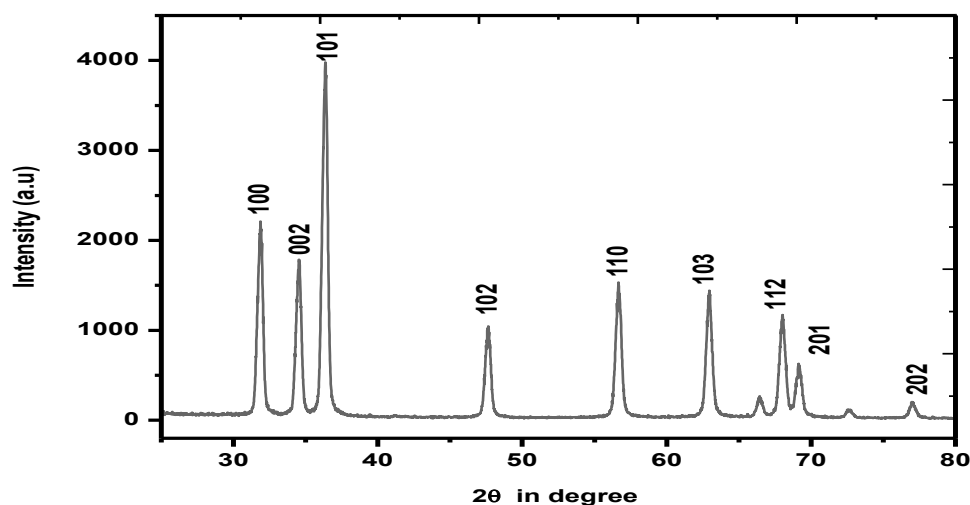


Figure 4. X-ray diffraction pattern of the synthesized NiO NPs

3.4 Thermo-gravimetric study (TGA)

To determine thermal characteristics and stability of the synthesized NiO NPs, TGA was performed, and the weight loss profile in the range of 100 to 800 °C was worked out and shown in Figure 5. Three distinct phases of mass loss are linked with the loss of surface-attached organic materials to the nanoparticles.

A primary loss of weight of about 5 per cent in the temperature range of 100-230 °C can be attributed to the removal of water and loosely bound volatile compounds of the nanoparticle surface. Such a thermal signature is commonly found in those nanomaterials of biologically active, which have their surface highly concentrated in bioactive compounds supplied by plants.

Considerable mass loss of approximately 22 percent is witnessed within the temperature period of 250 to 530 °C. This step is associated with the decomposition of organic residues in the form of thermal degradation of the plant extract, which was utilized in the formulation of reducing and stabilizing agents in the nanoparticles. These organic constituents have been detected (as it has been verified earlier by ATR analysis), indicating that surface functionalization of the NiO NPs has been achieved. The presence of these surface-bound species is essential in controlling the growth of particles as well as improving the general colloidal stability of the nanoparticles.

Beyond 530 °C, the sample shows minimal mass change, and at 800 °C, the mass changes significantly, indicating that the NiO NPs have a high thermal stability upon the removal of the surface-attached organic molecules. Such good thermal longevity indicates that the produced NiO NPs are capable of maintaining their structural integrity at high temperature conditions, which highlights their possible use in heterogeneous catalysis and other processes that need high temperature stability [13].

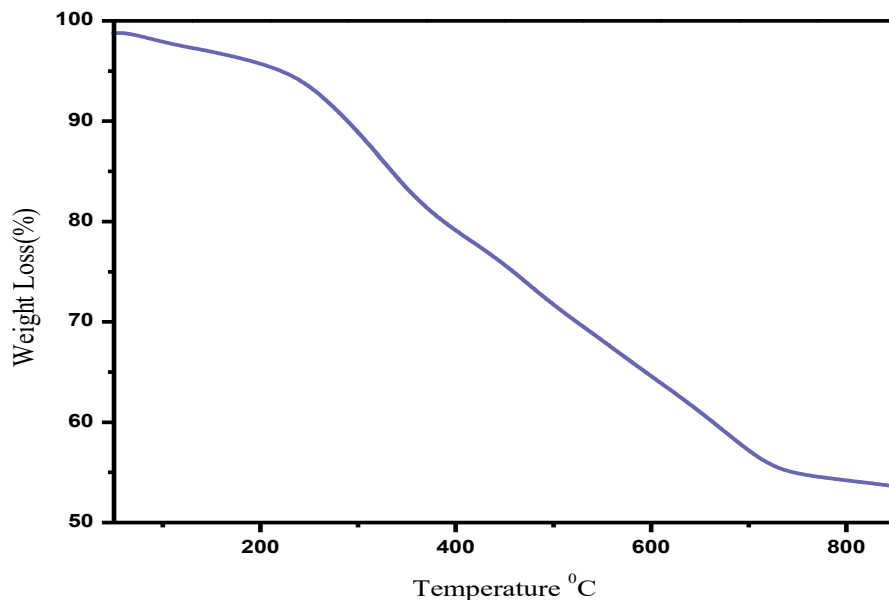


Figure 5. TGA profile of synthesized nickel nanoparticles

3.5 Field emission scanning electron microscopy (FESEM) analysis

FESEM was used to analyze the surface morphology and the size of the synthesized Ni nanoparticles, and representative micrographs are shown in Figure 6(A). As shown in the images, the nanoparticles are predominantly spherical, and the sizes of the particles lie in the range of about 30 and 55 nm. The particles tend to be well spread out, and there is barely any agglomeration. Such a homogeneous distribution is due to the presence of phytochemicals found in plants, which act as surface capping agents and retard particle growth, and actually reduce aggregation.

The synthesized NiO NPs had their elemental structure confirmed via the energy dispersive X-ray (EDX) analysis, with results as illustrated in Figure 6(B). The EDX spectrum is predominantly characterized by high signals of nickel, which proves the successful production of NiO NPs. In addition, there are weak carbon and oxygen indicators that are attributed to the presence of organic structures in the form of the plant extract. These are topmost attached organic materials that are used as stabilizing agents, and the presence of these materials is in line with the functional groups known by the ATR analysis and the mass loss pattern revealed by TGA analysis [14].

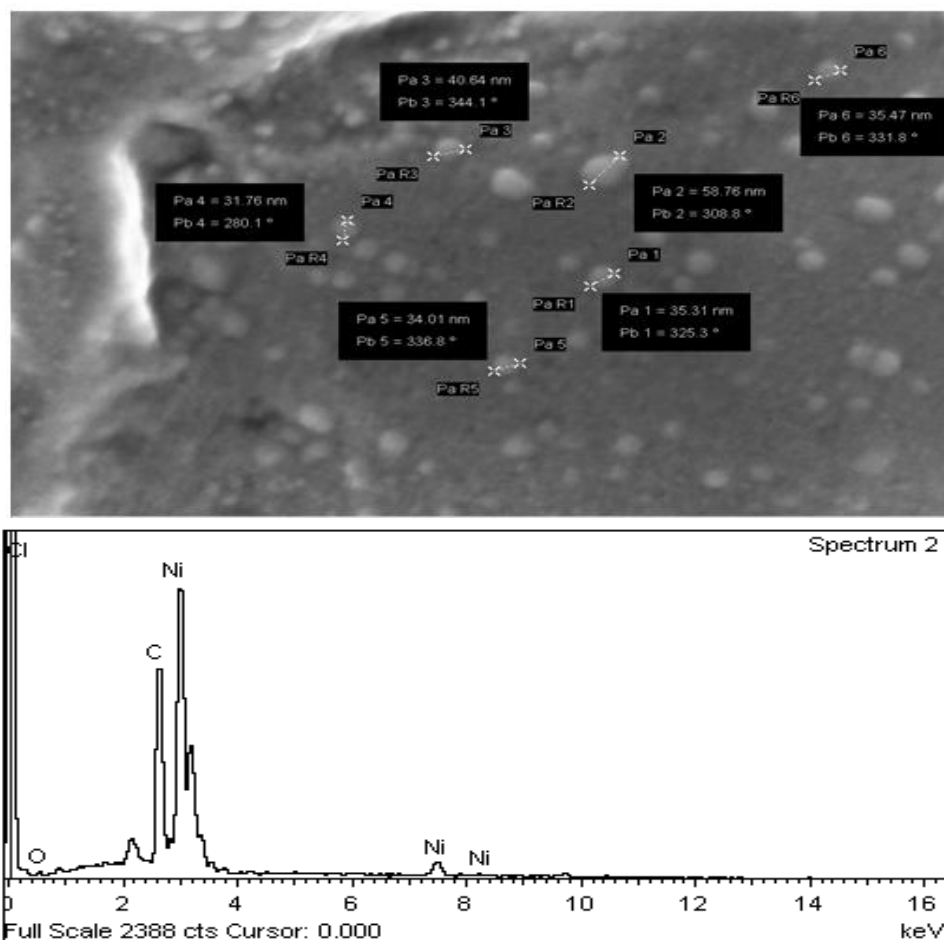


Figure 6. FESEM image of the synthesized nickel nanoparticles

3.6 Size and zeta potential of NiO NPs

Figures 7(a) and 7(b) show the particle size distribution and zeta potential of the synthesized NiO NPs, respectively. A dynamic light scattering shows a polydisperse system which has the average hydrodynamic size of approximately 23.5 nm. It is important to observe that such a size matches the effective nanoparticle size of the solution that is comprised not only of the metallic core itself but also of the surrounding organic matter of the plant extract.

Measurements of the zeta potential were used to determine the assessment of the surface charge and colloidal stability of the NiO NPs. The nanoparticles have a significant negative zeta potential of -40 mv meaning that a strongly charged surface is present. As a rule, zeta potential values higher than +25 or less than -25 mV will signify high dispersion stability because a strong repulsion reduces agglomeration between particles by the electrostatic repulsion force. This

study assigns the negative charge to a great extent to ionized functional groups, such as hydroxyl and carboxyl groups of phytochemical constituents that had been adsorbed onto the surface of the nanoparticle.

The high zeta potential of the synthesized NiO NPs indicates that there is a good dispersion of the synthesized NPs and the NPs have a high agglomeration resistance over a long period of time. This increase in colloidal stability is useful in all applications that depend upon nanoparticle suspensions, which have been steadied, e.g., catalytic or photocatalytic reactions, environmental remediation, and other nanotechnology pertinent applications [15].

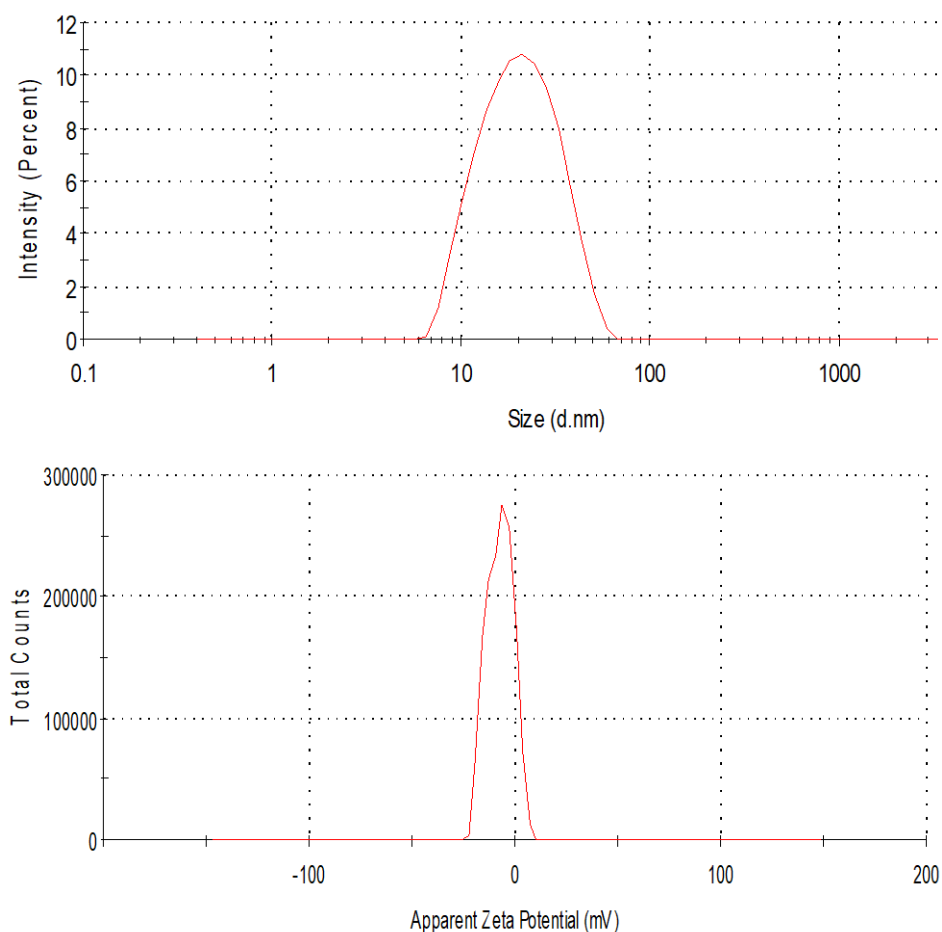


Figure 7. Particle size distribution of the synthesized NiO NPs

3.7 Cytotoxicity

The synthesized NiO NPs were investigated using Gram-positive and Gram-negative bacteria on the basis of their antibacterial ability, and the inhibition zones are presented in Figure 8. Trials were conducted at the 10, 20, and 30% concentrations of nanoparticles against *Aeromonas hydrophila*, *Escherichia coli*, and *Staphylococcus aureus*. The obtained findings indicate that the antibacterial effectiveness of the Ni nanoparticles depends on the concentration of the nanoparticles and the bacterial strain. In all microorganisms tested, a gradual expansion of the inhibition zones was observed as a result of the further increase in the nanoparticle concentration, which evidences the definite concentration-dependent antibacterial activity. *E. coli* was found to be the most susceptible of the examined strains, with the highest inhibition zone of 10 mm at the highest concentration of nanoparticles (30%). This increased sensitivity could be attributed to variations in bacterial cell envelope, particularly, membrane permeability, which might increase contacts between Ni nanoparticles and the cell surface.

On the other hand, *A. hydrophila* and *S. aureus* demonstrated comparatively low responses to antibiotics with the inhibitory rings of 9 mm and 9 mm, respectively, at the identical concentration. Ni nanoparticles most likely impact the antimicrobial effects via the combination of several mechanisms at once, including their ability to disrupt the bacterial cell membrane, their ability to generate reactive oxygen species, and reactions between released nickel ions and vital intracellular molecules, including proteins and nucleic acids, ultimately leading to cell death. These effects are enhanced by the small size and high surface area of the well, which dispenses the nanoparticles. The concentration-dependent inhibition observed in Table 2 confirms the quantitative data presented on the Gram-positive and Gram-negative bacteria with respect to the successful application of the NiO NPs in antimicrobial coatings and biomedical advancement [16].

Table 2.Inhibition zone versus chemical concentrations

NiO NPs	10%	20%	30%
<i>Aeromonas hydrophila</i> AH	7mm	8mm	9mm
<i>Escherichia coli</i> EC	8mm	9mm	10mm
<i>Staphylococcus aureus</i> SA	7mm	8mm	9mm

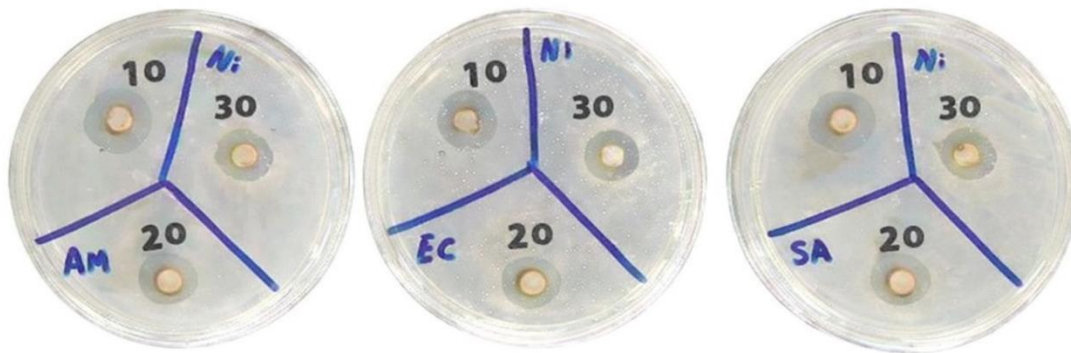


Figure 8: Cytotoxicity of NiO NPs

3.8 Photo-degradation's of textile wastewater

Photocatalytic performance of the synthesized NiO NPs was investigated through the degradation of organic pollutants in the textile wastewater in the presence of ultraviolet light, where changes in the UV/ visible spectra are shown in Figure 8. On treatment with UV light in the presence of NiO NPs, a strong reduction in the intensity of color was observed, which means effective photocatalytic degradation has occurred. This decolouring is caused by the breakdown of chromophoric azo ($-N=N-$) bonds of the dye molecules, which are largely responsible for causing the high absorption by the dye in the visible spectrum [17]. The analysis of the samples using UV/visible spectroscopies also confirmed successful degradation of dyes when commanded by NiO NPs in the presence of ultraviolet lights of a 500 W tungsten lamp. At pre-irradiation, the textile wastewater showed characteristic absorption peaks of 400, 480, and 591nm, which represent the characteristic chromophoric groups of the dyes in the wastewater. The intensities of these absorption bands progressively decreased with an increase in irradiation time, and this suggests that the dye concentration reduced continuously with photocatalytic activity. Such characteristic peaks are broken and ultimately removed in large proportions, which validates the effectiveness of the degradation of dye molecules throughout the photocatalytic reaction. The model degradation efficiency of the synthesized NiO NPs under the conditions of the experiment was estimated to be a high of 95%, and was a demonstration of the higher photocatalytic activity of the nanoparticles.

This enhanced activity may be attributed to the high affinity of the ultraviolet irradiation with the NiO NPs, which causes the generation of reactive species that initiate the dye degradation

mechanisms. These findings indicate that the NiO NPs synthesized during this study have exceptional photocatalytic efficiency and have much potential in the development of practical solutions in real-world scenarios in the degradation of dye-contaminated wastewater.

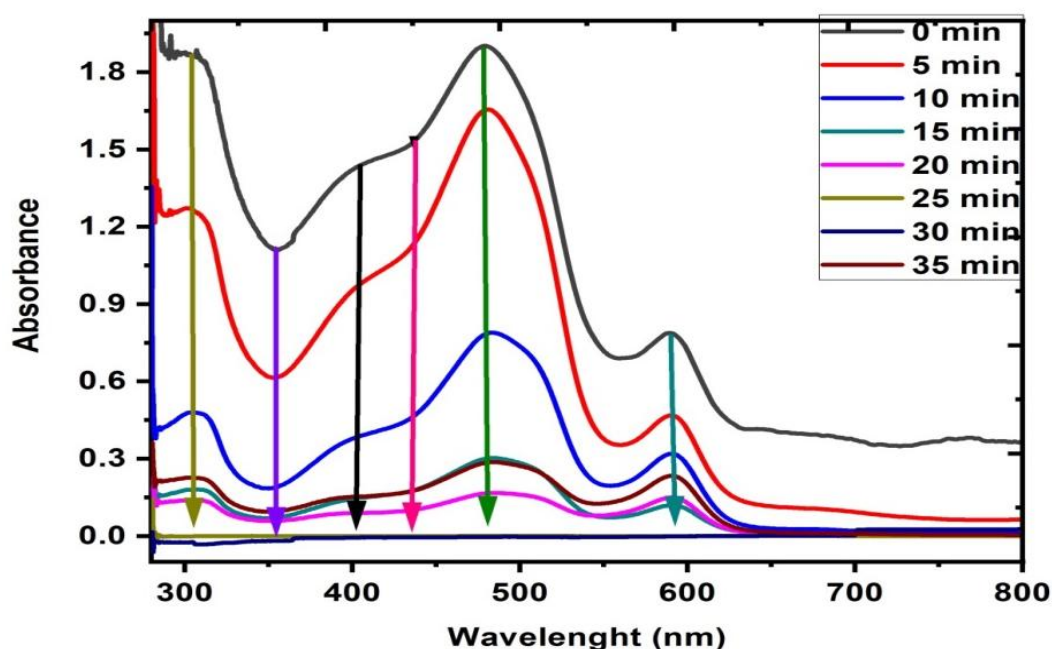


Figure 9. Time-dependent ultraviolet-visible spectra of textile wastewater

Conclusions

This has been successfully shown to be applicable in the production of NiO NPs in an environmentally friendly manner, with the synthesis of nanoparticles where the synthesis strategy is a sustainable production through the use of *Amaranthus viridis* as an extract in the form of ILMAE treatment. The production of the nano-crystalline NiO NPs was also supported with the assistance of photometric data analysis using UV/visible spectroscopy, X-ray, field emission, scanning electron microscopy, and dynamic light scattering. Morphological and particle size analyses were conducted, as geometrical analyses presented that the nanoparticles were well distributed and retained their unique features. Biological tests indicated that the biosynthesized NiO NPs were described to have considerable antibacterial abilities, which were good inhibitors of *Aeromonas hydrophila*, *Escherichia coli*, and *Staphylococcus aureus*. Besides the biological functionality, the synthetic nanoparticles also showed excellent performance in the photocatalytic domain, where the rate of degradation was up to 95 percent in textile wastewater.

The above findings highlight the opportunities of green-synthesized NiO NPs in the environmental and biomedical front.

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