Production of Magnesium Hydroxide and Magnesium Oxide Nanoparticles from Bittern and their Industrial Applications

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Abstract

In this research, magnesium hydroxide (Mg(OH)₂) nanoparticles with fiber-like and magnesium oxide (MgO) nanoparticles with platelet morphologies were produced from the bittern, a waste product of solar salt industry by precipitation method. The effects of calcination temperature on the formation and crystallite sizes of MgO nanoparticles were also studied by applying different temperatures, 300°C through 600°C. TG-DTA data of the Mg(OH)₂ nanoparticles indicated that the endothermic peak at 386.77°C due to decomposition of Mg(OH)₂ to MgO. Structural changes and crystallite sizes of nanoparticles studied by XRD showed the hexagonal phase for Mg(OH)₂ with the size of 13.45 nm and cubic crystalline phase for MgO with the size of 22.79 nm (at 600°C). The FTIR data of Mg(OH)₂ nanoparticles showed a pair of peaks at 3697.66 and 3421.83 cm⁻¹ due to stretching mode of hydroxyl group of Mg(OH)₂ and major adsorption peaks at 439.78 and 559.38 cm⁻¹ for stretching vibration of Mg-O bond. The TEM micrographs of MgO nanoparticles clearly showed cubic structure and the particle size of the powders were well distributed in the nano-size range (31-40nm). In this research, adsorption properties of Mg(OH)₂ and MgO nanoparticles were studied using Methylene Blue (MB) and two different dyes in textile waste effluents (blue and orange). The adsorption performance of MB dye (6 × 10⁻⁶ M) onto 0.8 g/L of Mg(OH)₂ nanoparticles (83.76 %) was better than that of MgO nanoparticles (38.33 %). Both of Mg(OH)₂ and MgO nanoparticles could remove the colour of blue dye (99.06 %, 98.39 %) more than that of orange dye (43.29 %, 39.53 %), respectively. Moreover, the antibacterial activities of Mg(OH)₂ and MgO nanoparticles were studied on S. aureus, E. coli and P. aeruginosa. The antibacterial activity of MgO showed higher than that of Mg(OH)₂ nanoparticles on microorganisms in order of S. aureus > E. coli > P. aeruginosa.

Keywords: Mg(OH)₂, MgO, nanoparticles, bittern, adsorption, antibacterial activity

1. Introduction

Magnesium hydroxide (Mg(OH)₂), so-called brucite, is usually used in flame retardant composite formulations because of its ability to undergo endothermic dehydration in fire conditions (Henrist et al., 2003). It can also be used to neutralize acid waste streams and to treat flue gases, thus providing cost-effective solutions to environmental problems (Booster et al., 2003). Mg(OH)₂ also exhibits the antibacterial behaviors in liquid culture and in paper sheets (Dong et al., 2010).

Magnesium oxide (MgO) nanoparticle is an exceptionally important material, with uses in catalysis, toxic-waste remediation agent, or as an additive in refractory, paint and superconducting products, as well as for fundamental and application studies. Ultrafine metal oxide particles have been used as bactericides and adsorbents (Makhluq et al., 2005). Magnesium oxide is one of the most useful ceramic materials because of its high melting temperature (about 2800°C) and it is usually used in fire-resisting bricks or crucibles (Tai et al., 2007).

Dyes are commonly used in many industries such as food, paper, carpets, rubbers, plastics, cosmetics, and textiles in order to colour their products (Dogan and Alkan, 2003). Moreover dyes are stable, recalcitrant, colorant, and even potentially carcinogenic and toxic. Their release into the environment creates serious environment, aesthetical and health

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problems. Thus, industrial dye-laden effluents are an increasingly major concern and need to be effectively treated before being discharged into the environment in order to prevent these potential hazards (Desai et al., 2014). Methylene Blue (MB) is a cationic dye widely used in paper colouring, cotton and wool dye, it can have various harmful effects on living organisms (Cengiz and Cevas, 2008).

The removal of dyes is one of the main problems associated with the treatment of textile wastewater. As dyes are designed to be chemically stable, they are highly persistent in natural environments. The discharge of dyes may therefore present an eco-toxic hazard and introduce the potential danger of bioaccumulation that may eventually affect human by transport through the food chain. Various physical, chemical and biological treatment techniques can be employed to remove the hazardous dyes from wastewater (Lin and Wang, 2009). Although different methods are available for the removal of dyes from wastewater, adsorption technique is a well-known separation process and is widely used to remove certain classes of chemical pollutants form water, especially those which are practically unaffected by conventional biological wastewater treatments. It has been found to be superior to other techniques in terms of initial cost, flexibility and simplicity of design, ease of operation and insensitivity to toxic pollutants (Desai et al., 2014). Activated carbon is the most popular adsorbent with high adsorption capacity, but it is expensive and desorption of the dye molecules is not easily achieved (Lin and Wang, 2009). Therefore, low-cost adsorbents, Mg(OH)\textsubscript{2} and MgO nanoparticles were studied for dyes removal from wastewater.

Due to the ubiquity of microorganisms and their ability to establish themselves, the control of microbial populations is a universal concern (Dong et al., 2010). Specifically, increased resistance of microorganisms towards current biocides is of great concern specifically in people of compromised immune systems like the elderly, children and the sick. This has led to increased efforts to explore new types of antimicrobial agents (Vatsha et al., 2013). As a result, inorganic antibacterial agents have received more and more recognition in the antibacterial product market (Wang et al., 2003). According to this needs, non-toxicity and low cost inorganic antibacterial agents; Mg(OH)\textsubscript{2} and MgO nanoparticles; have been studied in this research.

2. Materials and Methods

The X-ray Diffractometric (XRD model Rigaku D-Max 2200, Japan), TG-DTA (DTG 60/60 H, (SHIMADZU, Japan)), Fourier Transform Infrared spectrometric (FT IR) (Perkin-Elmer (Spectrum GX)) measurements were done at Universities’ Research Centre (URC), University of Yangon. Atomic Absorption Spectrophotometric (AA-6300, Shimadzu, Japan) measurement was done at AMTT Co. Ltd. Field Emission Scanning Electron Microscopic (EVO 60, Brand: Card ZEISS, Germany) was done at Defense Services Technological Academy (DSTA), Pyin Oo Lwin, Mandalay Region, Myanmar. Transmission Electron Microscopic (TEM microscope (Philips Teahai-TF FEG-TEM/STEM, Germany) was done at University of Stuttgart, Germany. Electronic shaker (EYELA Shaker, SS-8, Tokyo, Japan), centrifuge (Hettich Universal, D-7200, UK), UV-vis spectrophotometer (UV-vis 240, Shimadzu) and pH meter (HI 9812, pH-EC-TDS Meter, HANNA) were used.

The bittern used in this present work was collected from Myanmar Salt and Marine Chemical Enterprise, Ministry of Mines, Tharketa Township, Yangon Region, Myanmar. The chemicals used were 25% ammonia solution, sodium sulphate, 98% ethanol, gelatin, and sodium lauryl sulphate. All chemicals used in this work were obtained from British Drug House (BDH).
For adsorption measurements, Methylene Blue (C_{16}H_{18}N_{3}Cl, MW 319.9 from BDH) and two different dyes in textile waste effluent samples (blue colour, A, and orange colour, B) from Textile Factory in Thingangun Township, Yangon, Myanmar, were used. In vitro screening of antibacterial activities of magnesium hydroxide and magnesium oxide were carried out by shake flask method against three kinds of bacteria (S. aureus (N.C.P.C-6371), P. aeruginosa (N.C.T.C-6749) and E. coli (N.C.I.B-8134)), at Central Research and Development Center (CRDC), Ministry of Industry (1), Yangon, Myanmar.

**Analytical assay of bittern**

The specific gravity of bittern sample was determined by Baume hydrometer. Magnesium, calcium and trace elements in the bittern sample were determined by Atomic Absorption Spectrophotometric method (AAS). The chloride content was determined by titration method.

**Production of Mg(OH)₂ and MgO nanoparticles**

A 5 L of bittern sample was placed in 7 L flask and sodium sulphate, 1.5 times equivalent quantity as much as the quantity of Ca^{2+} in bittern, was added to eliminate the influence of Ca^{2+} on the precipitation process and the solution was agitated at 50 °C for 5 minutes. Calcium ion was removed as precipitates by filtering from the bittern solution. A 400 mL of 98 % ethanol and 250 mL complex solution of gelatin and lauryl sodium sulphate were added into the resultant bittern solution. Then, 25 % ammonia solution was slowly added with continuous stirring using magnetic stirrer. The pH value was monitored during the precipitation process. At pH 10, the suspension was aged at 30°C for 24 hours. After aging, the suspension was filtered and washed several times with dilute ammonia solution to remove impurities. Mg(OH)₂ nanoparticles were obtained after dried at 70°C for 24 hours, grinded and weighed. The above Mg(OH)₂ nanoparticles were calcined at different temperatures (300, 400, 500 and 600°C) for 3 hours to form MgO nanoparticles. Stepwise procedure for the production of Mg(OH)₂ nanoparticles is shown in Figure 1.

**Characterization of nanoparticles**

The prepared Mg(OH)₂ and MgO nanoparticles were characterized by TG-DTA, XRD, FT IR, FE-SEM and TEM techniques. TG-DTA measurement was carried out to study the weight losses with respect to temperature at a heating rate of 10°C/min and flow rate of 50 mL/min. The heating temperatures were changed from 35 to 600 °C. X-ray diffractogram was recorded by using X-ray diffractometer working with Cu/Kα radiation (λ = 1.54056 Å). The diffraction patterns were recorded in the 2θ range of 10° to 70°. The FT IR spectrum was recorded using FT IR spectrophotometer, within in the range of 400-4000 cm⁻¹. The sample was examined by FE-SEM for a visual inspection of external porosity and morphology. Model with magnifies and image at X-100 and 25000 sending and electron beam through the object. The morphology of the nanoparticles was investigated by Transmission Electron Microscope (TEM) and particles size distributions were measured by HMK-CD5, Particle Size Analyzer (Aimsizer Scitific).
Determination of methylene blue (MB) solutions

A solution of Methylene Blue (MB) was prepared by dissolving an accurately weighed amount of MB (0.1919 g) in deionized water in a 100 mL volumetric flask. Then the solution was made up to the mark with deionized water to obtain 6 x 10^{-5} M stock solution. This solution was made by serial dilution within the range between 2 x 10^{-6} M to 6 x 10^{-6} M. Then, the solution was adjusted to pH 5 using 0.1 M hydrochloric acid and 0.1 M sodium hydroxide solution. The absorbance value of concentration of MB solution 2 x 10^{-6} M at pH 5 was measured at wavelength ranging from (550-700 nm) by UV-vis spectrophotometer. Concentrations of MB in the supernatant solutions were estimated by measuring absorbance at maximum wavelengths of the dye (λ_{max}=664nm) (Figure 2) using the calibration curve shown in Figure3. The calibration curve of absorbance against MB concentration was obtained by using standard MB solutions at pH 5. The calibration curve shows that Beer's law (A=εbc) is obeyed in concentration range (2 x 10^{-6} M - 6 x 10^{-6} M). The experimental data reported in Figure 3 were fitted by a straight line with a high regression coefficient value (R^2 = 0.999).
Effect of pH

A 0.04 g of prepared Mg(OH)₂ was separately added into 250 mL capacity of clean and dry six beakers each containing 50 mL of MB dye solution (6 x 10⁻⁶ M) at pH 3, 4, 5, 6, 7 and 8. The mixtures were shaken for 180 minutes and sampling out 10 mL and centrifuged immediately the sampling mixture at 200 rpm for 20 minutes to obtain the clear blue solution. The residual MB dye concentration in the mixture solutions was determined by UV-vis spectrophotometer at wavelength 664 nm. The same procedure was carried out using MgO nanoparticles. The percentage removal of dye was calculated as follows:

\[ \text{Percentage removal (\% R)} = \frac{A_0 - A}{A_0} \times 100 \]

Where, \( A_0 \) is absorbance of dye solution before treatment, \( A \) is absorbance of dye solution after treatment.

Effect of contact time

A 0.04 g of prepared Mg(OH)₂ was separately added into 250 mL capacity of cleaned and dried beaker containing 50 mL of MB dye solution (6 x 10⁻⁶ M) of pH 3. The mixture was stirred and interval sampling out 10 mL every 15 minutes and centrifuged immediately the sampling mixture at 200 rpm for 20 minutes to obtain the clear blue solution. The residual methylene blue concentration in the mixture solution was determined by UV-vis spectrophotometer at wavelength 664 nm. The same procedure was carried out using MgO nanoparticles.

Effect of dosage

A 0.02, 0.04, 0.06 and 0.08 g of prepared Mg(OH)₂ was separately added into 250 mL capacity of four clean and dry beakers each containing 50 mL of MB dye solution (6 x 10⁻⁶ M) at pH 3. The mixtures were stirred and interval sampling out 10 mL every 15 minutes and centrifuged immediately the sampling mixture at 200 rpm for 20 minutes to obtain the clear blue solution. The residual MB dye concentration in the mixture solutions was determined by UV-vis spectrophotometer at wavelength 664 nm. The same procedure was carried out using MgO nanoparticles.

Determination of textile waste effluent

In this research, two different dyes in textile waste effluent samples (blue colour, A and orange, B) were collected from Thingangyun Township and adsorption experiments were carried out. The absorption spectra of two dyes were measured at wavelength ranging from (250-700 nm) by UV-vis spectrophotometer. Figure 4 and 5 show the absorption spectra of dyes in textile waste effluent. The wavelengths of maximum absorption were found to be 605 and 397 nm for samples A (blue) and B (orange) respectively.
Removal of dye in textile waste effluents

Each 50 mL of waste effluent sample A, from textile factory, 0.02, 0.04, 0.06, 0.08 and 0.10 g of prepared Mg(OH)₂ nanoparticles were separately added into 250 mL capacity of five clean and dry beakers. The other procedures were the same.

The whole of the above procedure was carried out using sample B in place of sample A. Similarly, the whole of the above procedures were carried out using MgO nanoparticles in place of Mg(OH)₂ nanoparticles. After dye removal experiments, absorbance of the sample solutions were measured by using UV-visible Spectrophotometer.

Bactericidal Tests

Nanopowder slurries (10 mg/mL) were prepared by 0.5 g of nanopowder samples in 50 mL phosphate buffer (pH 6.8) and autoclaved at 121°C for 20 minutes. The spore suspension 0.1 mL (10⁷ CFU/mL) was added into 50 mL of each of the different nanoparticles slurries or 50 mL sterile phosphate buffer (control). After shaking for 10 minutes, the mixture was serially diluted (1:10) in sterile distilled water. An aliquot (1.0 mL) of each of the diluted solution was placed into a sterilized Petri dish. Molten nutrient agar (20 mL) was poured into each of the Petri dishes. After incubation at 37°C for 24 hours, bacterial populations were determined by the average of the colony number. The percentage reduction of the bacteria counts (standard plate count) were obtained after treatment with MgO and Mg(OH)₂ nanoparticles was calculated according to the following formula:
PK = \left(1 - 10^{-LR}\right) \times 100 \% \\
Where, PK is percentage killed and LR is the log reduction (Hamilton, 2010).

3. Results and Discussion

In this study, Mg(OH)₂ nanoparticles with fiber-like morphology were produced using the bittern, by-products of solar salt production, as the commercial source of magnesium compounds. It was observed that 204.6721 g of white powder of Mg(OH)₂ nanoparticles can be produced from 5 L of bittern sample.

Analytical assay of bittern sample

The specific gravity of the sample was measured at room temperature by Baume hydrometer and it was found to be 1.25 at 29° Be˚. The composition of main elements and trace elements in bittern are listed in Table 1 and 2.

Table 1. Composition of major elements in bittern (g/L)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Mg²⁺</th>
<th>Ca²⁺</th>
<th>Na⁺</th>
<th>K⁺</th>
<th>Cl⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrations</td>
<td>85.93</td>
<td>0.25</td>
<td>1.90</td>
<td>5.19</td>
<td>149.49</td>
</tr>
</tbody>
</table>

Table 2. Composition of trace elements in bittern (ppm)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Fe</th>
<th>Cu</th>
<th>Cd</th>
<th>Mn</th>
<th>Pb</th>
<th>Zn</th>
<th>Cr</th>
<th>Hg</th>
<th>As</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrations</td>
<td>0.99</td>
<td>0.32</td>
<td>0.45</td>
<td>1.48</td>
<td>0.34</td>
<td>2.07</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

ND – Not Detected

Characterization studies

TG-DTA Analysis

The decomposition behavior of the Mg(OH)₂ nanopowder is shown in Figure 6. In the TGA data, total weight loss was found to be 52.304 % due to the loss of adhesive water and crystal water in the prepared Mg(OH)₂ nanopowder. In DTA curve, the decomposition of Mg(OH)₂ exhibit a pronounced weight loss at 385.77°C which can be attributed to the decomposition of Mg(OH)₂ accompanied by an endothermic effect according to the following reaction.

\[ \text{Mg(OH)}_2 \xrightarrow{\text{heat}} \text{MgO} + \text{H}_2\text{O} \]
Figure 6. TG-DTA thermogram of Mg(OH)$_2$ nanoparticles

FTIR Analysis

Figure 7 shows the FTIR spectra for Mg(OH)$_2$ nanoparticles. Wave numbers at 3697.66 cm$^{-1}$ and 3421.83 cm$^{-1}$ were due to vibration of OH group. Wave numbers at 439.78 cm$^{-1}$ and 559.38 cm$^{-1}$ were corresponding to stretching vibration of Mg-O bond. Wave number at 1639.55 cm$^{-1}$ was adsorption peak of OH group. Wave numbers at 1124.54 cm$^{-1}$ and 1535.39 cm$^{-1}$ were characteristic peaks of C-H group present in the organic matter (Xiang and Lin, 2009).

Figure 7. FTIR spectrum of Mg(OH)$_2$ nanoparticles

XRD Analysis

Powder X-ray diffraction was used to identify the surface nanostructures and examine the crystallinity of the nanoparticles. Figure 8 depicts the X-ray diffractogram of Mg(OH)$_2$ nanoparticles. The XRD peaks of the synthesized Mg(OH)$_2$ nanoparticles are consistent with the Mg(OH)$_2$ with hexagonal phase in the standard PDF library. The XRD patterns reveal diffraction peaks of (0 0 1), (1 0 0), (0 1 1), (0 1 2), (1 1 0), (1 1 1) and (1 0 2), which are characteristic of the Mg(OH)$_2$. The crystalline phases of Mg(OH)$_2$ are pure and have hexagonal phase. The average crystallite sizes of the Mg(OH)$_2$ nanoparticles were calculated by using Debye-Scherrer formula:

\[ D = \frac{k\lambda}{\beta \cos \theta} \]
where, D is the crystallite size, k is the shape factor, which usually takes a value of about 0.9, λ is the wavelength of X-ray source used, β is the full width at half-maximum (FWHM), and θ is the Bragg diffraction angle (Jenkins and Snyder, 1996) and found to be 13.43 nm.

In this work, the prepared Mg(OH)₂ nanoparticles were calcined to get MgO nanoparticles, and the effect of calcination temperatures on MgO nanoparticles were also investigated. The effect of calcination temperatures on decomposition of Mg(OH)₂ to MgO nanoparticles and their phase changes are shown in Figure 9. It can be seen that MgO starts to appear at 300°C but its characteristic peaks are not well developed. This was also agreed with DTA data. In this experiment, since the dehydration of Mg(OH)₂ was occurred at about 386.7°C, higher calcination temperature would lead to MgO nanoparticles. After calcined at 400°C, amorphous nature disappeared and crystalline nature of MgO appeared but its crystal structure has some impurities peaks.

After calcined at 500 and 600°C, the characteristic peaks of the MgO nanoparticles well agreed with those of cubic structure in the standard PDF card. The characteristic planes of Mg(OH)₂ absolutely disappeared and the planes (1 1 1), (2 0 0) and (2 2 0) of MgO appeared significantly. No characteristic peaks of Mg(OH)₂ and other impurities were detected in the XRD pattern, indicating the complete transformation of Mg(OH)₂ into MgO nanocrystals. The calculated crystallite sizes were found to be 22.15 and 22.79 nm for 500 and 600°C, respectively. The size data revealed that the crystallite size increased with the increase in the final calcination temperature. In order to obtain smaller MgO particles with well-developed crystal structures, calcination temperature for 600°C was chosen for the study of MgO characterization.

FE-SEM Analysis

Figures 10 and 11 show the FE-SEM images of Mg(OH)₂ and MgO nanoparticles. The FE-SEM images of Mg(OH)₂ nanoparticles have seemly fiber-like morphology and well matched with the literature (Qiang et al., 2007). From the FE-SEM image, the synthesized MgO nanoparticles have platelet shape due to agglomeration of nanoparticles.

TEM Analysis

In this research, TEM micrographs of MgO nanoparticles clearly showed cubic structure (Figure 12). And it is strongly agreed with XRD data. The particle size distribution of MgO nanoparticles were found to be 7% (21-30 nm), 73% (31-40 nm), 14% (41-50 nm) and 3% (51-60 nm), respectively (Figure 13).
Figure 8. XRD diffratograms of Mg(OH)$_2$ nanoparticles

Figure 9. XRD diffratograms of MgO nanoparticles calcined at (A) 300°C (B) 400°C (C) 500°C and (D) 600°C
Adsorption studies

Effect of pH

The pH of the initial solution is one of the most important factors influencing the adsorption of dyes on an adsorbent (Alencar et al., 2012). Figure 14 shows the effect of pH on the adsorption of MB dye onto Mg(OH)$_2$ and MgO nanoparticles. The removal percent of MB by MgO at pH 3, 4, 5, 6, 7 and 8 were about 31.13 %, 29.84 %, 23.78 %, 15.27 %, 14.14 % and 11.96 % respectively indicated that at lower pH, the higher adsorption capacity was achieved (Wanchanthuek and Thapol, 2011).

The effect of pH on adsorption of MB dye onto MgO was explained by Wanchanthuek and Thapol, 2011 such that the basis of two possible mechanisms: (i) this could relate to the increasing of –OH group at the surface of MgO at lower pH and –OH group might be the active adsorption site for MB molecules. Over surface of MgO before treated with MB solution was lack of –OH group. When the MgO was soaked with strong acid solution, the protonation of H$^+$ to surface of MgO to obtain Mg(OH)$_2$ might be occurred. MB is cationic dye which is more favorable adsorbed over anionic potential site which might be –OH group, (ii) chemical reaction between –OH group of active component over MgO surface (from (i)) and the reactive group Cl$^-$ in MB, resulting in MB adsorbed over MgO surface and eliminated HCl in solution (Wanchanthuek and Thapol, 2011).
In case of Mg(OH)$_2$, the removal percent of MB dye at pH 3, 4, 5, 6, 7 and 8 by Mg(OH)$_2$ nanoparticles were about 54.93 %, 58.42 %, 63.69 %, 64.15 %, 66.61 %, and 67.74 %, respectively indicated that at higher pH, the higher adsorption capacity was achieved.

**Effect of contact time**

In this research, adsorption of MB dye onto Mg(OH)$_2$ and MgO nanoparticles was studied using various contact time (15, 30, 45, 60, 75, 90, 120, 150 and 180 minutes). The removal percent of MB dye by nanoparticles was found to increase, reach a maximum value with increase in contact time (Figure 15). In some cases, it almost becomes constant with increase in contact time after 180 minutes. Based on these results, 180 minutes was considered to be sufficient for the optimum sorption time in adsorption experiments. The removal of MB dye from aqueous solutions by adsorption on nanoparticles increases with time, till the equilibrium is attained. It can be seen from the result that, the adsorptive efficiency of Mg(OH)$_2$ nanoparticles was higher than that of MgO nanoparticles.

![Figure 14. Changes of removal percent of MB dye using Mg(OH)$_2$ and MgO nanoparticles at different pH](image1)

![Figure 15. Changes of removal percent of MB dye using Mg(OH)$_2$ and MgO nanoparticles with contact time](image2)

**Effect of dosage**

The amount of nanoparticles also affects the process of dye removal. Different amounts of nanoparticles were used (0.02 to 0.08 g) and the results are shown in Figure 16. Removal percent of MB dye solution increased gradually with an increase in dosage of nanoparticles. The removal percent of MB dye using MgO and Mg(OH)$_2$ nanoparticles at doses of 0.02, 0.04, 0.06 and 0.08 g were found to be (22.86 %, 51.15 %), (31.11 %, 57.85 %), (34.79 %, 71.23 %) and (38.33 %, 83.76 %), respectively. According to the results, the adsorption performance of Mg(OH)$_2$ nanoparticles on dyes is better than that of MgO nanoparticles.
Removal of dyes from textile waste effluent

In this research, two different dyes in textile waste effluent samples (blue colour, A, and orange colour, B) were used. The percent removal of sample A using 0.02, 0.04, 0.06, 0.08 and 0.10 g of MgO and Mg(OH)$_2$ nanoparticles were found to be (27.63 %, 36.86 %), (57.79 %, 83.55 %), (83.41 %, 93.31 %), (97.32 %, 97.26 %), and (99.06 %, 98.39 %), respectively. In case of sample B, percent removal using same amount of above nanoparticles were found to be (21.21 %, 18.86 %), (31.29 %, 25.07 %), (33.71 %, 28.21 %), (37.79 %, 33.07 %) and (43.29 %, 39.93 %), respectively. The percent removal of the samples increase with increased in dosage of nanoparticles. The results are shown in Figures 17 and 18, from these results, both nanoparticles of Mg(OH)$_2$ and MgO can remove the colour of blue dye than that of orange dye.

The comparative removable properties of blue dye Mg(OH)$_2$ with MgO, Mg(OH)$_2$ showed more adsorptive properties except that dose of 0.08 g and 0.10 g. However, for orange dye, the percent removal of MgO was higher than that of Mg(OH)$_2$. From this point of view, the prepared Mg(OH)$_2$ and MgO nanoparticles are effective adsorbents for the removal of organic dyes in wastewater samples. This simple and cost effective adsorption technique to remove dyes from textile waste effluents using fine grained Mg(OH)$_2$ and MgO nanoparticles prepared from bittern can be easily implemented in industrial level to community water supply schemes.
Antibacterial studies

The antibacterial effects of magnesium hydroxide and oxide nanoparticles were investigated using gram positive and gram negative bacterial strains, *S. aureus*, *E. coli* and *P. aeruginosa*, respectively, by shake flask method.

Figure 19 shows the results of viable bacteria colonies with the same amount of initial bacterial suspension in the presence or absence of the Mg(OH)$_2$ and MgO nanoparticles after 10 minutes contact between bacteria and nanoparticles. In the absence of nanoparticles, it can be observed that a confluent growth (colonies aggregate together) of bacteria in growth media after 24 hours of incubation. However, in the presence of 10 mg mL$^{-1}$ of Mg(OH)$_2$ and MgO, only few live bacteria remain. It was clearly seen from the results that nanoparticles of Mg(OH)$_2$ and MgO caused significant reduction on the bacterial growth as compared to control.

As can be seen in Figure 20, both Mg(OH)$_2$ and MgO nanoparticles exhibit excellent bactericidal activity against *S. aureus*, *E. coli* and *P. aeruginosa* since all the efficiencies are above 91%. The antibacterial activity of MgO nanoparticles was better for *S. aeru*us, and *E. coli* compare to that of Mg(OH)$_2$ nanoparticles. However, its activity on *P. aeruginos*a was lower than that of Mg(OH)$_2$ nanoparticles. Moreover, the synthesized Mg(OH)$_2$ and MgO nanoparticles were found to be highly effective against *S. aeru*us than both *E. coli* and *P. aeruginos*a. This can be attributed that gram positive bacterial strains are more susceptible to antibacterial materials as compared to gram negative strains due to differences in their cell wall structure (Vatsha et al., 2013). The Gram-positive bacteria are encased in a plasma membrane covered with a thick wall of peptidoglycan, while Gram-negative bacteria are encased in a triple layer, the outermost layer being alilo-polysaccharide. Gram-negative bacteria may be more resistant to chemical agents than Gram-positive bacteria and it appears to be the case for the Mg(OH)$_2$ and MgO nanoparticles as well. Moreover, electrostatic interactions are directly responsible for the attachment of nanoparticles to bacteria. These interactions change the integrity of cell membrane of bacteria and toxic free radicals are released which induce oxidative stress on bacteria.
In this study, XRD diffractrogram of the resultant Mg(OH)$_2$ nanoparticles clearly indicated the pure Mg(OH)$_2$ with hexagonal phase and free from other impurities and the average crystallite size was found to be 13.43 nm. A 204.7 g of white powder Mg(OH)$_2$ nanoparticles was obtained from 5 L of bittern. The morphology of synthesized Mg(OH)$_2$ nanoparticles studied by FE-SEM showed fibre-like structure. The resultant Mg(OH)$_2$ nanoparticles were calcined at different temperatures of 300, 400, 500 and 600°C to get MgO nanoparticles. At 500°C, Mg(OH)$_2$ nanoparticles totally decomposed and MgO nanoparticles clearly appeared. The calculated crystallite sizes were found to be 22.15 nm at 500°C and 22.79 nm at 600°C, respectively. The adsorption performance of Mg(OH)$_2$ nanoparticles on Methylene Blue (6 x 10$^{-4}$ M) is better than that of MgO nanoparticles. The adsorption capacity of Mg(OH)$_2$ nanoparticles was achieved at higher pH value (pH = 8) and that of MgO nanoparticles was achieved at lower pH value (pH = 3). Both of MgO and Mg(OH)$_2$ nanoparticles could remove the colour of blue dye than that of orange dye. This simple and cost effective adsorption technique which remove dyes from textile waste effluents using fine grained Mg(OH)$_2$ and MgO nanoparticles prepared from bittern can be easily implemented in industrial level for community water supply schemes.

The studies were extended to antibacterial activities of MgO and Mg(OH)$_2$ nanoparticles on *S. aureus*, *E. coli* and *P. aeruginosa*. Both Mg(OH)$_2$ and MgO nanoparticles exhibit excellent bactericidal activity against *S. aureus*, *E. coli* and *P. aeruginosa* since all the efficiencies are above 91%.

Therefore, Mg(OH)$_2$ and MgO nanoparticles prepared from bittern are cost effective adsorbents for the removal of organic dyes in waste water samples as well as for the production of antibacterial agent, and for the environmental conservation.

Figure 19. Antibacterial activities of (i) Mg(OH)$_2$ nanoparticles (ii) MgO nanoparticles (iii) Control plate without nanoparticles on the growth of (A) *S. aureus* (B) *E. coli* (C) *P. aeruginosa*

Figure 20. Histogram of antibacterial efficiencies of Mg(OH)$_2$ and MgO nanoparticles towards *S. aureus*, *E. coli* and *P. aeruginosa*.
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