

# Materials Science inc. Nanomaterials & Polymers

# Effect of Molarity on Methylene Blue Dye Removal Efficacy of Nano Ca(OH)<sub>2</sub>

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With the increase in demand of textiles products, the polluted groundwater problem in the world is increasing proportionally and leading to environmental and health problems. Hence in this present work, we report on the dye removal efficacy of nano Ca(OH)<sub>2</sub> by changing the molarity of the reactants. In the process, the chemical precipitation technique is used to synthesize the phase pure nano Ca(OH)<sub>2</sub> powders using equimolar concentrations (e.g., 0.4 M, 0.6 M, 0.8 M and 1 M) of  $[Ca(NO_3)_2 \cdot 4H_2O]$  and NaOH solutions. The prepared material was characterized using XRD, FTIR, and UV-Vis spectroscopy. The results from the characterization study show, that the dye

### Introduction

Calcium Hydroxide [Ca(OH)<sub>2</sub>] is a material that has tremendous potential in terms of both fundamental science and technological applications. Therefore, it continues to attract the attention of many researchers from around the world. Further, the easy synthesis of calcium hydroxide by simple chemical methods with varying synthesis conditions makes it even more appealing to work on this material. Calcium hydroxide is extensively used in several applications e.g., Portland cement production,<sup>[1,2]</sup> cultural heritage conservations,<sup>[3,4]</sup> and vaterite blocks fabrication,<sup>[5]</sup> which is important for advanced bio

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removal behaviour is complex and is sensitive to a simultaneous combination of many factors e.g., the molarities of the reactants, the resultant nanocrystallite size, band gap energy, the concentration of the dye and, the temperature of adsorption. Therefore, these results are discussed in terms of relative variations in the microstructure, lattice strain, band gap energy, defect structure, and the amount of (OH<sup>-</sup>) ions. Further, the probable mechanism of dye removal behaviour is suggested. Finally, the consequences of these results in terms of microstructurally tuned nano  $Ca(OH)_2$  materials development for prospective futuristic applications are highlighted.

applications. Similarly, a very important emerging area of research is its utilization for nano-priming action on seed embryos e.g., *Indian Gram seeds*.<sup>[6]</sup> Rigorous efforts are currently underway to extend the inherent biocompatibility and antibacterial capacities of Ca(OH)<sub>2</sub> for a wide variety of applications such as intercanal medication for postoperative pain in root canal therapy,<sup>[7]</sup> advanced bone restoration,<sup>[8]</sup> endodontics,<sup>[9]</sup> and antimicrobial activity.<sup>[10]</sup> It is also utilized for thermochemical energy storage.<sup>[11]</sup> Recent efforts are also directed to use it in geopolymers to increase the bulk density and compressive strength,<sup>[12,13]</sup> and for aqueous naphthalene degradation.<sup>[14]</sup> It also shows excellent promise for biomass conservation,<sup>[15]</sup> and wastewater treatment.<sup>[16]</sup>

Wastewater released from textiles, mining, and agricultural industries poses a great environmental threat to all living species. Hence, low-cost wastewater treatment with efficient materials is essential to avoid health complications. Several research groups are working on wastewater treatment by different means. In a recent review,[17] it is proposed that polymer-based materials, bio-adsorbents, metal oxides, and carbon-based materials show better efficiency to remove pollutants from wastewater. The mechanism to remove pollutants from wastewater is discussed here in terms of pi-pi interaction, ion exchange, surface complexation, and electrostatic attraction.<sup>[17]</sup> Both cotton and graphene oxide are also reported to be used to design a Rayon-Graphene Oxide (GO) composite to remove methylene blue (MB) from water.<sup>[18]</sup> The re-usability of the designed composite is verified with high removal efficiency up to five cycles.<sup>[18]</sup> The nanocomposite made of nickel oxide and carboxymethyl cellulose is also reported to be used to remove MB dye from wastewater through a spontaneous and endothermic process.<sup>[19]</sup> Further, the roles of pH, nanocomposite concentration, contact time,



Table 1. The data on lattice parameters a and c (in (Å)), c/a ratio, nanocrystallite size, t <sub>D-5</sub> (in nm), atomic displacement (u), anion-cation bond length (in (Å), and lattice volume (in (Å) <sup>3</sup> ) for the various nano Ca(OH) <sub>2</sub> samples S1, S2, S3, and S4.										
Sample	Lattice par a (Å)	rameters c (Å)	c/a	Crystallite size, t <sub>D-s</sub> (nm)	Atomic displacement (u)	Anion-cation bond length (Å)	Volume (ų)			
S1 (0.4 M)	3.59037	4.89842	1.36432	31.9356	0.42908	2.10181	54.68456			
S2 (0.6 M) S3 (0.8 M)	3.59418 3.59783	4.91394 4.91378	1.36719 1.36576	30.6658 32.6464	0.42833 0.42870	2.10478 2.10654	54.97433 55.08421			
S4 (1.0 M)	3.57874	4.87867	1.36324	33.4358	0.42936	2.09473	54.11187			

temperature, and dye concentration are investigated to find out the best efficiency of the MB dye removal process.<sup>[19]</sup> The CdS/Ag<sub>2</sub>O nanocomposites are utilized for photocatalytic degradation of MB and with the maximum efficiency of up to 88.8%.<sup>[20]</sup> The exploitation of the photoluminescence (PL) spectroscopy confirms the successful adsorption of the toxic Cd<sup>2+</sup> and Pb<sup>2+</sup> ions from simulated wastewater is reported to achieved by the utilization of the GO-Mgbe (OH)<sub>2</sub> nanocomposite.<sup>[21]</sup> There is a singular report on the usage of Ag-doped calcium hydroxide for MB dye removal from wastewater.<sup>[16]</sup> The aforesaid literature survey clearly points out that the systematic studies on how a change of molarity of chemical reactants in the chemical precipitation process of calcium hydroxide affects the physical and especially, the wastewater treatment efficacy are far from well-studied.[1-21] This gap of information in literature creates the scope of this study. Hence, the purpose of the current study is to investigate the effect of the molarity of sodium hydroxide (NaOH) and calcium nitrate tetrahydrate [Ca(NO<sub>3</sub>)<sub>2</sub>·4H<sub>2</sub>O] on the properties of synthesized Ca(OH)<sub>2</sub> and its impact on the efficacy of the wastewater treatment i.e., MB dye removal. The details about the synthesis and characterization techniques are already reported by us elsewhere, [22,23] and hence, those aspects will be only briefly described here.



**Figure 1.** The XRD spectra of the nano  $Ca(OH)_2$  samples S1, S2, S3, and S4. As the molarities of the equimolar concentration of the reactants enhance, the samples S1, S2, S3, and S4 exhibit relatively higher intensity for a given peak suggesting thereby the presence of the relatively larger number of nano-crystallites taking a part in the X-ray diffraction process.

# **Results and Discussion**

### Structural Study

X-ray diffraction was used to study the phase, lattice parameters, structure, c/a ratio, crystallite size, atomic displacement, atomic volume, and anion-cation bond length of all the samples. In Figure 1, we show the XRD pattern of all the samples. From the analysis of the XRD spectra, the major phase of the synthesized samples is noted to be the hexagonal Ca(OH)<sub>2</sub> phase with space no.164 and space group of P3 m1 with minor differences in other structural parameters.<sup>[22]</sup>

The structural parameters like lattice parameters, c/a ratio, crystallite size calculated by Scherrer equation,<sup>[23]</sup> anion-cation bond length, volume, and atomic displacement of all the samples S1, S2, S3, and S4 are presented in Table 1. The average crystallite sizes are about 31.9 nm, 30.6 nm, 32.6 nm, and 33.4 nm considering all the planes of the samples S1, S2, S3, and S4 respectively. Thus, the average crystallite size varies from about 30 to 33 nm. Thus, the nanocrystallite size increases with an increase in reactant molarity. This increase in crystallites size with the increase in reactant molarity can be attributed to the increasing no. of reacting species per unit volume in the solution. Hence, with increasing molarity, the solution contains more calcium and hydroxide reactants to react. This process results in a larger size of crystallite.

### Functional group analysis

The functional groups present in the synthesized material are characterized using FTIR spectra (Figure 2). Most of the functional groups are present in all samples with a little variation and are well-matched with those reported in the literature.<sup>[23,24]</sup> The sharp absorption peak at 3740 cm<sup>-1</sup> in the spectra of all four samples corresponds to the stretching mode of the OH group. It also reveals that the Ca(OH)<sub>2</sub> hexagonal structure is present in all the samples. However, samples S3 and S4 with higher molarity indicate less intensity of -OH stretching modes. This could be due to the relatively lesser absorption of light in these relatively denser samples comprised of relatively larger nanocrystallites. The minor peaks at  $\sim 2400 \text{ cm}^{-1}$  and 1700 cm<sup>-1</sup> correspond to the atmospheric adsorption stretching of CO<sub>2</sub> and C=O respectively. Here also there is relatively lesser intensity noted for the samples S3, and S4. It may be due to the relatively lesser atmospheric adsorptions in these samples. The broad peak centered at 1500 cm<sup>-1</sup> is assigned to the v3 symmetric stretching of the surface CO<sub>3</sub> group. The peak





**Figure 2.** The FTIR spectra of the nano  $Ca(OH)_2$  samples S1, S2, S3, and S4. The FTIR spectra show the characteristic presence of both hydroxide and carbonate groups of calcium, as expected. The slight differences in relative intensities of various absorption bands could be due to the intrinsic variations in nanocrystallite size, microstructure and the amount of water present on the surface as well as in the structure of the various nano Ca(OH)<sub>2</sub> samples S1, S2, S3, and S4.

corresponds to the v2 symmetric deformation of the  $CO_3$  group appearing at 860 cm<sup>-1</sup>. The FTIR spectrum of all the samples shows the material characteristic peaks of both the groups of hydroxide and carbonate of calcium, as likely to appear.

### **Optical studies of samples**

The UV-Vis spectra of all the prepared samples as a function of wavelength as shown in Figure 3 with the wavelength range of 190–800 nm. The respective Tauc plots of the synthesized samples were shown in Figure 4 (a), (b), (c), and (d). The linear fits of Tauc plots give the direct optical band gap energy ( $E_g$ ) values of the samples S1, S2, S3, and S4 to be of ~5.74, 5.90, 5.73, and 5.25 eV in turn. Therefore, the optical band gap

generally decreases with an increase in molarity because the nanocrystallite size increases (Figure 1, Table 1), as expected.

These data (Figure 4) are comparable to the optical band gap energy value of about 5.81 eV measured by the similar UV-Vis spectroscopy technique for  $Ca(OH)_2$  nanopowders.<sup>[25]</sup> Thus, as the particle size decreases the gap between the valence and conduction bands increases. Therefore, the band gap energy value increases. It is further interesting to note that first principle calculations predict the band gap energy of Ca(OH)<sub>2</sub> to be in the range of 7.3 to 7.6 eV, as expected for a wide band gap semiconductor.<sup>[26]</sup> Thus, the experimentally measured band gap energy values are in reasonable match with the theoretical prediction.<sup>[26]</sup>

For hexagonal nanoparticles like the present  $Ca(OH)_2$  materials, the recent modeling shows that the energy band gap is given by:<sup>[27-29]</sup>

$$E_{g} = E_{b} \left[ 1 + \left\{ \frac{2d}{(4\pi R/3)^{1/3}} \right\} \right]$$
(1)

In Equation (1), d is the atomic diameter of the concerned atom, and R is the size of the corresponding nanocrystallite/ particle of that atom. Since the atomic diameter of  $Ca(OH)_2$  is constant, so (d) is constant in the present case. Therefore, it follows that if the nanocrystallite size increases  $E_g$  should decrease. This prediction exactly matches with the current experimental data trend (Figure 4). These observations also corroborate well with the data obtained from the structural (Figure 1) analysis by XRD and the functional group studies (Figure 2) by the FTIR technique.

### Wastewater study

The roles of several factors e.g., molarity, temperature, and reaction time were studied to understand their relative



Figure 3. The UV-Vis spectroscopy based absorbance spectra of the nano  $Ca(OH)_2$  samples S1, S2, S3, and S4 as a function of wavelength from 190 to 800 nm. The shift in absorbance band edge with the variation in nanocrystallite size in samples from S1 to S2 to S3 to S4 is very much evident.



Figure 4. The Tauc's plots for evaluation of the direct band gap energy values  $(E_g)$  of the different nano Ca(OH)<sub>2</sub> samples: (a) S1,  $E_g$  = 5.74 eV, (b) S2,  $E_g$  = 5.90 eV, (c) S3,  $E_g$  = 5.73 eV, and (d) S4,  $E_g$  = 5.25 eV.

contributions to the MB dye removal efficacies of the prepared samples.

# Effect of MB dye solution concentration and temperature on removal amount of MB Dye by samples

The percentage removal of the MB dye by the prepared samples S1, S2, S3, and S4 as a function of different MB dye concentrations were shown in Figure 5 (a), (b), (c), and (d), respectively for the three different temperatures of 25 °C, 35 °C, and 45°C. For almost all the cases (e.g., in 8 out of 9) the adsorption is the highest at the highest temperature of 45 °C. These data show further that at a given temperature, the % removal of MB dye solution increases with concentration, albeit, a little slowly. This happens as more MB dye molecules are available for the adsorption process to occur as the concentration of the MB dye solution increases. At a given temperature, however, the adsorption process tends to saturate out albeit slowly as the concentration increases. It happens as the number of MB dye molecules that could be taken care of by the adsorption process becomes exhausted soon. There are of course some small fluctuations in the data. These basically represent the intrinsic, random, statistical nature of the adsorption process. The linear trend lines are only to highlight the fundamental nature of variation. The adsorption capacities of all the four samples S1, S2, S3, and S4 at the three temperatures as a function of various MB dye concentrations are shown in Figures 6 (a), (b), (c), and (d) respectively. As

ChemistrySelect 2022, 7, e202200393 (4 of 9)

mentioned earlier, the adsorption capacities at a given MB dye solution concentration increase as the temperature increases. The viscosity of the dye solution decreases with an increase in temperature.<sup>[30,31]</sup> Therefore, the diffusion rate of the adsorbate across the surface and also within the internal pores of the adsorbent particles increases with an increase in temperature. The internal pores of the adsorbent samples can be seen in the FESEM image and are shown in the inset of respective Figures 5 (a), (b), (c), and (d). This process leads to increases in the adsorption capacities at a given MB dye solution concentration for all the samples with the increase in temperature. The underlying reason is that as the temperature increases the greater number of dye molecules may acquire sufficient energy. This process helps them to undergo more interactions with the active sites that are available on the surfaces of the nanocrystalline Ca(OH)<sub>2</sub> samples S1, S2, S3, and S4. A rise in adsorption process temperature also does two additional things. It decreases the force between the adjacent molecules of the MB dye. As a result, the viscosity decreases as mentioned above. Further, it enhances the adsorptive force between the MB dye molecule and the surface active sites of the nanocrystalline Ca(OH)<sub>2</sub> samples. The energetics of this process is also related to the band gap energy. Thus, it seems plausible to argue that all the related factors e.g., molarities of the initial reactants, the resultant microstructure, the nanocrystallite size, the consequent changes in surface area which provide the surface-active sites available to act as an adsorption site, the band gap energy, the concentration of the MB dye, and the





**Figure 5.** The % removal of methylene blue (MB) dye by different nano  $Ca(OH)_2$  samples as a function of MB concentration (100-500 ppm) with parametric variation in adsorption process temperatures, 25 °C ( $\blacksquare$ ), 35 °C ( $\bullet$ ), and 45 °C ( $\blacktriangle$ ): (a) S1, (b) S2, (c) S3, and (d) S4. The insets show the presence of pores in the respective microstructures of S1, S2, S3, and S4 viewed by the FESEM technique. All scale bars in the insets are of length 500 nm. The dotted trend lines are meant to depict only the basic trend of variation in the experimental data.

adsorption temperature may have complex yet simultaneous contributions on the dye removal capabilities of the samples S1, S2, S3, and S4. This is suggested to be the process that is most likely responsible for the relatively higher adsorption capacities of the nanocrystalline adsorbents S1, S2, S3, and S4 utilized for the various MB dye solutions, Figure 6. As shown in Table 2, there is a very good linear relationship between  $q_{ep}$  (i.e., the predicted value of  $q_e$ ) and concentration, C with  $R^2$  being more than 0.99 in most of the cases. These high values of  $R^2$  confirm that the proposed relationships in Table 2 genuinely represent the nature of variation in the data.

# Effect of molarity on % removal and absorption capacity of methylene blue dye

The data on percentage removal efficacies of the MB dye solutions of 100 to 500 ppm concentrations by the samples S1, S2, S3, and S4 at three different temperatures of  $25 \,^{\circ}$ C,  $35 \,^{\circ}$ C, and  $45 \,^{\circ}$ C as a function of dye concentrations are shown in Figure 7 (a), (b) and (c) respectively. Generally, at a given temperature the percentage removal efficacies of the MB dye solutions are also the highest for the sample S4 which corresponds to the highest i.e., 1 M concentrations of both Ca(NO<sub>3</sub>)<sub>2</sub>.4H<sub>2</sub>O and NaOH (Figure 7b,c). The general trend is

that the efficacies increase with the increase in molarities of the samples. In other words, the efficacy of S4 is > the efficacy of S3 is > the efficacy of S2 is > the efficacy of S1. However, there is a small exception to this general data trend. Thus, the data plotted in Figure 7 (a) show that the sample S2 prepared with a molarity of 0.6 M possesses the best removal efficiency at 25 °C followed by those of the samples S4, S3, and S1. It could be related to its relatively lower nanocrystallites size (Table 1), higher intensity of the surface hydroxyl group (Figure 2), and relatively higher optical band gap (Figure 4). Thus, it seems plausible to argue that since adsorption is the surface phenomenon the relatively higher surface to volume ratio results in the best performance of MB dye removal by the sample S2 at only room temperature. However, as the adsorption temperature increases due to the reasons explained above, the adsorption scenario changes to the general trend wherein the sample derived from the highest equimolar concentration of the initial reactants i.e., S4 exhibits the best adsorption efficacies; Figure 7 (b), and (c). Here also the linear trend lines are only to highlight the fundamental nature of variation.





**Figure 6.** The quantity ( $q_e$  in mg/g) of methylene blue (MB) dye adsorbed as a function of MB dye concentration (100-500 ppm) at adsorption process temperatures of 25 °C ( $\blacksquare$ ), 35 °C ( $\blacklozenge$ ), and 45 °C ( $\blacktriangle$ ) in various nano Ca(OH)2 samples: (a) S1, (b) S2, (3) S3, and (d) S4. The different solid lines are linear fits to the experimental data (Please see Table 2 and the related text for further details).

**Table 2.** The predicted linear relationships between the amounts of MB dye removed ( $q_{ep}$ ) and concentration (C) of MB dye as a function of adsorption process temperatures (e.g., 25 °C, 35 °C, and 45 °C) based on experimental data obtained for various nano Ca(OH)<sub>2</sub> samples S1 (Figure, 6a), S2 (Figure 6b), S3 (Figure 6c), and S4 (Figure 6d). The predicted linear relationships between the % of MB dye removed (MBR<sub>p</sub>%) and contact time T (0-60 min) for the various nano Ca(OH)<sub>2</sub> samples S1, S2, S3, and S4 based on experimentally measured data (Figure 8) are included in addition. The goodness of fit (i.e., R<sup>2</sup>) values is also included for all the fitted lines.

Figure	Calculated parameter	Data	Equation of line	R <sup>2</sup>
Figure 6a	$q_{ep}$ Predicted value of $q_{e}$ , C = Dye Concentration	0.4 M -25 °C	q <sub>ep</sub> =0.5553 C -42.93487	0.93411
		0.4 M -35 °C	$q_{ep} = 0.76153 C + 1.43287$	0.99582
		$0.4~\text{M}-45~^\circ\text{C}$	q <sub>ep</sub> =0.96213 C -8.08547	0.99845
Figure 6b	$q_{ep}$ Predicted value of $q_{e}$ , C = Dye Concentration	0.6 M -25 °C	q <sub>ep</sub> =0.97687 C -5.12762	0.99973
		0.6 M -35 °C	$q_{ep} = 0.8516 \text{ C} + 9.21129$	0.97358
		0.6 M -45 °C	q <sub>ep</sub> =0.98721 C -21.3395	0.99838
Figure 6c	$q_{ep}$ Predicted value of $q_{e}$ , C = Dye Concentration	0.8 M -25 °C	q <sub>ep</sub> =0.66788 C -23.59115	0.98329
		0.8 M -35 °C	q <sub>ep</sub> =0.90533 C -13.25403	0.99569
		0.8 M -45 °C	q <sub>ep</sub> =0.98055 C -4.60565	0.9997
Figure 6d	$q_{ep}$ Predicted value of $q_{e}$ C = Dye Concentration	1.0 M −25 °C	q <sub>ep</sub> =0.93654 C -18.32024	0.99902
		1.0 M −35 °C	q <sub>ep</sub> =0.99744 C -11.61647	0.99974
		1.0 M -45 °C	q <sub>ep</sub> =1.00205 C -8.90425	0.99967
Figure 8	MBR <sub>p</sub>	0.4 M	$MBR_{p}$ (%) = -0.03167T + 90.35432	0.96231
	(Predicted value of % MB Dye Removal), T -Time of Contact	0.6 M	$MBR_{p}$ (%) = -0.02091T + 91.72183	0.97891
		0.8 M	$MBR_{p}$ (%) = -0.02899T + 91.2482	0.9938
		1.0 M	$MBR_{p}$ (%) = $-0.0282T + 90.64846$	0.98089





Figure 7. Comparison of methylene blue (MB) dye removal efficacies of various nano Ca(OH)2 samples S1( $\blacksquare$ ), S2 ( $\bullet$ ), S3 ( $\blacktriangle$ ), and S4 ( $\triangledown$ ) as a function of the adsorption process temperatures: (a) 25 °C, (b) 35 °C, and 45 °C. The dotted trend lines are meant to depict only the basic trend of variation in the experimental data.



**Figure 8.** The comparison of methylene blue (MB) dye removal efficacies of various nano Ca(OH)2 samples S1( $\blacksquare$ ), S2 ( $\bullet$ ), S3 ( $\blacktriangle$ ), and S4 ( $\checkmark$ ) as a function of the contact time (0 to 60 min) at room temperature (e.g., 25 °C). The different solid lines are linear fits to the experimental data (Please see Table 2 and the related text for further details).

#### Effect of Contact Time on % Removal Efficacy of the MB Dye

Figure 8 shows the effect of contact time (0.5 to 60 min) of MB dye with the adsorbents S1, S2, S3, and S4 on the % removal efficacy by the adsorption process at room temperature. It is evident from the experimental data plotted in Figure 8 that the rate of dye removal is higher in beginning in all the samples. This may be due to the fact that in the beginning, the large surface area of the adsorbent is available for MB dye adsorption. After a few seconds, the adsorption process is slowed down because many of the available external sites available on the surface of the adsorbent are already occupied by the adsorbed dye. This process results in the slow diffusion of MB molecules on the surface and into the pores of the adsorbent. Consequently, it leads to the smaller percentage efficacies of MB dye removal. Similar observations are also for carbon-based adsorbents.<sup>[32,33]</sup> Here also, the predicted percentage of MB dye removal (MBRp%) bears a strong linear relationship with contact time T with R<sup>2</sup> values in most of the cases being more than 0.99 (Table 2). These high values of R<sup>2</sup> confirm that the proposed relationships in Table 2 genuinely represent the nature of variation in the data. As far as the mechanism of adsorption is concerned it is well-known that MB belongs to the category of cationic dye. Thus, it is suggested that the MB dye molecules get adsorbed on the surface of the Ca(OH)<sub>2</sub>



nano powders. This could happen because, alike Mg(OH)<sub>2</sub> nano powders, the Ca(OH)<sub>2</sub> nano powders also possesses a highly reactive, negatively charged surface.<sup>[34,35]</sup>

The implications of the present results are manifold. The first is of course that the  $Ca(OH)_2$  nano powders can be microstructurally tuned just by changing the molarities of the equimolar reactants such that better adsorption of the toxic MB dye could be affected. The process is found to be sensitive to variations in temperature and contact time as well as dye concentration. It also implies that such microstructural tuning could be also useful for the removal of other toxic ions such as  $Pb^{2+}$ ,  $Cu^{2+}$ ,  $As^{3+}$ ,  $Cu^{2+}$ , etc. In addition, it appears plausible to argue that appropriate optimization of nano crystallites size, hence surface area, and surface reactivity, as well as the porosity, could be done to give the desired performance for wastewater remediation. Such unique activities as well as the detailed study of the related reaction kinetics may provide the scope of our future work in this field.

### Conclusions

In the present research, it is concluded that by changing the molarity of reactants in the chemical precipitation method the physical properties of Ca(OH)<sub>2</sub> material can be varied. Four samples of different molarities of reactants are prepared. The major phase of hexagonal Ca(OH)<sub>2</sub> is observed by XRD. The synthesized material is highly effective in removing the MB dye from the aqueous solution. The adsorption capacity of Ca(OH)<sub>2</sub> is found to be dependent on the crystallite size, temperature, contact time, and MB dye concentration. From the results, it is observed that at low temperature i.e. 25°C the Ca(OH)<sub>2</sub> properties play an important role to remove the MB dye. However, at high temperatures i.e., 35°C and 45°C, the temperature factor becomes dominant in removing the MB dye from the aqueous solution. It is suggested that the temperature effect on dye removal may be related to the viscosity and molecular mobility.

## **Supporting Information Summary**

The supporting information includes the experimental details for the synthesis of calcium hydroxide, description of characterizations techniques, and the methylene blue dye removal experimental procedure.

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### **Conflict of Interest**

The authors declare no conflict of interest.

### **Data Availability Statement**

The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Keywords:** Calcium hydroxide · Ceramics · Dye removal · Methylene blue dye · Molarity effect · Nanoparticles

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