

# FTIR Spectral Analysis of Chitosan-Lignin Nanocomposites: A Comparative Analysis Before and After Imidazole Functionalization

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**Abstract:** In this work, chitosan, lignin, and their nanocomposite are analyzed using Fourier Transform Infrared Spectroscopy (FTIR) both before and after imidazole functionalization. The components' chemical bonds and structural interactions were assessed using FTIR. After composite synthesis and further modification, significant spectral changes and the appearance of additional absorption bands were noted. The findings demonstrated that imidazole groups were successfully conjugated to the chitosan-lignin matrix, increasing the variety of its functional groups and opening up new possibilities for environmental cleanup. The emergence and displacement of important peaks, including aromatic C=C stretching, amide I bands, and O–H/N–H stretching, revealed information on the creation of new covalent bonds and hydrogen bonds. These results confirm FTIR's validity as a trustworthy method for describing molecular interactions in bio-based nanomaterials.

**Keywords:** Ftir , Imidazole, Functional Groups, Chitosan, Lignin, Nanocomposites

## Introduction

Lignin adopts different functional groups such as  $-\text{OH}$ ,  $-\text{COOH}$ ,  $-\text{OCH}_3$  which gives rise to good water solubility under alkaline conditions. The water-soluble lignin can enhance the dispersion stability therefore is a good candidate as a coating agent to prepare magnetite nanoparticles. However, amino acids or organic acids with lower costs are usually used as capping agents of magnetite but have a poor dispersion stability in water. For developing a more economical and effective strategy, this simple and eco-friendly water-soluble conjugated system was reported using Lignin Dihydrate (LDH) as a surfactant for the first time to synthesize magnetite and lignin-based magnetite nanocomposite using a one-pot process. Firstly, the carboxyl groups ( $-\text{COOH}$ ) in LDH readily interact with  $\text{Fe}^{3+}$ , thus effectively coordinating and inhibiting the agglomeration of the formed magnetite. Secondly, it was further illustrated that the interaction between  $\text{Fe}^{3+}$  and the phenolic- $\text{OH}$  groups of LDH was responsible for the phase transfer of magnetite from organic to aqueous media. Finally, the doxorubicin (DOX) drug loading capability of L-MNPs was investigated (1),(2). The good load efficiency and a sustained drug release profile were achieved.

A growing interest is emerging in developing low-cost, low toxic and efficient adsorbents for the removal of heavy metals from wastewater. Limonene, a nonpolar terpenoid compound derived from plant sources, possesses the capability of metal ion extraction which forms a complex with Lewis acid to form stable neutral ion-paired in nonpolar medium. However, its eventual elimination from environment and its relatively poor performance make it less desirable for use in practical applications. A new hybrid composite was synthesized as a novel adsorbent for the removal of  $\text{Cu}(\text{II})$  from aqueous solution fabricated by dispersing a biopolymer lignin with eco-friendly sedimentation technique. The  $\text{Cu}(\text{II})$  removal mechanism was elucidated through FTIR and UV-vis spectroscopy which confirmed the binding of lignin with  $\text{Cu}(\text{II})$  ions. On the basis of its low-cost and robust merits, the as-obtained adsorbent exhibits great promise for practical applications in effective removal of  $\text{Cu}(\text{II})$  ions from wastewater, inspiring the design of other hybrid composites. Additionally, the novelty of the hybrid composite lies in its unique surfactant property which can be related with its potential for removal of organic pollutants from water (3),(4).

## Materials and methods

The chemical bonds were verified using FT-IR spectroscopy. The instrument utilized was a Tensor 2 (Bruker, Germany). A 12-ton press was used to crush the samples into pellets after they had been combined with 200 mg of KBr. The range of spectra measured was  $400\text{--}4000\text{ cm}^{-1}$ . Peaks were examined to find imidazole,  $-\text{OH}$ , and  $-\text{NH}_2$  groups. The chemical alterations at every stage of the procedure were validated by these signs (5).

A comprehensive image of the nanocomposite was provided by the integration of the data from FT-IR, The element mapping produced the anticipated outcomes. The presence of bonding was verified by the FT-IR peaks. The synthesis's success was validated by all three instruments.

## Results

### FT-IR Spectroscopic Analysis

To verify the chemical changes and bonding interactions between chitosan and lignin, FT-IR spectroscopy was used. The comparative FT-IR spectra of pure chitosan, lignin, and the original chitosan-lignin nanocomposite are shown in ( Table 1)  $-\text{OH}$  and  $-\text{NH}_2$  stretching are represented by distinctive peaks in the chitosan spectra at  $3400\text{ cm}^{-1}$  and  $1650\text{ cm}^{-1}$ , respectively. Lignin displayed clear  $\text{C}=\text{O}$  stretching at around  $1270\text{ cm}^{-1}$  and aromatic ring vibrations close to  $1600\text{ cm}^{-1}$ . Shifts and overlaps in these peaks within the chitosan-lignin composite validate the two polymers' chemical connection and hydrogen bonding.

**Table (1) : FTIR Spectral Analysis of Functional Groups in Lignin, Chitosan, and Nanocomposite**

Peak Position (cm <sup>-1</sup> )	Observed In (Lignin / Chitosan / Nanocomposite)	Functional Group Assignment
3400	Lignin, Chitosan, Nanocomposite	O–H stretching (hydroxyl groups)
2940	Lignin, Nanocomposite	C–H stretching (methyl and methylene groups)
1700	Lignin, Nanocomposite	C=O stretching (carbonyl groups)
1650	Chitosan, Nanocomposite	Amide I (C=O stretching in amide groups)
1600	Lignin, Nanocomposite	C=C stretching (aromatic rings)
1380	Chitosan, Nanocomposite	C–N stretching (amine groups)
1270	Lignin, Nanocomposite	C–O stretching (phenolic groups)

( Table 2 ) provides further information by comparing the FT-IR spectra of Chitosan-Lignin and Chitosan-Lignin-IM. Near 1720 cm<sup>-1</sup> and 1575 cm<sup>-1</sup>, the imidazole-functionalized material exhibits new bands that correspond to imidazole ring vibrations and C=O stretching. These spectrum characteristics verify that carboxylic imidazole was successfully grafted onto the backbone of the polymer. The imidazole moiety may be involved in bonding interactions, as shown by the decrease in the –OH stretching intensity. All of these findings show that the nanocomposite has improved structurally and undergone chemical conjugation.

**Table (2) : FT-IR Peak Assignments for Chitosan-Lignin and Chitosan-Lignin-IM Nanocomposites**

Wavenumber (cm <sup>-1</sup> )	Assignment	Notes
~3400	O–H and N–H stretching	Broad peak, more intense in Chitosan-Lignin, indicating hydrogen bonding
~1650	Amide I (C=O stretching)	Prominent in Chitosan-Lignin; shifts in Chitosan-Lignin-IM
1500–1400	C=N and aromatic C=C stretching	Imidazole incorporation affects this region
~1480	Aromatic C=C stretching	Indicates presence of aromatic structures
~1380	C–N stretching	Present in Chitosan-Lignin; altered in Chitosan-Lignin-IM
1250–1050 (not labeled)	Possibly C–O–C or C–O vibrations	May vary depending on lignin/chitosan linkage

Imidazole ring vibrations are responsible for the emergence of new bands about 1500–1400 cm<sup>-1</sup>, indicating effective grafting. The development of covalent bonds and hydrogen bonds with the imidazole is further supported by the decrease in O-H/N-H stretching intensity.

### Discussion

The synthesis of Chitosan-Lignin-IM nanocomposites in this study showed that natural biopolymers can be successfully combined with imidazole groups. This created a hybrid material

with strong ability to remove heavy metals from water. FESEM images revealed a clear nanostructure. The particles were evenly spread across the surface. This supports the idea of nanoscale integration. Ayanda *et al.* also found that better particle dispersion improves surface activity and pollutant binding. They explained this happens because of higher surface area and more active sites (6). FT-IR analysis further confirmed that imidazole groups were attached to the composite. This modification is important. It increases electron-donating properties and helps the material attract metal ions. A similar benefit was described by Boominathan and Sivaramakrishna. They showed that adding polar groups like imidazole to chitosan can enhance metal ion chelation and pollutant removal (7). Important chemical alterations in the chitosan-lignin nanocomposite following imidazole functionalization are highlighted by the spectrum data in Table (2). The participation of hydroxyl and amine groups in new covalent bonding is shown by the decrease in intensity of the wide band at around  $3400\text{ cm}^{-1}$  (O–H and N–H stretching). A change in the  $\sim 1650\text{ cm}^{-1}$  (C=O stretching) band indicates that imidazole and carbonyl groups are interacting (8) The imidazole ring's effective grafting is confirmed by new, stronger peaks at  $1500\text{--}1400\text{ cm}^{-1}$ . The lignin aromatic structure is preserved, as seen by the  $\sim 1480\text{ cm}^{-1}$  peak. Changes in the  $1250\text{--}1050\text{ cm}^{-1}$  area indicate variations in ether or polysaccharide connections as a result of the altered chemical environment, whereas changes in the  $\sim 1380\text{ cm}^{-1}$  (C–N stretching) band demonstrate the involvement of amine groups in bonding (9) (10) .

## Conclusion

In this study, The chemical modification and stepwise synthesis of chitosan-lignin nanocomposites were successfully validated by the FTIR analysis. The appearance of distinctive spectral bands and changes in preexisting peaks served as confirmation of the integration of imidazole functional groups. These spectrum characteristics are in line with structural alterations that improve the nanocomposite's adsorption and other environmental application capabilities. A useful technique for tracking chemical interactions in bio-based nanomaterials is FTIR spectroscopy.

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