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Exploring Gelatin Films for Environmental Applications: Challenges and Opportunities

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ABSTRACT

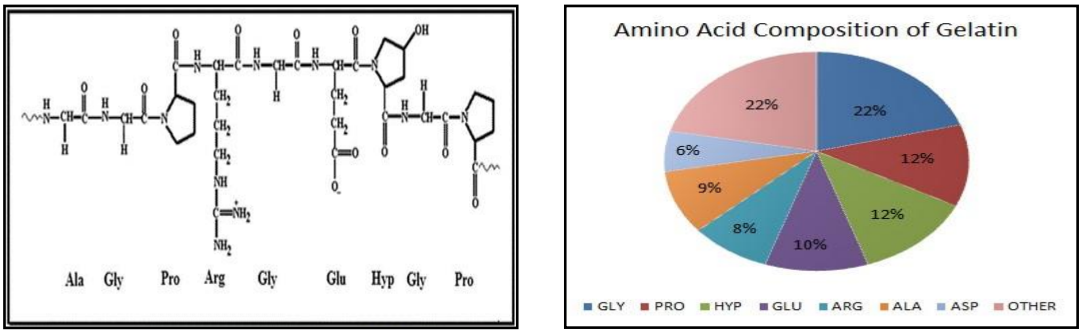
In this study, gelatin films were prepared by dissolving gelatin in distilled water with mechanical stirring, followed by casting the solution into films. The biodegradability of these films was confirmed through soil burial tests, and their rapid dissolution in water was evident, with a measured water solubility of 29±1.6%. The structural integrity and thermal stability of the films were characterized using UV and FTIR. The films exhibited significant UV-visible light absorbance, with a peak at 300 nm within the 280 to 480 nm range. FTIR spectra revealed the characteristic amide peaks of gelatin, indicating the presence of key functional groups. This research also highlighted the films' ability to adsorb copper ions from acidic solutions, as demonstrated by iodometric titration, and to treat hard water through complexometric titrations. These findings illustrate the potential of gelatin films as effective adsorbents for copper ions and water hardness, making them promising candidates for environmental remediation and wastewater treatment. The study highlights rapid water solubility as a critical limitation of gelatin films, restricting their functionality in aqueous and humid environments. Addressing this challenge could significantly enhance their stability and expand their potential applications in environmental remediation and water treatment technologies.

Keywords: Gelatin; Environment-friendly; Biodegradable; Film; Transparent; Swelling; Solubility; Adsorption; Iodometric; Complexometric.

1. Introduction

Gelatin-based films are emerging as promising alternatives to synthetic materials due to their unique properties and versatility. Gelatin, derived from collagen through partial hydrolysis, is widely recognized for its effectiveness in film formation and diverse applications across various industries. It is used in food packaging, coatings, cosmetics, and as a binding agent in the paper industry due to its natural surfactant properties and biocompatibility [1][2][3]. Additionally, gelatin films are utilized in biomedical applications such as wound dressings, drug delivery systems, and tissue engineering, benefiting from their ability to support cell growth and controlled drug release [4][5][6].

The hydrophilic nature of gelatin makes it suitable for membrane-based applications in water filtration and bioengineering [7][8]. Gelatin films possess functional groups that can chelate heavy metal ions through complexation or ion exchange [Figures 1 (a) and (b)], and their porous structure provides a large surface area for effective adsorption [9]. This capability makes them suitable candidates for water treatment, metal ion recovery from industrial effluents, groundwater remediation, and wastewater purification [10].



(a) (b)

Figure 1. (a) Structure of Gelatin, and (b) Amino acid composition [11,12]

Despite these advantages, gelatin films encounter challenges such as poor water solubility and limited adsorption capacity for heavy metals, which restrict their broader application in environmental remediation. Overcoming these limitations is crucial for fully realizing the potential of gelatin films as sustainable adsorbents.

To advance this field, the research focuses on specific objectives: preparation and characterization of gelatin films for structural analysis using spectroscopic techniques and optimization of film properties. This study includes a comprehensive examination of gelatin films, covering physico-chemical properties such as film thickness, swelling behavior, solubility, pH, and biodegradability. The films are also subjected to biodegradability tests and characterized using UV spectroscopy, FTIR, and TGA to evaluate their chemical and thermal stability.

Furthermore, the study explores the environmental potential of gelatin films, specifically their capacity for copper metal ion uptake and treatment of hard water. Using iodometric and complexometric titration techniques, this research quantifies copper ion adsorption and evaluates the films' effectiveness in mitigating water hardness. By addressing these aspects, the study aims to enhance the practical applications of gelatin films in environmental remediation and contribute to the development of sustainable materials.

1.1. Study Objectives

The objectives of this study are: (1) To synthesize gelatin films and evaluate their potential applications, (2) To analyze the physico-chemical properties of the synthesized films, (3) To characterize the films using UV and FTIR spectroscopy for structural and functional insights, (4) To explore the environmental application of the films by assessing their metal ion uptake capacity for copper sulphate using iodometric titration, and (5) To examine their effectiveness in hard water treatment through complexometric titration.

2. Materials and Methods

2.1. Materials Required

Gelatin (Molychem), Distilled Water, Copper sulphate solution ($CuSO_4$)[CDH (P)Ltd.], Hard water (GBU), Soil, pH meter (Hach HQ440d multi), U.V. Spectrometer(Shimadzu UV-1800), IR spectroscopy (Bruker FTIR Alpha II), TGA (Perkin Elmer 4000), heating mantle, filter paper, petri dish, magnetic stirrer, burette, pipette, M/40 sodium thiosulphate solution (Laboratory Reagent Rankem), KI (Analytical Reagent Rankem), starch [CDH (P)Ltd.], EDTA (Analytical Reagent Rankem), EBT (Laboratory Reagent Rankem), NH_4Cl (Sigrama-Aldrich), spatula, beakers.

2.2. Preparation of gelatin films

A digital balance was used to correctly weigh three different amounts of gelatin powder: 1000mg, 5000mg, and 10,000mg. In a clean and dry beaker, each weighed amount of gelatin powder was added to 60 mL of distilled water separately. To ensure proper mixing, the gelatin-water combination was carefully mixed. The beaker containing the gelatin-water solutions was put on a heating mantle and heated to 60 °C. The heating process lasted 2 hours, with constant stirring using a magnetic stirrer. The goal was to completely dissolve the gelatin in water and get a homogenous solution. After two hours of heating and stirring, the gelatin solutions were ready for casting into films. The solution casting method was employed for this purpose. Each gelatin solution was poured into separate petri dishes, and the dishes were covered with lids to prevent dust and contamination.

The petri dishes containing the gelatin solutions were then left to cool and solidify at room temperature. The cooling process typically took 2 to 4 days, depending on the specific composition of the gelatin solution. This allowed the gelatin films to set and achieve their desired physical properties.

The gelatin films were carefully removed from the petri dishes once they had solidified. The thickness, swelling behaviour, solubility, UV-visible absorbance, FTIR and TGA of the films were then measured. The films were biodegradable tested by burying them in natural soil and monitoring their deterioration over time.

The results of the film characterisation and biodegradability tests were evaluated to identify the effect of gelatin concentration on the film properties. The findings were put to use to better understand the relationship between gelatin composition and film performance.

2.3. Physico-chemical properties of gelatin films

2.3.1. Film thickness

The thickness of the films was measured using a screw gauge with an accuracy of ± 0.01 mm.

2.3.2. Swelling behaviour

After the gelatin films had solidified and attained their desired physical properties, each film was carefully cut into two pieces, each measuring (2x3) cm, using a clean and sharp cutting tool. This ensured uniformity in the film dimensions for accurate measurements.

The cut film samples were then dried to remove any surface moisture and ensure accurate measurements. Each film piece was placed in a controlled environment, such as an oven or desiccator, to facilitate the drying process. Once completely dried, the initial weight (W_1) of each film piece was measured using a precise digital balance. To measure the swelling behaviour of the gelatin films, the dried film pieces were submerged in water. The films were left in the water for a sufficient period to allow them to swell. The water absorption during swelling is a characteristic property of the gelatin films. After the swelling process was complete, the swollen film pieces were carefully removed from the water and placed on a clean surface. To remove excess surface water, filter paper or blotting paper was gently pressed against the film samples. This step ensured that the measurements were not affected by surface moisture and the experiment was repeated three times.

Final Weighing: Once the surface water was partially removed, the swollen film pieces were weighed again using the same digital balance. The final weight (W_2) of each swollen film piece was recorded.

Calculation of Swelling Percentage: For each film sample, the swelling percentage was calculated using Eq. (1):

$$\text{Swelling\%} = 100 * (W_2 - W_1) / W_1 \quad \ldots(1)$$

Where: W_2 = Weight of the swollen film, W_1 = Weight of the dried film.

The swelling percentage was calculated for both pieces of each film, and the measurements were taken twice to ensure accuracy [13].

2.3.3. Solubility behaviour of gelatin films

Once the gelatin films were completed, they were cut into (2×3) cm pieces with a clean and sharp cutting tool. The film pieces were handled with care to achieve uniform size and shape.

Each piece of film was dried to remove any surface moisture. The dry film fragments were then individually weighed using a precision digital scale to ascertain their initial weight (W_i).

The dried film segments were then submerged separately in 20 mL of distilled water and placed in clean containers. The immersion was done out at room temperature (ambient temperature) to imitate typical environmental conditions.

The films were submerged in water for 8 hours, during which time the gelatin films absorbed water, causing swelling and solubilization. During the 8-hour immersion time, any insolubilized residues or undissolved sections of the films were removed from the water and placed on filter paper to drain excess water.

The insolubilized residual film, which represents the fraction of the film that did not dissolve during the immersion, was weighed separately on the same digital balance. The weight of the insolubilized residual film was recorded as W_f.

Calculation of Solubility Percentage: For each film, the solubility percentage was calculated using the given Eq. (2):

$$\text{Solubility \%} = 100 * (W_i - W_f) / W_i \qquad \ldots(2)$$

Where: W_i = Initial weight of the film, W_f = Weight of the insolubilized residue film.

The measurements were taken at different time intervals for each film until complete dissolution occurred and the experiment was repeated three times.

2.4. pH

Accurately measured 500mg of gelatin using a digital balance and placed it in a clean and dry beaker. Added 100 mL of distilled water to the beaker containing the gelatin. Stir the mixture gently to aid the dissolution process.

Once the gelatin is completely dissolved in the water, use a pH meter to determine the pH of the solution. The determination of the pH of the gelatin solution is essential for understanding its acidity or basicity.

2.5. Characterization

The combination of UV-visible and FTIR spectroscopy provides valuable information about the absorbance and chemical properties of the gelatin films.

2.5.1. UV- Visible spectroscopy

The gelatin film was subjected to UV-visible spectroscopy in the wavelength range of 200-480 nm. To prepare the sample, 500mg of gelatin was dissolved in lukewarm water at 40°C and allowed to cool to room temperature. As a reference, distilled water was used as a standard solution during the spectral measurement in the same wavelength range.

2.5.2. Fourier transform infrared spectroscopy

Within gelatin molecules, chemical bonding, conformation, and interactions can be obtained [14,15]. The gelatin film was first dissolved in chloroform before being subjected to FTIR examination [16]. The FTIR spectra of pure gelatin films made by solution casting were obtained in the 400-4000 cm^{-1} wavenumber region with a resolution of 4 cm^{-1}.

2.6. Environmental applications

2.6.1. Metal ion uptake

The iodometric titration offers a quantitative measure of the copper sulphate concentration, which aids in understanding the adsorption effectiveness of gelatin films and their prospective uses in environmental and wastewater treatment processes. The following approach was used to test the adsorption behaviour of gelatin films of varied weights (1000mg, 5000mg, and 10,000mg) toward copper sulphate solution. The experiment gives details regarding the adsorption behaviour of gelatin films of varied thicknesses and their ability to reduce the concentration of copper sulphate solution. The decreasing concentration trend with time is demonstrated by the graphical display of the titration findings. To accomplish iodometric titration, following approach was adopted.

1M solution of copper sulphate was made by dissolving 159.6 grams of copper sulphate in 1 litre of distilled water. The solution was thoroughly agitated until the copper sulphate was entirely dissolved, yielding a homogeneous blue-coloured solution of copper sulphate.

Prepared 1M copper sulphate solution and 10 mL solution of it was taken in an iodometric flask. A suitable amount of KI was added to the copper sulphate solution in the iodometric flask. The mixture was stirred gently to ensure proper mixing. Covered the iodometric flask and kept it undisturbed until the solution turned brown due to the liberation of iodine (I_2). The reaction is represented by Eq. (3). Titrated the liberated iodine with a standard solution of sodium thiosulphate ($Na_2S_2O_3$) until the brown solution turned straw-yellow. Added a small amount of starch as an indicator to the solution. The solution turned blue due to the formation of the starch-iodine complex. The liberated iodine reacted with sodium thiosulphate, forming sodium tetrathionate and sodium iodide, as shown in Eq. (4). The reactions that are taking place are:

$$2CuSO_4 + 4KI \rightarrow I_2 + Cu_2I_2 + 2K_2SO_4 \quad \ldots(3)$$

$$KI + I_2 \rightarrow KI_3 \quad \ldots(4)$$

$$2Na_2S_2O_3 + I_2 \rightarrow Na_2S_4O_6 + 2NaI \quad \ldots(5)$$

Titration was resumed with sodium thiosulphate until a milky-whitish blue precipitate of CuI (copper iodide) appeared. Recorded the titre value, which represented the volume of sodium thiosulphate solution used in the titration.

Three distinct gelatin films were taken, each weighing 1000mg, 5000mg, and 10,000mg, and cut into uniform measurements of (2x3) cm with a clean and sharp cutting tool. To remove any surface moisture, the gelatin film was dried. Individual dry gelatin films were weighed using a digital scale to ascertain their initial weights in the dried state.

Separate beakers with 10mL of copper sulphate and hard water solution were prepared. Each gelatin film was immersed in its beaker containing the solution. The films were immersed in the solution for 4-5 hours to enhance the absorption process.

Removed the gelatin films from the copper sulphate solution once the adsorption process was complete. The oxidising agent (copper sulphate) solution liberates iodine from potassium iodide (KI) in this process. The released iodine is then titrated using starch as an indicator against a standard solution of sodium thiosulphate (hypo) from a burette.

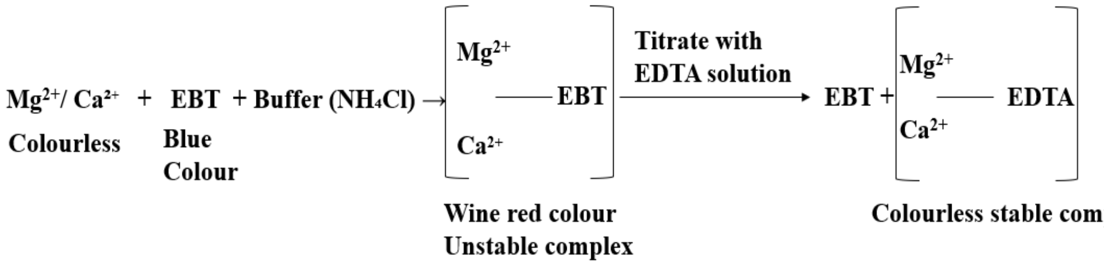
Calculated the concentration of the copper sulphate solution using the titre value and the known concentration of the standard sodium thiosulphate. By maintaining the films in separate solutions, the same method is repeated for each gelatin film (1000mg, 5000mg, and 10,000mg). Titration was carried out at regular intervals, such as every 1 hour, until the films were entirely dissolved. Titration results were recorded at various time intervals for each gelatin film. By following this procedure, observed the change in the concentration of the copper sulphate over time, as the gelatin films adsorb the copper sulphate.

2.6.2. Treatment of hard water

In complexometric titration, water hardness is determined using 0.1M EDTA, Eriochrome Black T (EBT) as an indicator, and an NH_4Cl buffer. The procedure begins by adding EBT to the hard water sample, which results in a wine-red colour due to the formation of a complex between EBT and the calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions present in the water. The NH_4Cl buffer maintains a stable pH throughout the titration, which is crucial for accurate results.

Complexometric titration using 0.1M EDTA measures water hardness by titrating against calcium and magnesium ions. A 0.1M EDTA solution was prepared by dissolving 372.2 grams of EDTA in 1 litre of distilled water. Eriochrome Black T (EBT) indicator was used, which changes from wine-red to blue at the endpoint, signalling the total concentration of these ions in the sample.

During the titration, EDTA is gradually added to the solution. EDTA has a higher affinity for Ca^{2+} and Mg^{2+} ions than EBT, so it preferentially forms complexes with these ions. As the EDTA binds to the free Ca^{2+} and Mg^{2+} ions, the EBT is displaced, leading to a gradual colour change. The endpoint of the titration is reached when all the Ca^{2+} and Mg^{2+} ions are complexed by EDTA, causing the solution to change from wine-red to blue. This colour change indicates that EDTA has completely removed the Mg^{2+} ions from the EBT, signalling the completion of the titration as shown in Eq. (6).



$$\underset{\text{Colourless}}{Mg^{2+}/Ca^{2+}} + \underset{\substack{\text{Blue}\\ \text{Colour}}}{EBT} + \text{Buffer }(NH_4Cl) \rightarrow \underset{\substack{\text{Wine red colour}\\ \text{Unstable complex}}}{\left[\begin{matrix} Mg^{2+} & \\ & \text{—— } EBT \\ Ca^{2+} & \end{matrix}\right]} \xrightarrow{\substack{\text{Titrate with}\\ \text{EDTA solution}}} EBT + \underset{\text{Colourless stable complex}}{\left[\begin{matrix} Mg^{2+} & \\ & \text{—— } EDTA \\ Ca^{2+} & \end{matrix}\right]} \qquad (6)$$

The volume of EDTA used at the endpoint is measured and used to calculate the hardness of the water, reflecting the total concentration of Ca^{2+} and Mg^{2+} ions. This method is effective because EDTA forms stronger and more stable complexes with these metal ions than EBT, ensuring precise and reliable results.

Three distinct gelatin films were taken, each weighing 1000mg, 5000mg, and 10,000mg, and cut into uniform measurements of (2x 3) cm with a clean and sharp cutting tool. To remove any surface moisture, the gelatin film was dried. Individual dry gelatin films were weighed using a digital scale to ascertain their initial weights in the dried state.

Separate beakers with 10mL of hard water solution were prepared. Each gelatin film was immersed in its beaker containing the solution. The films were immersed in the solution for 4-5 hours to enhance the absorption process.

Calculated the concentration of the hard water using the titre value and the known concentration of the EDTA solution respectively. By maintaining the films in separate solutions, the same method is repeated for each gelatin film (1000mg, 5000mg, and 10,000mg). Titration was carried out at regular intervals, such as every 1 hour, until the films were entirely dissolved. Titration results were recorded at various time intervals for each gelatin film. By following this procedure, observed the change in the concentration of the hard water solutions over time, as the gelatin films adsorb the ions (Ca^{2+} and Mg^{2+}) of the water.

3. Results

3.1. Physical properties and thickness

A dry, pale yellow and thick films are formed and slowly peeled off from the petri dishes as shown in Figure 2.

Physical appearance of films:

(a) Odour: odourless

(b) Colour: colourless or pale yellow

(c) Taste: tasteless

(d) Appearance: transparent

(e) Brittleness: 1000mg is brittle while 5000mg and 10,000mg are strong and hard

(f) Solubility: soluble in polar solvents

(a) (b) (c)

Figure 2. Physical Appearance of Gelatin film (a) 1000mg, (b) 5000mg, and (c) 10,000mg

A screw gauge with the lowest count of 0.01 is used to measure the thickness of all three films. The thicknesses of 1000mg, 5000mg, and 10,000mggelatin films were 0.05mm, 0.21mm, and 1.09mm, respectively. This demonstrates that as the concentration of the gelatin films grows, along with their thickness.

3.2. Physico-chemical properties of gelatin films

3.2.1. Swelling behaviour

The swelling percentage of gelatin films at different concentrations is shown in Figure 3. As the concentration of gelatin increases, consequently increases the ability of the films to swell. The swelling percentage after using 1000mg of gelatin is 167.4%. With 5000mg of gelatin, the swelling percentage climbs to 292.1%, and with 10,000mg of gelatin, it rises to 426.7%.

Figure 4 depicts the swelling behaviour of gelatin films in visual form. This suggests that larger gelatin concentrations cause higher degrees of swelling in the gelatin films.

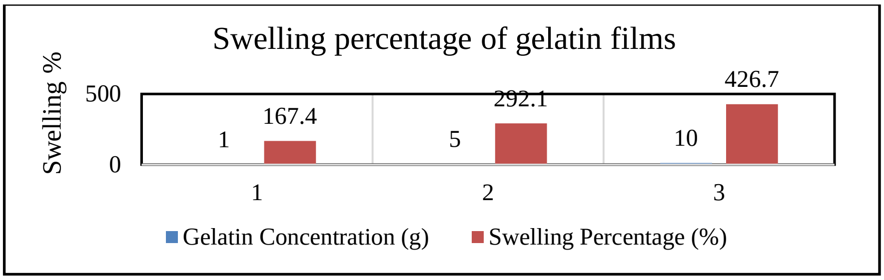
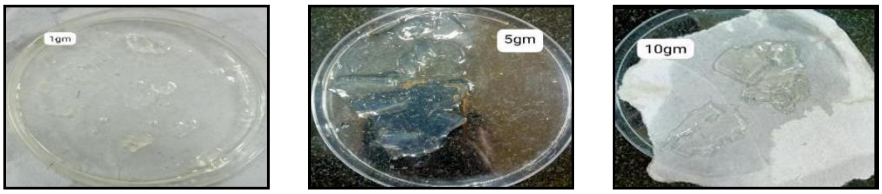


Figure 3. Swelling percentage of gelatin films at different concentrations



(a) (b) (c)

Figure 4. Solubility of Gelatin films (a) 1000mg, (b) 5000mg, and (c) 10,000mg

3.2.2. Solubility behaviour of gelatin films

Figure 5 represents the solubility percentage of gelatin films under different conditions. As the weight of the gelatin film increases, the solubility percentage decreases. For a gelatin film weighing 1000 mg, the solubility percentage is 29 ± 1.6%, for 5000 mg gelatin film the solubility percentage decreases to 12 ± 0.8% and for a 10,000 mg gelatin film, the solubility percentage further reduces to 7.2 ± 0.6%.

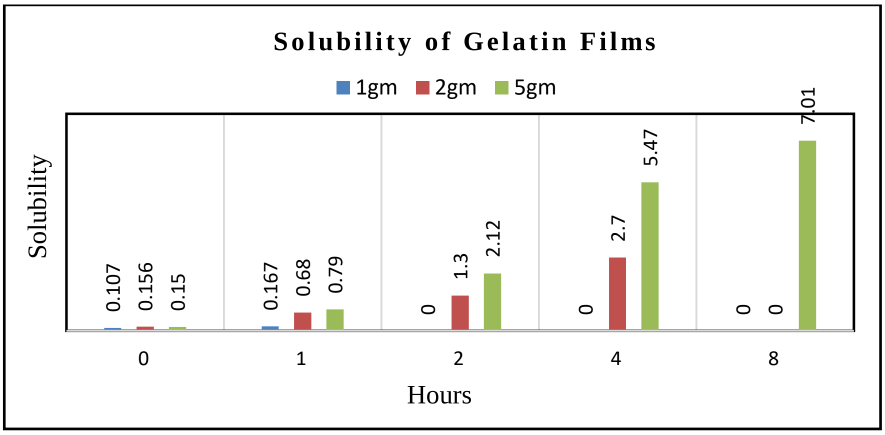


Figure 5. Solubility of Gelatin films

According to the research, higher gelatin film weights result in lower solubility percentages, implying that films with greater mass are more resistant to dissolving in water. All gelatin films are water soluble to some extent, and prolonged exposure to high levels of ambient humidity may result in partial disintegration and loss of fibre structure in the films.

3.2.3. pH

Gelatin film which is non-shiny, pale yellow and odourless has a pH value of 5.15 measured by using a pH meter.

3.3. Characterization

3.3.1. UV- Visible spectroscopy

The UV spectrum graph of gelatin typically shows a peak at 300 nm. This peak is sharper and more pronounced because proteins, including gelatin, exhibit a strong absorbance at this wavelength. The absorbance is primarily attributed to the presence of specific amino acid residues, such as Tryptophan and Tyrosine, in the gelatin molecule. Tryptophan and Tyrosine are aromatic amino acids with conjugated double bonds in their side chains, which makes them particularly sensitive to UV light. When exposed to UV radiation, these residues efficiently absorb the light, resulting in a characteristic peak in the UV spectrum.

This UV absorbance peak at 300 nm can be utilized to identify and quantify gelatin in various samples and is a valuable tool for analysing the protein content of gelatin-based materials as shown in Figure 6.

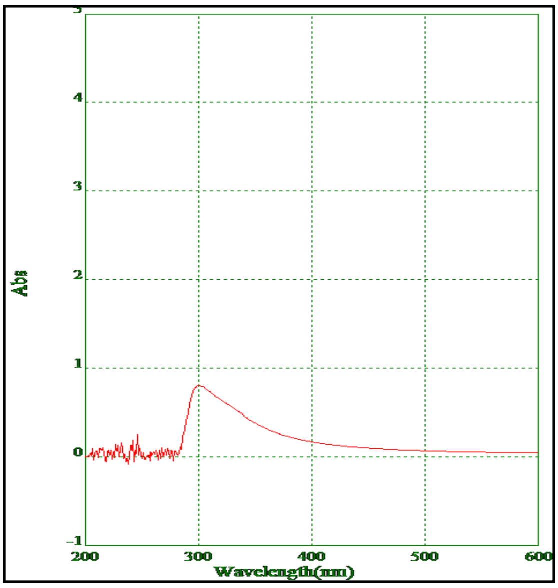


Figure 6. UV-VIS Spectrum graph of gelatin

3.3.2. Fourier transform infrared spectroscopy

The FTIR spectrum of gelatin, as shown in Figure 7, displays several characteristic peaks that correspond to different functional groups present in the gelatin molecule. The reported gelatin peaks and their corresponding wavenumbers are as follows [17]:

Amide-A and free water: Observed at 3418 cm-1, indicating the presence of O-H stretching vibrations and possibly associated with both amide groups and free water molecules in the gelatin.

Amide-I: Occurring at 1636 cm-1, this peak corresponds to the C=O stretching vibrations and hydrogen bonding pairs involving COO^- groups in the gelatin sample.

Amide-II: Evident at 1455 cm-1, this peak represents the bending vibrations of N-H groups and stretching vibrations of C-N groups in the gelatin structure.

Amide-III: Detected at 2123 cm-1, this peak is associated with vibrations in the plane of N-H and C-N groups of the amide bonds in gelatin.

Peak at 2926 cm-1, is observed due to the presence of asymmetric stretching vibrations of CH_2 groups in the gelatin molecule.

Peak at 620 cm-1, is observed due to the presence of OCN bending groups present in gelatin molecule.

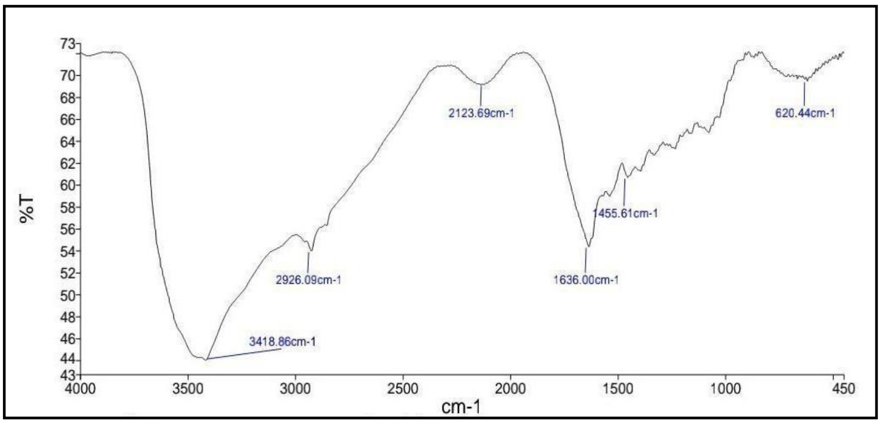


Figure 7. FTIR spectrum of Gelatin

3.4. Environmental applications

A novel approach involving titration was performed for the first time to investigate the adsorption properties of gelatin film via metal ion uptake experiment.

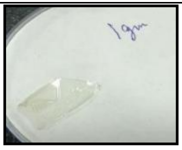
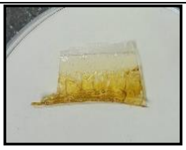
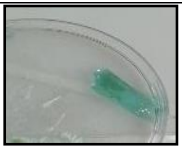
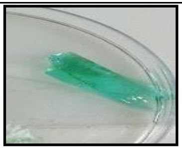
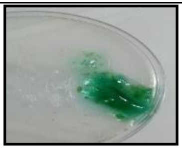
The adsorption process is defined by a rate law, and the concentration of adsorbate (copper ions and hardness of water) drops with time until either the adsorbate or the adsorbent (gelatin film) is exhausted. The initial adsorption process is quick, resulting in a large reduction in concentration during the first few hours. However, as the time passes, the adsorption process slows down, probably due to a decrease in the accessible surface area of the film, resulting in a drop in the efficacy of adsorbing ions.

3.4.1. Metal ion uptake

The absorption phenomenon is observed in gelatin film by colour changing method from pale yellow of pure gelatin film to blue of copper sulphate solution. This indicates that the polymeric film absorbs metal ions. For this, samples of films were kept in the $CuSO_4$ solution in a beaker and taken out after every 1 hour and checked till they dissolved completely in the solution.

Iodometric titration was performed to determine the change in the concentration of copper sulphate solution over time. Table 1 represents the colour change of gelatin films at different time intervals during the adsorption process of Cu(II) ions from the copper sulphate solution. Initially, all three gelatin films (1000mg, 5000mg, and 10,000mg) appeared as pale yellow, which is the natural colour of pure gelatin film. After 3 hours, the 1000mggelatin film becomes soluble in the copper sulphate solution, indicating the absorption of Cu(II) ions onto the film. After 4 hours, 5000mg gelatin film is soluble in the copper sulphate solution, suggesting the complete absorption of Cu (II) ions onto these films. The 10,000mggelatin film was still pale yellow after 5 hours, implying that it had not yet absorbed all the Cu(II) ions from the solution.

Table 1. Pictorial representation of the adsorption process of Cu (II) ions by Gelatin films

Time (hours)	**1000mg**	**5000mg**	**10,000mg**
Initial			
1			
2			
3			
4	Soluble		
5	Soluble	Soluble	
6	Soluble	Soluble	Soluble

This pictorial representation demonstrates the progressive absorption of Cu(II) ions by gelatin films over time, with higher gelatin concentrations (5000mg and 10,000mg) taking longer to reach complete absorption compared to the lower concentration (1000mg) film.

The results demonstrating the reduction in Cu ion concentration by gelatin films through the adsorption method are summarized in Table 2. Figure 8 provides a graphical representation of the copper sulphate solution concentration over time for gelatin films of varying thicknesses (1000 mg, 5000 mg, and 10,000 mg) at a pH of 5.15. As time passes, there is a decrease in the concentration of copper sulphate solution in all cases, indicating the adsorption of copper ions by the gelatin films. The 10,000mg gelatin film exhibited a more rapid uptake of copper ions and a quicker reduction in water hardness during the initial stages of the experiment compared to the 1000mg and

5000mg films. In contrast, the 1000mg film demonstrated a slower and more gradual adsorption process over time. The 10,000mg film, being larger, initially presents a greater surface area for contact with the surrounding solution. This creates a steeper concentration gradient between the copper ions in the solution and the film's interior, driving faster diffusion and absorption. The larger film might have a more open or porous structure initially, allowing for easier penetration of copper ions. Over time, as the film absorbs ions and undergoes structural changes, its absorption rate might decrease. Smaller films may reach equilibrium with the solution more quickly due to their higher absorption rate. This may be because they saturate with copper ions sooner, limiting further absorption. The larger film, with its slower initial absorption, might still have available binding sites for copper ions even after the smaller films have reached equilibrium.

Table 2. Tabular representation of decrease in volume of M/40 $Na_2S_2O_3$ solution by adsorption of Cu(II) ions from 0.1 M $CuSO_4$ using Gelatin films

Films → **Hours ↓**	**Volume of $Na_2S_2O_3$ (mL)**		
	1000 mg	**5000 mg**	**10,000 mg**
Initial (without gelatin films)	19.1	19.5	18.7
1	10.7	9.1	7.4
2	6.6	7.5	7.2
3	4.6	6.4	6.8
4	-	4.6	5.1
5	-	-	4

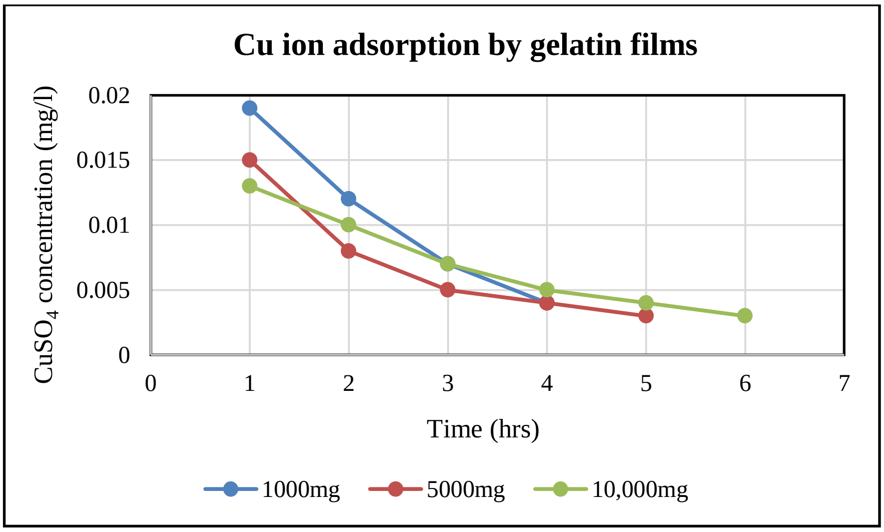


Figure 8. Concentration of Copper Sulphate solution decreases with increase in time at different concentrations of Gelatin films (1000mg, 5000mg and 10,000mg) having pH 5.15

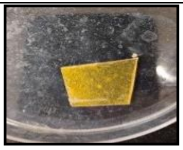
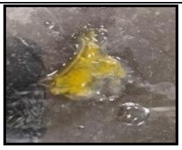
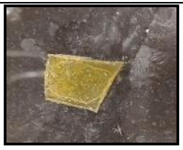
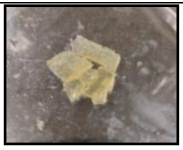
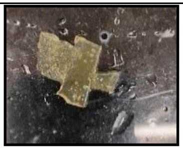
3.4.2. Treatment of hard water

The absorption phenomenon is observed in gelatin film by colour changing method from pale yellow of pure gelatin film to white of hard water. This indicates that the polymeric film absorbs metal ions. For this, samples of films were kept in the hard water solutions in a beaker and taken out after every 1 hour and checked till they dissolved completely in the solution.

Complexometric titration was performed to determine the change in the concentration of hardness of water. The procedure was followed for the gelatin films (1000mg, 5000mg, and 10,000mg) immersed in copper sulphate solution and hard water. At regular intervals of 1 hour, the films were titrated against EDTA using EBT as an indicator until the films completely dissolved.

Table 3 represents the colour change of gelatin films at different intervals during the absorption process of the hardness of the water. Initially, all three gelatin films (1000mg, 5000mg, and 10,000mg) appeared pale yellow, which is the natural colour of pure gelatin film. After 2 hours, the 1000mg gelatin film becomes soluble in the hard water and after 3 hours 5000mg gelatin film is soluble in the hard water solution. The 10,000mg gelatin film was still in the solution indicating that it had not absorbed the ions present in hard water.

Table 3. Pictorial representation of adsorption process of hardness of water by Gelatin films

Time (hours)	**1000mg**	**5000mg**	**10,000mg**
Initial			
1			
2			
3	Soluble		
4	Soluble	Soluble	
5	Soluble	Soluble	Soluble

This pictorial representation demonstrates the progressive absorption of ions from hard water by gelatin films over time, with higher gelatin concentrations (5000mg and 10,000mg) taking longer to reach complete absorption compared to the lower concentration (1000mg) film.

The reduction in water hardness by gelatin films through the adsorption method is summarized in Table 4. Figure 9 illustrates the change in hardness concentration over time for gelatin films of different thicknesses (1000 mg, 5000 mg, and 10,000 mg) at a pH of 5.15. As time passes, there is a decrease in the concentration of hardness of water in all cases, indicating the adsorption of hardness by the gelatin films.

Table 4. Tabular representation of decrease in volume of 0.1 M EDTA solution by adsorption of Ca^{2+} and Mg^{2+} ions hard water using Gelatin films

Films → **Hours ↓**	**Volume of EDTA (mL)**		
	1000 mg	**5000 mg**	**10,000 mg**
Initial (without gelatin films)	6.7	7.1	6.8
1	5.1	6.2	5.9
2	1.6	5.1	4.8
3	-	3.6	3.1
4	-	-	2.9

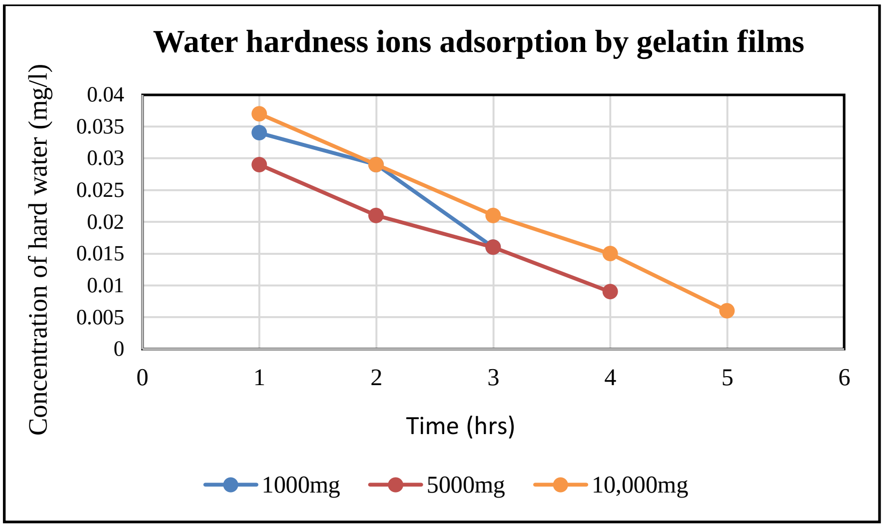


Figure 9. Concentration of Hard water decreases with an increase in time at different concentrations of Gelatin films (1000mg, 5000mg and 10,000mg) having pH 5.15

When compared to the 1000mg and 5000mg films, the 10,000mg gelatin film adsorbed ions from the hardwater more quickly in the first several hours. In comparison to the other films, the 1000mg film demonstrated slower and more progressive adsorption over time.

The results demonstrate that gelatin films can effectively absorb metal ions from hard water. The absorption rate is influenced by the film's mass, with smaller films exhibiting faster dissolution and higher ion uptake. Gelatin films, rich in amino acids with chelating functional groups, effectively absorb metal ions from hard water due to their porous structure and high surface area. Smaller films exhibit faster absorption rates and reach equilibrium more quickly due to steeper concentration gradients.

The interaction between metal ions and the film can induce swelling or dissolution, exposing additional functional groups for chelation. These factors collectively contribute to gelatin's effectiveness in metal ion removal, making it a promising material for applications like water purification and metal recovery.

4. Conclusion

Gelatin films, known for their renewability, biodegradability, and natural origins, offer a promising alternative to synthetic materials. The study demonstrates that gelatin films, characterized by their thickness and a pH of 5.15, possess notable physical properties such as high dispersibility, solubility, and biodegradability.

The sharp peak at 300 nm in the UV spectrum of gelatin indicates the presence of aromatic amino acid residues, particularly tryptophan and tyrosine, within the gelatin molecule. These amino acids possess conjugated double bonds in their side chains, which enables them to efficiently absorb UV light. The resulting absorbance at 300 nm serves as a valuable indicator of the protein content and structural integrity of gelatin films.

Their ability to adsorb copper ions from acidic solutions, as evidenced by iodometric titration, and to treat hard water through complexometric titrations, illustrates the potential of gelatin films as effective adsorbents for copper ions and water hardness. This demonstrates their significant promise for environmental remediation and wastewater treatment. These characteristics align with green chemistry principles, emphasizing the importance of environmentally friendly technologies in addressing heavy metal pollution.

This study highlights gelatin films as a sustainable alternative to synthetic materials with promising applications in water treatment and environmental remediation.

5. Future Suggestions

The study emphasizes that water solubility poses a significant challenge for gelatin films after prolonged use, restricting their practical applications. Resolving this limitation is crucial to improving their performance and unlocking their full potential in various fields.

Addressing the solubility issue could pave the way for the effective use of gelatin films in membrane technology, food packaging, and biomedical applications. This requires focused research and development to enhance the films' properties and broaden their usability.

Optimizing biodegradable gelatin films can play a vital role in promoting sustainable practices by offering viable alternatives to synthetic plastics. Such advancements would not only contribute to environmental conservation but also provide innovative solutions for industrial and environmental challenges.

Declarations

Source of Funding

This study did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

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References

[1] Mushtaq, F., Raza, Z.A., Batool, S.R., Zahid, M., Onder, O.C., Rafique, A., & Nazeer, M.A. (2022). Preparation, properties, and applications of gelatin-based hydrogels (GHs) in the environmental, technological, and biomedical sectors. International Journal of Biological Macromolecules, 218: 601–633. https://doi.org/10.1016/j.ijbiomac.2022.07.168.

[2] Ahmad, M.I., Li, Y., Pan, J., Liu, F., Dai, H., Fu, Y., & Zhang, H. (2023). Collagen and gelatin: Structure, properties, and applications in food industry. International Journal of Biological Macromolecules, 254: 128037. https://doi.org/10.1016/j.ijbiomac.2023.128037.

[3] Said, N.S., Howell, N.K., & Sarbon, N.M. (2023). A review on potential use of gelatin-based film as active and smart biodegradable films for food packaging application. Food Reviews International, 39(2): 1063–1085. https://doi.org/10.1080/87559129.2021.1929298.

[4] Mohanto, S., Narayana, S., Merai, K.P., Kumar, J.A., Bhunia, A., Hani, U., & Vora, L.K. (2023). Advancements in gelatin-based hydrogel systems for biomedical applications: a state-of-the-art review. International Journal of Biological Macromolecules, 127143. https://doi.org/10.1016/j.ijbiomac.2023.127143.

[5] Wattanavijitkul, T., Khamwannah, J., Lohwongwatana, B., Puncreobutr, C., Reddy, N., Yamdech, R., & Aramwit, P. (2024). Development of Biocompatible Coatings with PVA/Gelatin Hydrogel Films on Vancomycin-Loaded Titania Nanotubes for Controllable Drug Release. ACS omega, 9(35): 37052–37062. https://doi.org/10.1021/acsomega.4c03942.

[6] Naharros-Molinero, A., Caballo-González, M.Á., de la Mata, F.J., & García-Gallego, S. (2024). Shell formulation in soft gelatin capsules: Design and characterization. Advanced Healthcare Materials, 13(1): 2302250. https://doi.org/10.1002/adhm.202302250.

[7] Kolya, H., & Kang, C.W. (2023). Next-generation water treatment: Exploring the potential of biopolymer-based nanocomposites in adsorption and membrane filtration. Polymers, 15(16): 3421. https://doi.org/10.3390/polym15163421.

[8] Ji, K., Liu, C., He, H., Mao, X., Wei, L., Wang, H., & Zhou, F. (2023). Research progress of water treatment technology based on nanofiber membranes. Polymers, 15(3): 741. https://doi.org/10.3390/polym15030741.

[9] Rizwan, K., Babar, Z.B., Munir, S., Arshad, A., & Rauf, A. (2022) Recent advancements in engineered biopolymeric-nanohybrids: A greener approach for adsorptive-remediation of noxious metals from aqueous matrices. Environmental Research, 215: 114398. https://doi.org/10.1016/j.envres.2022.114398.

[10] Singh, S., Paswan, S.K., Kumar, P., Singh, R.K., & Kumar, L. (2023). Heavy metal water pollution: an overview about remediation, removal and recovery of metals from contaminated water. Metals in Water, Pages 263–284. https://doi.org/10.1016/b978-0-323-95919-3.00018-5.

[11] Milano, F., Masi, A., Madaghiele, M., Sannino, A., Salvatore, L., & Gallo, N. (2023). Structure and Properties of Gelatin. In Encyclopedia. https://encyclopedia.pub/entry/44735.

[12] Mikhailov, O.V. (2023). Gelatin as it is: history and modernity. International Journal of Molecular Sciences, 24(4): 3583. https://doi.org/10.3390/ijms24043583.

[13] Kaliampakou, C., Lagopati, N., Pavlatou, E.A., & Charitidis, C.A. (2023). Alginate–Gelatin Hydrogel Scaffolds; An Optimization of Post-Printing Treatment for Enhanced Degradation and Swelling Behavior. Gels, 9(11): 857. https://doi.org/10.3390/gels9110857.

[14] Derkach, S.R., Voron'ko, N.G., & Kuchina, Y.A. (2022). Intermolecular interactions in the formation of polysaccharide-gelatin complexes: a spectroscopic study. Polymers, 14(14): 2777. https://doi.org/10.3390/polym14142777.

[15] Bäther, S., Hundschell, C.S., Kieserling, H., & Wagemans, A.M. (2023). Impact of the solvent properties on molecular interactions and phase behaviour of alginate-gelatin systems. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 656: 130455. https://doi.org/10.1016/j.colsurfa.2022.130455.

[16] Lin, B., Zhang, X., Ou, D., Chen, Y., Chen, Y., & Chen, X. (2023). Characterization of anglerfish gelatin/polyvinyl alcohol film and its application in preservation of small yellow croaker (*Larimichthys polyactis*). Journal of Food Engineering, 357: 111641. https://doi.org/10.1016/j.jfoodeng.2023.111641.

[17] Pulidori, E., Micalizzi, S., Koutsomarkos, N., Bramanti, E., Tinè, M.R., Vozzi, G., & Duce, C. (2023). Analysis of gelatin secondary structure in gelatin/keratin-based biomaterials. Journal of Molecular Structure, 1279: 134984. https://doi.org/10.1016/j.molstruc.2023.134984.