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Removal of copper (II) ions from aqueous solutions by biosorptive-flotation technique using powdered lemon leaves (PLL) as a sorbent and oleic acid as a surfactant

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powdered lemon
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Oleic acid.

Abstract

Environmental protection requires the use of natural products as a replacement for chemicals to reduce pollution. Therefore, this study was carried out to examine the potential and effectiveness of using powdered lemon leaves, which was prepared from lemon leaves (a cheap agricultural and non-toxic material), to remove copper from water. A series of bench-scale experiments were conducted in the laboratory, aiming to assess the feasibility of using powdered lemon leaves (PLL) as an effective biosorbent and oleic acid (HOL) as a surfactant. The effects of the process variables such as: initial solution pH, sorbent, surfactant and copper concentrations and shaking time that influence the biosorptive-flotation process were examined. Promising results were obtained under the optimum conditions, according to which nearly 100% of copper, at pH 7 and at room temperature ($\sim 25^{\circ}\text{C}$), was removed. Moreover, a sorption and flotation mechanism is suggested.

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Introduction

Copper is a widely used industrial metal used for electrical wiring, plumbing, air conditioning tubing and roofing. The properties of copper, which make it suitable for these applications, include high electrical and thermal conductivity, good corrosion resistance, ease of fabrication and installation, attractive appearance, ready availability, and high recyclability. Additionally, copper, which is an essential nutrient to humans and other life forms, is biostatic/biocidal to certain organisms. However, copper (II) is known to be one of the heavy metals most toxic to living organisms and it is one of the more widespread

heavy metal contaminants of the environment. The potential sources of copper in industrial effluents include metal cleaning and plating baths, pulp, paper board mills, wood pulp production, and the fertilizer industry, etc. Therefore, wastewaters of these industries contain high levels of copper (II) ions and in order to avoid water pollution treatment is needed before disposal (Aksu al. 2001; Ozer et al. 2004; Ho et al. 2003; Yang et al. 1999 Nidal, H. and Chedly, T. 2013).

During the last few years, increasing attention has been focused on the separation, preconcentration and/or determination of trace-metal ions in the environment. This field of interest is becoming a real challenge due to the

specificity, accuracy and sensitivity required by even-more and more stringent regulations (Havens et al., 2000 and Brach-Papa et al., 2002). Numerous techniques are available in this concern and have been reported (Ghazy et al., 2001; Leyden et al. 1981; Mizuike et al., 1986; Agafonkina and Kuznetsov., 2014). These techniques may involve: chemical precipitation, ion exchange, reverse osmosis, electro-deposition, adsorption, solvent extraction and flotation separation processes. Of these, adsorption has proved to be an effective technique. However, the adsorption may suffer from economic limitations owing to difficulties encountered in separating the sorbent from the suspension in order for it to be regenerated (Zouboulis et al., 1994). Therefore, attempts have been made to develop separation techniques.

Flotation as a solid/liquid or liquid/liquid (or both) separation process has recently received considerable interest owing to its simplicity, rapidity, good separation yields ($R > 95\%$) for small impurity agent concentrations (10^{-6} – 10^{-2} mol.l⁻¹), a large possibility of applications for species having different nature and structure, flexibility and friability of equipment and processing for recovery purpose (Salmani, and Ehrapoush., 2012). It is believed that this process will soon be incorporated as a clean technology to treat both water and wastewater Wiwid, (2014).

For the aforementioned reasons a combination of adsorption and flotation into a unified operation termed sorptive-flotation could be considered as a vital process.

In developing countries, the pollution control measures frequently need to be based on lower cost technologies. In this context, one area that is being explored is the use of naturally occurring materials that have the potential for adsorbing pollutants (Kapur., 2014).

Accordingly, this investigation aims to establish a selective, rapid and simple procedure for the removal of copper ions from aqueous solutions using powdered lemon leaves (PLL) as an effective biosorbent (which may be inexpensive, readily available and as alternative to existing commercial adsorbents) and oleic acid (HOL) as a surfactant under the recommended conditions.

Experimental

1. Sorbent

Lemon leaves were provided from Valley of Rabea, Tripoli, Libya. The lemon leaves were first dried to obtain minimum humidity. Then, the dried sample was washed several times with double distilled water. After collecting sufficient quantities, the washed adsorbent was heated in a furnace oven at temperature of 110°C for time of 2 days. Then, adsorbent was ground to get powder form and sieved to obtain particle size of 500 µm. Finally, the prepared samples were stored in air tight bottles and placed in a CaCl₂ desiccator until use in experiments.

1.1. Sorbent characteristics

1.1.1. Fourier Transform-Infrared spectroscopy (FT-IR):

FT-IR investigates the surface carbon-oxygen groups and used to obtain information about the nature of possible interaction between the functional groups present on PLL surface with Cu²⁺. The PLL sample was diluted with KBr, compressed into wafer and FT-IR spectrum was recorded by FT/IR-6100 type A spectrophotometer. The result obtained is given in figure 1.

A variety of C-O (carbon oxygen) surface functional groups were observed in the PLL sample:

O-H stretching mode of hydroxyl groups and adsorbed water, carbonyl group, C-O stretching in acids, alcohols, phenols, ethers and esters. Not only the C-O of phenolic, carbonyl and carboxylic groups were present in the FT-IR spectrum of activated carbon, but also the asymmetric and symmetric stretching of C-H stretching vibrations of methylene group were observed. The presence of such methylene groups induces hydrophobicity into the PLL material.

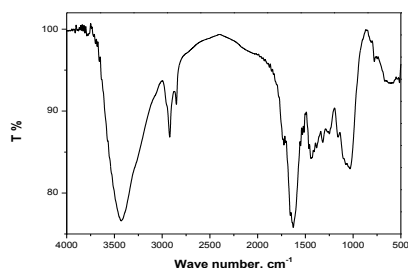


Fig. 1: FT-IR spectrum of PLL sample.

1.1.2. Surface morphology:

A scanning electron microscope (SEM) was used to examine the surface of PLL sample. The SEM image (Figure 2) show a porous morphology of the surface with pores of different sizes and shapes. These pores act as active sites for copper adsorption.

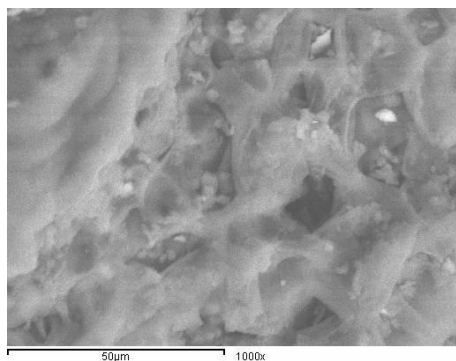


Fig.2: SEM image of PLL sample.

1.1.3. Surface area determination

The surface area of the sorbent was determined from the respective nitrogen adsorption isotherms by applying the conventional BET equation and found to be: $138 \text{ m}^2 \cdot \text{g}^{-1}$

2. Reagents

All of the solutions were prepared from certified reagent grade chemicals. A copper stock solution ($1000 \text{ mg} \cdot \text{l}^{-1}$) was prepared from $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (BDH Ltd., Poole, England) by dissolving 3.92 g in doubly distilled water and diluting to 1 L. An oleic acid (HOL) stock solution, $6.36 \times 10^{-2} \text{ mol} \cdot \text{l}^{-1}$, was prepared from the food grade with sp. gr. 0.895 (provided from J. T. Baker Chemical Co.) by dispersing 20 ml of HOL in 1 L kerosene. Aqueous solutions of HCl and NaOH were used for pH adjustments. Further dilutions were prepared daily as required.

3. Methodology

The residual Cu (II) concentration in the filtrate was analyzed by AAS spectrometry at 327.4 nm using a Perkin-Elmer Atomic Absorption Spectrophotometer with air-acetylene flame.

4. Instruments and equipments

A flotation procedure was carried out in a flotation cell, which was a cylindrical tube of 1.5 cm inner diameter and 29 cm length with a stopcock at the bottom. The stirring of solutions was performed with a magnetic stirrer Model VEHP, Scientifica, Italy. The shaking of solutions was performed with a nuve SL 350 shaker at 250 rpm. The pH was measured using a HI931401 microprocessor pH meter.

5. General procedure

To study the different parameters affecting the sorptive-flotation process, 10 ml aliquot of suspension containing defined amounts of Cu^{2+} ion, sorbent sample, HCl, HNO_3 or H_2SO_4 and/or NaOH (for controlling pH) was introduced into a flotation cell. The flotation cell was shaken for the optimized time, to ensure complete adsorption of Cu^{2+} ions by PLL. To this suspension inside the cell, 3 ml of HOL was added. Again, the cell was inverted upside down twenty times by hand and kept standing for 5 min to complete flotation. The removal percentage (R_e %) of Cu^{2+} calculated from the relationship:

$$R_e \% = (1 - C_r/C_i) \times 100\%$$

where: C_i and C_r denote the initial and residual Cu^{2+} ions concentrations.

To study the flotation of PLL alone, the previous procedure steps were performed in the absence of Cu^{2+} ion. After complete flotation, the float containing sorbent was filtered through a G₅ sintered-glass filter (porosity 1-1.5 μm) and dried in an oven at 125°C to a constant weight.

The floatability percentage (F %) of the sorbent was calculated as following:

$$F \% = C_r/C_i \times 100\%$$

where: C_i and C_r denote the initial and residual concentrations of the PLL sorbent.

All experiments were carried out at room temperature ($\sim 25^\circ\text{C}$)

Results and Discussion

1. Floatability of powdered lemon leaves (PLL)

The removal of fine particles of (PLL) sorbent from aqueous solutions (particularly those that passed through a filtration medium) was an obvious economic measure for the undertaken studies.

1.1. Effect of pH

Preliminary series of experiments was conducted to float 60 mg.l^{-1} of PLL over a wide range of pH values (1-10) using $1 \times 10^{-3} \text{ mol.l}^{-1}$ HOL. The obtained results are depicted in figure 3, from which it is clear that flotation percentage increased as pH increased from 1 to 5 then a maximum flotation (~100%) for PLL was attained over a wide pH range(6-9).

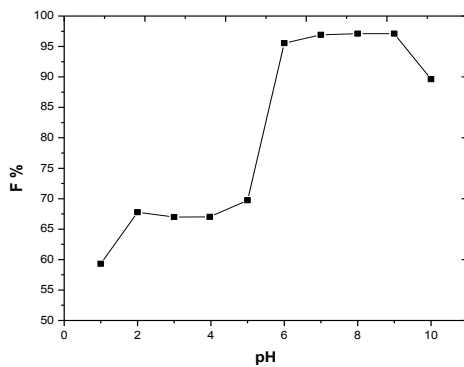


Fig. 3: Flotation of 60 mg.l^{-1} of PLL using $1 \times 10^{-3} \text{ mol.l}^{-1}$ HOL at different pH values.

1.2. Effect of surfactant concentration

The separation of 60 mg.l^{-1} of PLL using different concentrations of oleic acid (HOL) surfactant at pH 7 is presented in figure 4. The results proved that oleic acid is an effective surfactant for a quantitative removal (~100%) of the sorbent at lower concentrations (1×10^{-3} and $2 \times 10^{-3} \text{ mol.l}^{-1}$).

In general, it was found that for the undertaken studies the recommended HOL concentration was $1 \times 10^{-3} \text{ mol.l}^{-1}$.

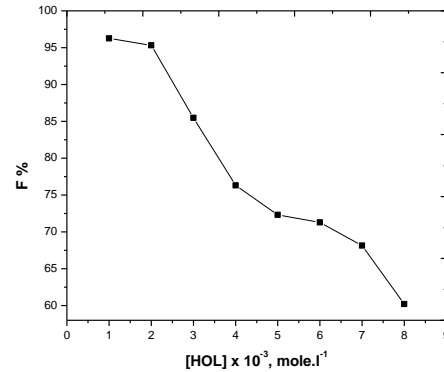


Fig.4: Flotation of 60 mg.l^{-1} of PLL at pH7 using different concentration of HOL.

1.3. Effect of sorbent concentration

Another series of experiments was carried out to float different concentrations of PLL sample using $1 \times 10^{-3} \text{ mol.l}^{-1}$ of HOL at pH 7. As can be seen from the data recorded in figure 5, quantitative separation (~100%) of the sorbent was attained over a wide concentration range (up to 100 mg.l^{-1}) then the flotation percentage decreased after 100 mg.l^{-1} . Hence, for all experiments the recommended concentration of PLL is 60 mg.l^{-1} .

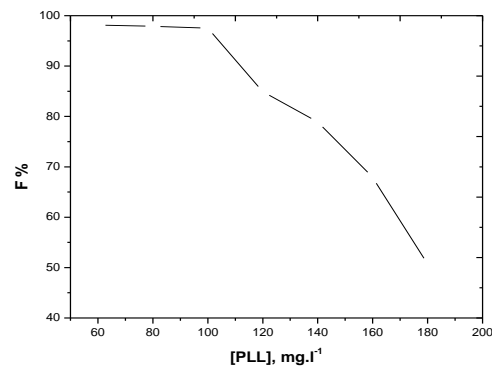


Fig. 5: Flotation of different concentrations of PLL using $1 \times 10^{-3} \text{ mol.l}^{-1}$ HOL at pH7.

1.4. Effect of temperature

In order to find the suitable temperature for complete flotation of 60 mg.l^{-1} of PLL at pH 7 using $1 \times 10^{-3} \text{ mol.l}^{-1}$ HOL, an extensive series of experiments was carried out at different temperatures. The results recorded in figure 6 show that the floatability of sorbent was increased as temperature increased from 5°C to 25°C then the floatability of sorbent not affected by increasing the temperature up to 80°C .

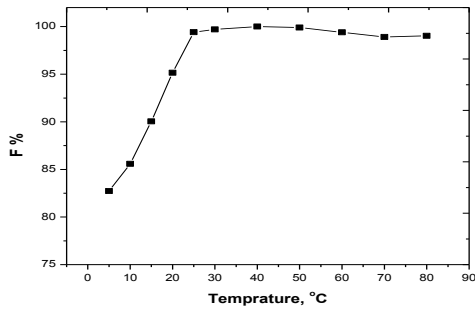


Fig. 6: Effect of temperature on the flotation of 60 mg.l^{-1} of PLL using $1 \times 10^{-3} \text{ mol.l}^{-1}$ HOL at pH 7.

From the previous results it is obvious that the process is economic and effective ($F \sim 100\%$) since it needs small concentration of surfactant ($1 \times 10^{-3} \text{ mol.l}^{-1}$ HOL) to float high concentration of PLL (60 mg.l^{-1}) and acting at a wide range of pH (6-9) and temperature range of ($20\text{-}80^\circ\text{C}$).

2. Removal of copper ions

2.1. Effect of pH

The concentrating tendency of hydroxyl ion in the float is sensitive to variations in the solution pH. In order to find the optimal pH value for the biosorptive-flotation process, the removal efficiency of Cu^{2+} ions over the pH range (1-10) was studied. Figure 7 illustrates the influence of the pH on the combined process of sorption and flotation for the removal of 30 mg.l^{-1} of Cu^{2+} ions using 60 mg.l^{-1} of PLL and $1 \times 10^{-3} \text{ mol.l}^{-1}$ of HOL.

It should be noted that the removal of Cu^{2+} ions was diminished at ($\text{pH} < 5.0$), which may be attributed to the fact that at strong acidic medium i.e. at higher H^+ ion concentration, the adsorbent surface becomes more positively charged, thus reducing the attraction between adsorbent and metal ions.

When the pH increases, the concentration of hydronium ion (H_3O^+) is very low, biosorbent surface was more negatively charged, and functional groups of biomass were more deprotonated in a wide range of pH from (5-9), thus the sites are easily available for metal ion binding. So, the proton competition was decreased, and the removal percentage of metal ions is increased.

The decrease in the removal rate at high pH values (> 9) may be attributed to the fact that oleate anions are not capable of combination with the negative surface of PLL. Therefore, pH 7 was recommended throughout all other experiments.

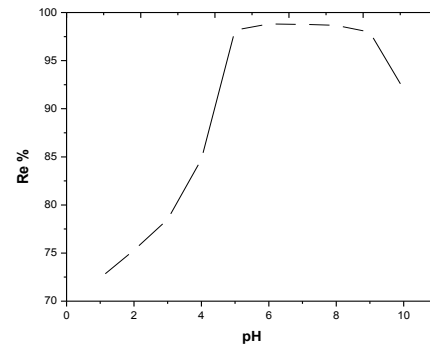


Fig. 7: Removal percentage of 30 mg.l^{-1} of Cu^{2+} ions from aqueous solutions as a function of pH using 60 mg.l^{-1} of PLL and $1 \times 10^{-3} \text{ mol.l}^{-1}$ of HOL.

2.2. Effect of sorbent and metal ion concentrations

Two parallel series of experiments were performed to study the influence of PLL dose (Figure 8) and changing copper concentrations (Figure 9) on the removal percentage of Cu^{2+} ions from aqueous solutions at pH 7 using $1 \times 10^{-3} \text{ mol.l}^{-1}$ of HOL. As can be seen from figure 8, the removal percentage of Cu^{2+} ions increased as the PLL dose increased, while it decreased as the concentration of the metal ion increased (Figure 9). The reason for attaining a maximum removal of Cu^{2+} ions ($\sim 100\%$) at higher PLL dose may be due to an increase in the number of binding sites on the adsorbent available to Cu^{2+} ions. Hence, 60 mg.l^{-1} of PLL may be a suitable dose for the removal of Cu^{2+} ions having a concentration of $\leq 30 \text{ mg.l}^{-1}$.

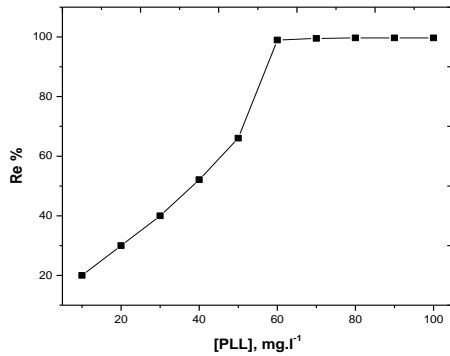


Fig. 8: Removal percentage of 30 mg.l⁻¹ of Cu²⁺ ions from aqueous solutions using different concentrations of PLL and 1×10⁻³ mol.l⁻¹ of HOL at pH 7.

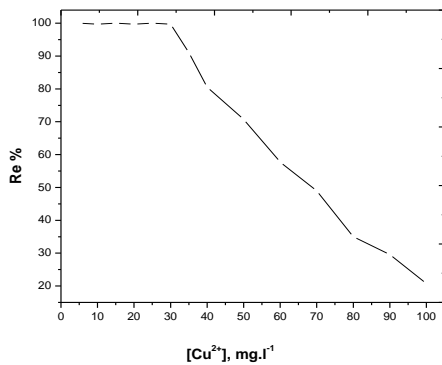


Fig. 9: Removal percentage of different concentrations of Cu²⁺ ions from aqueous solutions using 60 mg.l⁻¹ of PLL and 1×10⁻³ mol.l⁻¹ of HOL at pH 7.

2.3. Effect of surfactant concentration

A series of experiments was undertaken to float 30 mg.l⁻¹ of Cu²⁺ ions from aqueous solutions at pH 7, in the presence of 60 mg.l⁻¹ of PLL sorbent, using different concentrations of HOL. The obtained results (Figure 10) showed that a complete removal of Cu²⁺ ions (~100%) was attained at the HOL

Concentrations of (1×10⁻³ and 2×10⁻³ mol.l⁻¹). The removal of Cu²⁺ ions decreased at higher concentrations above these concentrations, a phenomenon that may be attributed to the formation of a stable hydrated envelop of surfactant on the air bubble surface, or alternatively to the formation of a hydrated micellar coating on the solid surface. In either case, the hydrophobicity of the surface would then not be satisfactory for flotation (Ghazy et

al., 2001b and Klassen et al., 1963). Consequently, the concentration of HOL was fixed at 1×10⁻³ mol.l⁻¹ throughout all other experiments.

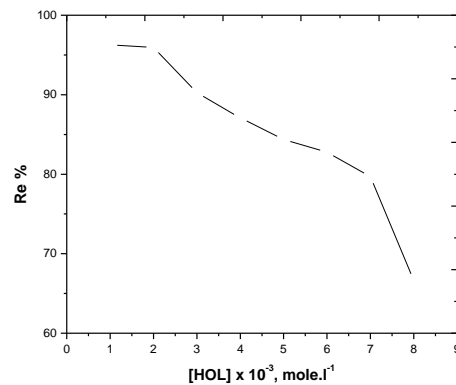


Fig. 10: Removal percentage of 30 mg.l⁻¹ of Cu²⁺ ions from aqueous solutions using 60 mg.l⁻¹ of PLL and different concentrations of HOL at pH 7.

2.4. Effect of shaking time

The variation in the removal percentage of Cu²⁺ ions with the shaking time was also studied using 30 mg.l⁻¹ of Cu²⁺ ions, 60 mg.l⁻¹ of PLL and 1×10⁻³ mol.l⁻¹ of HOL at pH 7. The shaking time was varied from (1-10) min. The obtained results (Figure 11) showed that the removal percentage increased to its maximum value (~100%) after shaking time of 5 min for 30 mg.l⁻¹ of Cu²⁺ ions.

Therefore, 5 min of shaking was considered to be sufficient for the removal of Cu²⁺ ions having a concentration of 30 mg.l⁻¹. Thus, 5 min of shaking was recommended for all experiments in this investigation.

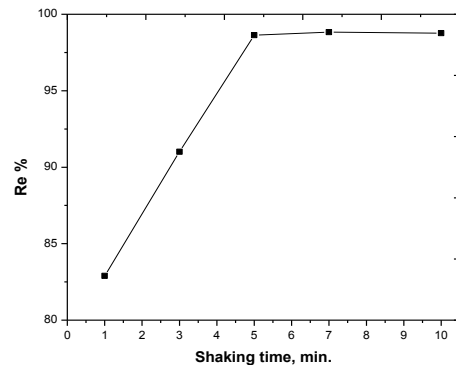


Fig. 11: Effect of shaking time on the removal percentage of 30 mg.l⁻¹ Cu²⁺ ions using 60 mg.l⁻¹ of PLL and 1×10⁻³ mol.l⁻¹ of HOL at pH 7.

2.5. Effect of temperature

Studies of the influence of temperature on the separation process seemed to be important from a practical viewpoint, especially in the case of hot industrial effluents. For such studies, one solution containing 30 mg.l⁻¹ of Cu²⁺ ions and 60 mg.l⁻¹ of PLL and a second solution containing 1×10⁻³ mol.l⁻¹ of HOL were either heated or cooled to the same temperature using a water bath. The surfactant solution was quickly poured onto the Cu²⁺ solution contained within a flotation cell jacketed with 1-cm thick fibreglass insulation. The mixture was then floated using the previously described process. The obtained results (Figure 12) indicated that the removal percentage of Cu²⁺ ions increased as the temperature increased. Such data indicate that the adsorption of Cu²⁺ ions may proceed through chemical bond formation and the creation of new active sites on the surface of PLL available for Cu²⁺ ions adsorption.

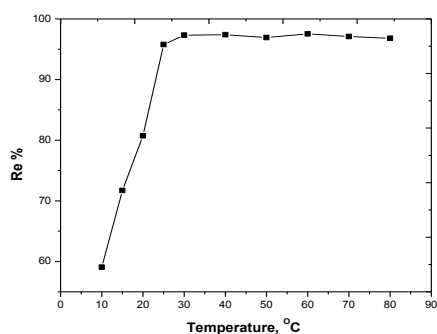


Fig. 12: Effect of temperature on the removal percentage of 30 mg.l⁻¹ Cu²⁺ ions using 60 mg.l⁻¹ of PLL and 1×10⁻³ mol.l⁻¹ of HOL at pH 7.

Biosorptive-flotation mechanism

Before discussing the possible mechanism involved, the following points need to be taken into consideration:

1. Most metal cations are removed by: (i) adsorption onto solid phases via coprecipitation of their insoluble hydroxides; (ii) flocculation by the adsorption of hydrolytic products or (iii) complexation with specific surface sites, provided that the appropriate conditions prevail (Apak et al., 1998 and Zouboulis et al., 1995).

2. As a function of the solution pH, copper species may exist as soluble hydroxo-complexes (Cu(OH)⁺, Cu(OH)₃⁻) in addition to the insoluble copper hydroxide Cu(OH)_{2(s)}.
3. FT-IR characterization of the surface of PLL was carried out and the obtained results reveal that: carboxylic, lactic and phenolic functional groups were present on the surfaces of the PLL sample and the presence of carboxylic and phenolic groups on PLL surface was confirmed by the appearance of characteristic bands at (1500-1750 cm⁻¹) and (3400 – 3500 cm⁻¹), respectively.
4. Oleic acid (HOL) surfactant begins to dissociate at pH ≥ 5.2 (Ghazy et al., 2001b).

Therefore, the proposed mechanism may occur as follows:

- a. At pH < 5, the hydrolytic species of copper may be adsorbed on sites of the PLL sorbent. The adsorbent-adsorbate system is made hydrophobic by combining with undissociated oleic acid molecules. Such a combination may occur through hydrogen bonding of the hydroxide group of HOL.
- b. In the pH range (5 – 9), where the maximal removal of Cu²⁺ ions occurred, adsorption may be electrostatically in nature. The aggregate of PLL-Cu²⁺ system is made hydrophobic by combination with undissociated oleic acid through hydrogen bonding and/or chemically with oleate anions. These hydrophobic aggregates are floated to the solution surface with the aid of air bubbles.
- c. In an alkaline medium, at pH > 9, the removal of Cu²⁺ ions decreases, which may be attributed to the incapability of adsorption of the negative species, Cu(OH)₃⁻, or the negative oleate ions on the negative surface of PLL.

Conclusion

The powder lemon leaves (PLL) used as an effective and inexpensive biosorbent for the removal of Cu²⁺ ions from aqueous solutions.

Flotation technique which has advantages (compared with other separation methods) of being simple, inexpensive, less time consuming and expected to be soon incorporated as a clean technology to treat water and wastewater has been applied in this investigation. Moreover, the removal of Cu^{2+} ions attained ~100% in the presence of oleic acid as a cheap surfactant.

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إزالة أيونات النحاس الثنائي من محاليل مائيه بواسطه التعويم الإمتزازي الحيوي بإستخدام بودره أوراق الليمون كسطح إمتزاز و حمض الأوليك كعامل سطحي نشط

سالم السيد سمره ،هاني مصطفى يوسف، عمرو عوض إبراهيم، سالم محمد النقيب
قسم الكيمياء، كلية العلوم، جامعه المنصوره، المنصوره، مصر

إن الحمايه البيئيه تتطلب إستخدام منتجات طبيعيه كبديل للمواد الكيمائيه لتقليل التلوث. لذلك تم في هذا البحث إختبار كفاءه بودره أوراق الليمون المحضره من أوراق الليمون في إزاله أيونات النحاس الثنائي. نم عمل تجارب معمليه بهدف إزاله أيونات النحاس الثنائي من الوسط المائي ولقد إعتمدت التجارب على إستخدام بودره أوراق الليمون المحضره من أوراق الليمون كسطح إمتزاز فعال وتم إستخدام حمض الأوليك كعامل سطحي نشط. تم دراسة تأثير العوامل المختلفه والتي تؤثر تأثيرا مباشرا على عملية التعويم الإمتزازي الحيوي مثل: الأس الهيدروجيني، تركيزات كل من النحاس الثنائي، سطح الإمتزاز، العامل السطحي النشط، درجة الحرارة، ووقت الرج. تم الحصول على نتائج جيده وذلك عند أس هيدروجيني ٧ وعند درجة حرارة الغرفه ($25 \pm 2^\circ\text{C}$) ويقتررب الفصل من ١٠٠٪. أخيرا تم إقتراح ميكانيكيه لعملية التعويم الإمتزازي الحيوي.