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The efficiency of the flotation technique for the removal of nickel ions from aqueous solution

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ABSTRACT

A simple and cost-effective treatment procedure was proposed to remove nickel(II) from aqueous solution under the optimized conditions. It is based on the sorption of Ni^{2+} ions from aqueous solutions onto limestone (LS) fines, which is an inexpensive and widespread over the globe, followed by flotation with oleic acid (HOL) surfactant. The different parameters (namely: solution pH, sorbent, surfactant and nickel concentrations, shaking times, ionic strength, temperature and the presence of foreign ions) influencing the sorptive-flotation process were examined. Nearly, 99% of Ni^{2+} ions were removed from aqueous solutions at pH 7 after shaking for 5 min and at room temperature (~25°C). The procedure was successfully applied to recover nickel(II) spiked to some natural water samples. Moreover, a sorption and flotation mechanism is suggested.

Keywords: Nickel; Flotation; Limestone; Surfactant; Sorbent

1. Introduction

Nickel is commonly used in refining, electroplating and welding industries and human exposure to nickel is highly probable in such environments. Nickel can cause a variety of pathologic effects like skin allergy, lung fibrosis and cancer [1–6]. The most important health problems due to exposure to nickel and nickel compounds are allergic dermatitis (nickel itch) and increased incidence of cancers. Nickel is genotoxic and mutagenic as well. Though there are very many harmful effects of nickel on human health, production of its compounds is essential and one has to look at the ways of reducing its input into the environment from the waste streams. The health hazards of nickel in waters have been reported in many journals [7,8]. The US Environmental Protection Agency (EPA) requires nickel not to exceed 0.015 mg/L in drinking water [9]. Therefore, cost-effective treatment technologies are needed to meet these requirements of recovery and/or removal of metal ions. During the last years, increasing attention has been focused on the separation, pre-concentration 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 more and more stringent regulations [10,11]. Numerous techniques are available in this concern and have been reported [12–15]. These techniques may involve: chemical precipitation, ion exchange, reverse osmosis, electrodeposition, adsorption, solvent extraction and flotation separation processes. Of these, adsorption has proved to be an effective technique, but it may suffer from economic limitations owing to difficulties encountered in separating sorbent from suspension in order for it to be regenerated [15]. Therefore, attempts have been made to develop separation techniques.

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Flotation as a solid/liquid or liquid/liquid (or both) separation process has recently received a considerable interest owing to: simplicity, rapidity, economic, good separation yields ($R > 95\%$) for small impurity agent concentrations (10^{-6}–10^{-2} mol l^{-1}), a large possibility of application for species having different nature and structure, flexibility and friability of equipment and processing for recovery purposes [16,17]. It is believed that this process will soon be incorporated as a clean technology to treat water and wastewater [18]. 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 recent years there has been a considerable interest in the development of new products which are abundant in nature, low in cost and have minimal environmental impact for restoration or remediation of natural resources [19]. Limestone (LS), which is produced in large quantities in many countries (among them is Tunisia), is a low-cost reactive medium that can be used for retaining heavy metals and the subsequent clean up of industrial effluents, leachates and contaminated ground water [19–21]. Hence, the present work aims to establish a selective, rapid and simple sorptive-flotation procedure using LS (which is naturally occurring or readily available and alternative to existing commercial adsorbents) as a sorbent and oleic acid as a surfactant for removing nickel ions from aqueous solutions and natural waters under the recommended conditions.

2. Experimental

2.1. Samples

The LS, $CaCO_3$, samples used in this study were obtained from the El-Nahli area Ariana (Tunisia) where some private and governorate quarries are located. The samples were crushed and pulverized in the laboratory and 10–15 μm particle size range was used in the experiments. The sample contained [22], 92% calcite ($CaCO_3$) and 3% dolomite ($MgCO_3$), with the reminder being composed of common minor constituents such as silica, clays, feldspar, pyrite, and sedrite [23]. The samples were dried for 2 h in an oven at 125°C, packed into stoppered bottles and stored in a desiccator for future use. Functional groups of LS were characterized through infrared analysis. The LS spectrum coincided with pure $CaCO_3$. The surface area and porosity of LS was measured using Brunauer, Emmett, Teller (BET) method. LS presented no BET porosity and its measured surface area was 3.88 $m^2\ g^{-1}$. The pH values of points of zero charge (pH_{PZC}) were 9.1 (not aged), 6.2 (aged 60 min) and 8.3 (aged several days) and this agreed with the previously reported data [24].

2.2. Reagents

All the solutions were prepared from certified reagent grade chemicals. A nickel nitrate $Ni(NO_3)_2$ stock solution (780 mg L^{-1}) was prepared and the working solutions were made by diluting the former with doubly distilled water.

An oleic acid (HOL) stock solution, 6.36×10^{-2} mol L^{-1}, was prepared from food grade with sp. gr. 0.895 (provided by J.T. Baker Chemical Co.) by dispersing 20 cm^3 of HOL in 1 L kerosene. Aqueous solutions of HNO_3 and NaOH were used for pH adjustments.

2.3. Apparatus

A Pekin-Elmer 2380 Atomic Absorptions Spectrophotometer with air-acetylene flame was used for the determination of nickel concentration at 217.0 nm. The infrared analyses were undertaken via a Mattson 5000 FT-IR spectrophotometer using KBr disc method. The pH was measured using Jeanway 3311 pH meter. The stirring of the solutions was performed with a magnetic stirrer Model VEHP, Scientifica, Italy. The flotation procedure was carried out in a flotation cell, which was a cylindrical tube of 1.5 cm inner diameter and 29 cm length fitted with a stopcock at the bottom and a stopper at the top [25].

2.4. Procedure

To study the various parameters affecting the sorption-flotation process, a 20 mL aliquot of a suspension containing 3.0 mg L^{-1} Ni^{2+} ions and 1000 mg L^{-1} sorbent (LS) of initial pH 7 was introduced into the flotation cell. The cell was shaken for 5 min (optimized time) to ensure complete adsorption of Ni^{2+} ions by LS. Then 3 mL of 1×10^{-3} mol L^{-1} HOL was added. The cell was again inverted 20 times by hand and allowed to stand for 5 min to complete flotation. The residual Ni^{2+} ion concentration in the mother liquor was analyzed using a Perkin-Elmer 2380 atomic absorption spectrophotometer at a wavelength of 217.0 nm. The percentage floatability of Ni^{2+} ions (%F) was calculated from the relationship:

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

where C_i and C_r denote the initial and residual Ni^{2+} ion concentrations. To study the flotation of LS alone,

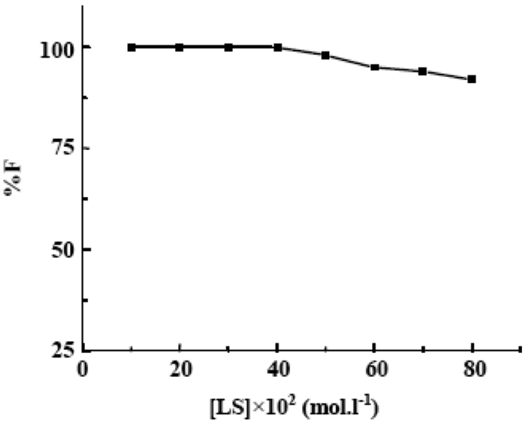

Fig. 1. Floatability of different concentrations of LS using 1 × 10^{-3} mol L^{-1} HOL at pH 7.

the previous procedural steps were conducted in the absence of Ni^{2+} ions. After complete flotation, the LS-containing float was filtered through a G_5 sintered-glass filter (porosity, 1–1.5 μm) and dried to constant weight in an oven at 125°C. The percentage floatability of LS (% *F*), was calculated from:

$$\%F = C_f/C_i \times 100 \qquad (2)$$

where C_i and C_f denote the initial and float concentrations of the LS sorbent. All experiments were carried out at room temperature (~25°C).

To asses the applicability of the procedure, another series of experiments were conducted on 1 L suspension of natural water samples (placed in a 2 L glass beaker) containing 3.0 or 5.0 mg Ni^{2+} ions, 1000 mg L^{-1} LS and 10 mL of 1 × 10^{-3} mol L^{-1} HOL with an initial pH of 7. The suspension was stirred magnetically for 10 min at 250 rpm where it was noted that the Ni-LS-HOL system was self-floatable without a stream of air bubbles being necessary.

3. Results and discussion

3.1. Floatability of powdered LS

A preliminary series of experiments (using a constant concentration of HOL equal to 1 × 10^{-3} mol L^{-1} at pH 7) was undertaken to float various concentrations of LS. The results obtained are depicted in Fig. 1 from which it is clear that a maximum flotation (~100%) for LS was attained over a wide concentration range up to 4000 mg L^{-1}.

Hence, the concentration of powdered LS favorable for nickel(II) removal was presumed to be 1000 mg L^{-1} at pH 7.

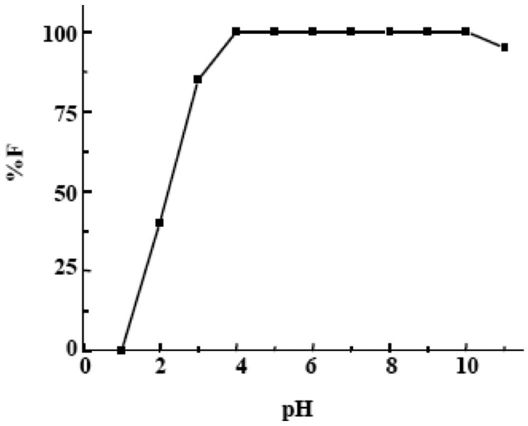

Fig. 2. Floatability of 1000 mg L^{-1} of LS at different pH values using 1 × 10^{-3} mol L^{-1}HOL.

Another series of experiments was conducted to study the effect of pH on the flotation of 1000 mg L^{-1} of LS using 1 × 10^{-3} mol L^{-1} HOL. The results are depicted in Fig. 2 and show that maximum flotation of LS (~100%) was attained over the pH range 4–10. It should also be noted that at pH values less than 3, the process was not effective due to the partially dissolution of the LS sorbent. For this reason, a pH value of 7 was used in all subsequent measurements. To find out the suitable concentration of HOL for the complete flotation of 1000 mg L^{-1} of LS a series of experiments was performed using different concentrations of HOL in acidic, neutral and alkaline media.

The results shown in Fig. 3 indicate that the floatability of LS did not exceed ~85% at pH 3, but attained maximum value (~100%) in the HOL concentration range 1 × 10^{-4} – 2.5 × 10^{-2} mol L^{-1} at pH values of 7 and 9. For simplicity, 1 × 10^{-3} mol L^{-1} HOL was used in other experiments at an initial pH 7.

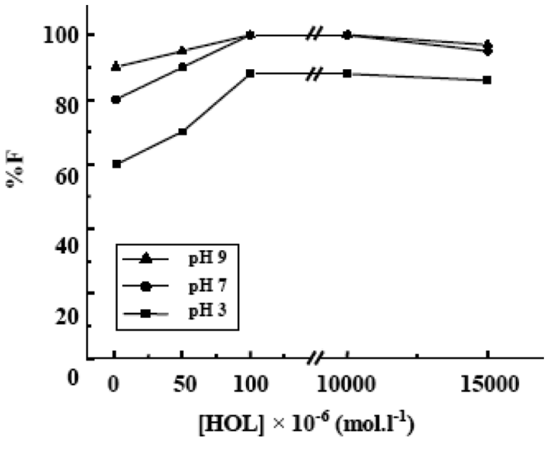

Fig. 3. Floatability of 1000 mg L^{-1} of LS at different concentrations of HOL using different pH values.

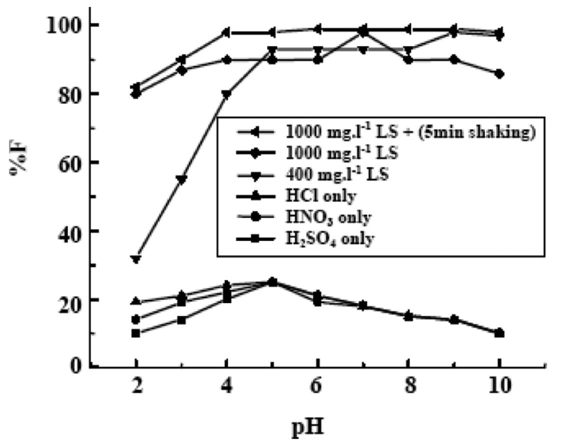

Fig. 4. Floatability of 3 mg $\mathrm{L}^{-1}$of Ni^{2+} at different pH values with or without shaking using different concentrations of LS and 1×10^{-3} mol L^{-1} of HOL.

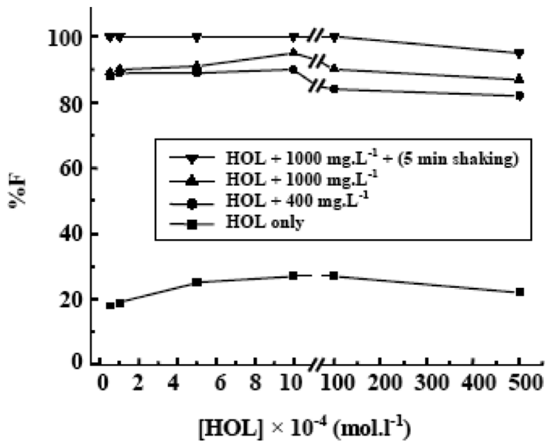

Fig. 5. Floatability of 3 mg L^{-1} Ni^{2+} ions versus HOL at pH 7 using different concentrations of LS.

3.2. *The removal of nickel(II) ions*

3.2.1. *Effect of pH*

Generally, adsorption and flotation are sensitive to variations in the pH of the medium and knowledge of how the pH value affects each system was a prerequisite to studies employing these methods. As a function of solution pH [3,26], Ni^{2+} is the dominant species below pH 5.5. Between pH 6 and 10, Zn undergoes hydrolysis to $\mathrm{Ni(OH)}^{+}$. Above pH 9, solid lead hydroxide $\mathrm{Ni(OH)_2}$ is thermodynamically the most stable phase, while $\mathrm{Ni(OH)_3^{-}}$ is predominant at pH above 11.

The influence of pH on the combined process (sorption and flotation) for the removal of 3 mg $\mathrm{L}^{-1}$of Ni^{2+} ions was investigated in the absence and presence of 400 and 1000 mg L^{-} of LS using 1×10^{-3} mol L^{-1} of HOL without or with shaking for 5 min. The pH of solutions was adjusted with $\mathrm{HNO_3}$, HCl, $\mathrm{H_2SO_4}$ and/ or NaOH.

The results are presented in Fig. 4 and indicate that the removal of Ni^{2+} ions from aqueous solutions with HOL only did not exceed ∼25%.

For this reason, a mean of enhancing the process was required. Inspection of the figure indicated that the use of LS as a sorbent increased the removal of Ni^{2+} ions as the pH increased, reaching a maximum value (∼100% after shaking for 5 min) at pH $\geq$ 4. At pH values less than 2, the removal of Ni^{2+} ions reaches zero which may be attributed to the complete solubility of LS (consists mainly from $\mathrm{CaCO_3}$ and $\mathrm{MgCO_3}$), thereby hindering the sorption of nickel ions.

The removal of the Ni^{2+} ions at pH values < 4 may be attributed to a possible ion-exchange mechanism between Ni^{2+} ions and calcium containing LS in similar manner to that reported [27]. Adsorbed nickel ions generally occupy calcium sites within the calcite lattice [28]. Moreover, Ni^{2+} ions may be adsorbed electrostatically with the negatively charged surface of LS [22]. The enhanced removal of metal ion as the solution pH is increased (more than 4) can be attributed to adsorption of hydrolytic product $\mathrm{Ni(OH)}^{+}$ and/or surface precipitation of the metal as the insoluble hydroxides, $\mathrm{Ni(OH)_2}$, forming successive layers on the sorbent surface [29]. It is also clear that the shaking for 5 min is necessary. Moreover, adjusting the pH with $\mathrm{HNO_3}$ in the acidic medium is favorable than with HCl or $\mathrm{H_2SO_4}$. Therefore, pH 7 was recommended throughout all other experiments.

3.2.2. *Effect of surfactant concentration*

In order to find a suitable concentration of HOL for removing 3 mg $\mathrm{L}^{-1}$of Ni^{2+} ions from aqueous solutions, a series of experiment was conducted at pH 7 in the absence and presence of 400 and 1000 mg L^{-1} LS using different concentrations of HOL. The results obtained are presented in Fig. 5.

It can be seen that the removal of Ni^{2+} ions attained a maximum values (∼25%) in the absence of LS and (ca. ∼90% and ∼95%) in the presence of 400 and 1000 mg L^{-1} of LS, respectively. An enhancement in the flotation efficiency of Ni^{2+} ions to ∼100% was achieved after shaking for 5 min. These maximal values were attained over the HOL concentration range of $1 \times 10^{-4} - 2.5 \times 10^{-2}$ mol L^{-1}. Higher concentrations of the surfactant impaired flotation. This impairment has been discussed by some workers [22] who concluded that poor flotation at high surfactant concentration was caused by the formation of air bubbles on the surface of stable, hydrated envelope of surfactant or, perhaps, by the formation of a hydrated micelle coating on the solid

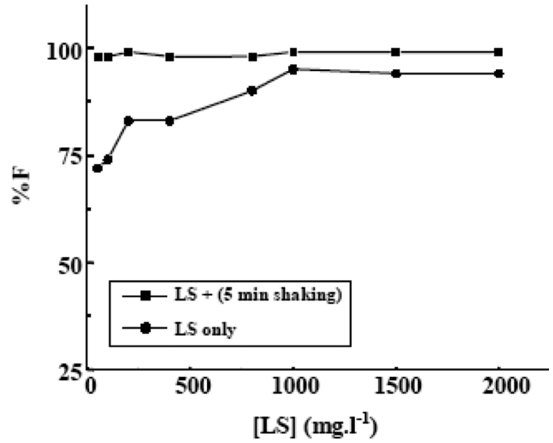

Fig. 6. Floatability of 3 mg L^{-1} Ni^{2+} ions versus LS concentrations at pH 7 using 1×10^{-3} mol L^{-1} HOL.

surface. As a result, the hydrophobicity of the resulting surface was not satisfactory for flotation. Consequently, the concentration of HOL employed was fixed at 1×10^{-3} mol L^{-1} throughout all other studies.

3.2.3. *Effect of sorbent and metal ion concentration*

Two parallel series of experiments were conducted to study the influence of powdered LS concentration (Fig. 6) and changing the nickel ion concentration (Fig. 7) on the removal percentage of Ni^{2+} ions from aqueous solutions at pH 7 using 1×10^{-3} mol L^{-1} of HOL without or with shaking for 5 min.

As can be seen from Fig. 6, the removal percentage of Ni^{2+} ions increased as the LS dose increased, while it decreased as the concentration of the metal ion increased (Fig. 7). The reason for attaining a maximum removal of Ni^{2+} ions ($\sim$100%) at higher LS dose, after shaking for 5 min may be due to an increase in the number of binding sites on the sorbent available to Ni^{2+} ions. Hence, 1000 mg L^{-1} of LS may be a suitable dose for the removal of Ni^{2+} ions having a concentration of ≤ 5 mg L^{-1} after shaking for 5 min.

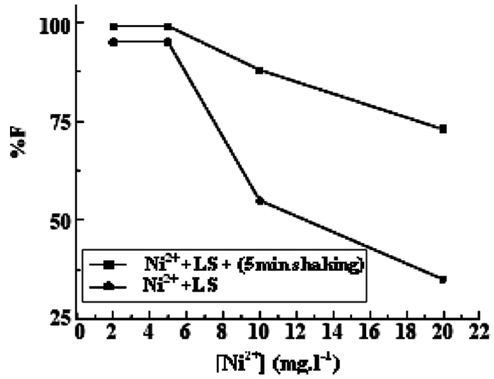

Fig. 7. Floatability of different concentrations of Ni^{2+} ions at pH 7 using 1000 mg L^{-1} of LS and 1×10^{-3} mol L^{-1} HOL.

Table 1
Effect of temperatures on the floatability (%) of 3 mg L^{-1} Ni^{2+} ions at pH 7 using 1000 mg L^{-1} of LS and 1×10^{-3} mol L^{-1} of HOL with or without shaking for 5 min

Temperature, °C	% *F* without shaking	% *F* with shaking, 5 min
3	90.0	99.2
5	94.0	99.9
10	95.0	99.9
30	95.9	100.0
40	97.2	99.9
60	96.3	99.7
70	96.4	99.6
90	91.1	99.5

3.2.4. *Effect of temperature*

Studies of the influence of temperature on the flotation efficiency of Ni^{2+} ions seemed to be important without shaking from a practical viewpoint, especially in the case of hot industrial effluents. For such studies, one solution containing 3 mg L^{-1} Ni^{2+} ions and 1000 mg L^{-1} of LS 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 Ni^{2+} solution contained within a flotation cell jacketed with 1-cm thick fiberglass insulation. The mixture was then floated using the previously described procedure. The results obtained (Table 1) indicated that the percentage removal of Ni^{2+} ions ($\sim$100%) was not markedly affected by raising the temperature from 3°C to 90°C after shaking for 5 min. Therefore, the simple procedure presented here may find application in the removal of Ni^{2+} ions from hot industrial wastewater.

3.2.5. *Effect of shaking time*

The effect of manually shaking time (2–30 min) on the floatability of 3 mg L^{-1} Ni^{2+} ions was investigated at pH 7 using 1×10^{-3} mol L^{-1} of HOL. The data obtained showed the removal of Ni^{2+} ions almost quantitatively ($\sim$100%) after shaking from 5 to 30 min. So, 5 min shaking was recommended for all experiments in this investigation.

Table 2
Floatability (%) of 3 mg L^{-1} Ni^{2+} ions from different solution volumes at pH 7 using 1000 mg L^{-1} of LS and 1×10^{-3} mol L^{-1} of HOL with or without shaking for 5 min

Volume, mL	% F without shaking	% F with shaking, 5 min
10	90.0	99.9
20	94.0	99.9
50	95.1	98.9
100	95.9	98.0
250	97.2	97.9
500	96.5	97.7
1000	90.4	97.6

3.2.6. *Floatability of Ni(II) ions from different volumes*

The floatability (%) of 3 mg L^{-1} Ni^{2+} ions from different solution volumes (10–1000 mL) using 1000 mg L^{-1} of LS and 1×10^{-3} mol L^{-1} HOL at pH 7 with or without shaking for 5 min was investigated. The data obtained (Table 2) revealed that after shaking for 5 min the floatability percentage of Ni^{2+} ions was satisfactory up to 1000 mL solution. This means that the simple recommended procedure may be expected to apply on a large scale.

3.2.7. *Effect of foreign ions*

Under the optimized conditions determined as above, the percentage removal of 3 mg L^{-1} Ni^{2+} ions from a solution of pH 7 containing 1000 mg L^{-1} of LS and 1×10^{-3} mol L^{-1} HOL was studied (with and without shaking for 5 min) in the presence of high concentrations of various cations and anions, usually found in some water samples. All cations were used as their nitrates whereas the anions were used as their sodium or potassium salts. The cations and anions were investigated separately not in combination. The tolerable amounts of each ion giving a maximum error of $\pm 2\%$ in the flotation efficiency are summarized in Table 3.

An inspection of the data indicates that all the investigated cations and anions did not interfere. However, it should be noted that higher concentrations of Al^{3+}, Cr^{3+}, Co^{2+} or Pb^{2+} could have harmful effect on the removal process. This may be due to competition between these cations and Ni^{2+} ions for sorption onto the active sites of LS. This problem could be overcome by increasing the amount of sorbent. Thus, the recommended procedure could be fairly employed for the removal of Ni^{2+} ions from various complex water samples.

3.2.8. *Application*

To investigate the applicability of the recommended procedure, a series of experiments was performed to recover 3.0 and 5.0 mg of Ni^{2+} ions added to aqueous and some natural water samples. The sorptive-flotation experiments were carried out using 1 L of clear, filtered, uncontaminated sample solutions after adjusting their pH values to 7.0. The results obtained are listed in Table 4 and show that the recovery was satisfactory and quantitative (~100%). Moreover, the

Table 3
Effect of some selected foreign ions on the floatability (%) of 3 mg L^{-1} Ni^{2+}ions at pH 7 using 1000 mg L^{-1} LS, and 1×10^{-3} mol L^{-1} HOL, with or without shaking for 5 min

Cation	Concentration $\times 10^3$ (mg/L^{-1})	% F		Anions	Concentration $\times 10^3$ (mg/L^{-1})	% F	
		Without shaking	With 5 min shaking			Without shaking	With 5 min shaking
Na^+	11.5	82	98	Cl^-	17.8	81	99
Ba^{2+}	6.9	87	99	I^-	65.3	92	99
NH_4^-	9	88	99	CO_3^{2-}	3	72	99
K^+	19.5	92	99	SO_4^{2-}	48	94	99
Mg^{2+}	12.2	72	98	NO_3^{2-}	31	83	99
Ca^{2+}	2	83	97	S^{2-}	16	81	98
Co^{2+}	0.3	80	98	CH_3COO^-	5.5	80	99
Pb^{2+}	0.3	80	98	$Cr_2O_7^{2-}$	108	83	98
Cu^{2+}	1.8	75	98	Citrate	29	85	99
Cd^{2+}	1.13	87	99	$S_2O_3^{2-}$	5.6	80	97
Mn^{2+}	1.2	85	97				
Al^{3+}	0.04	73	97				
Cr^{3+}	0.04	73	97				

Table 4
Recovery of Ni^{2+} ions from various natural water samples of pH 7 using 1000 mg L^{-1} of LS and 1×10^{-3} mol L^{-1} HOL after shaking for 5 min

Sample (location)	Added Ni^{2+} (mg L^{-1})	Found Ni^{2+} (mg L^{-1})	% F
Tap water (our laboratory)	2.997	5.8	99.9
	5.000	7.8	100.0
Lake water (Majerda)	2.994	5.82	99.8
	4.995	7.7	99.9
Sea water (Gammarth)	2.991	5.6	99.7
	4.990	7.5	99.8

data indicated that the method could be successfully applied for the separation of Ni^{2+} ions from natural water samples containing large amounts of salt matrix under the recommended conditions.

3.2.9. Adsorption and flotation mechanism

Before discussing the possible sorptive-flotation mechanism involved, the following points need to be taken into consideration: Most metal cations are removed by: (a) adsorption on solid phases via coprecipitation of their insoluble hydroxides; (b) flocculation by adsorption of hydrolytic products; (c) ion exchange or (d) complexation with specific surface sites, provided that the appropriate conditions prevail [29,30].

1. As a function of solution pH [3,26], nickel species may exist as soluble Ni^{2+} and hydroxo-species [$Ni(OH)^+$ and $Ni(OH)_3^-$] in addition to the insoluble lead hydroxide $Ni(OH)_2$.
2. The powdered LS consists mainly of calcite ($CaCO_3$). When calcite (as sparingly soluble salt type mineral) is suspended with water, HCO_3^-, Ca^{2+}, $CaHCO_3^+$ and $CaHO^+$ are formed as surface-charged species and their presence is a function of solution pH [24]. Moreover, OH^-, H^+ and HCO_3^- are considered as potential determining ions in addition to Ca^{2+} and $CaCO_3$. The dissociation of these groups leads to an acidic or alkaline surface (positive or negative surface charge). These findings were confirmed by stirring the LS sorbent with distilled water for 4 h after which the suspension pH increases. This may be attributed to adsorption of H^+ ions from solution or desorption of OH^- ions from the sorbent surface which well agree with the literature data that most natural surfaces are negatively charged [31].
3. 4-Oleic acid (HOL) surfactant begins to dissociate at pH $\leq$ 5.2 [22]. Therefore, the proposed mechanism may occur as follows. At pH < 4, the removal of the Ni^{2+} ions may be attributed to a possible ion-exchange mechanism between Ni^{2+} ions and calcium containing LS in similar manner to that reported [27]. Adsorbed nickel ions generally occupy calcium sites within the calcite lattice [28]. Also, adsorption may take place through precipitation of nickel on LS surface according to the following equations [32]:

$$CaCO_3^0 + M^{2+} + HCO_3^- \rightleftharpoons CaCO_{3(S)} + = MCO_3^0 + H^+ \tag{3}$$

$$MCO_3^0 + M^{2+} + HCO_3^- \rightleftharpoons MCO_{3(S)} + = MCO_3^0 + H^+ \tag{4}$$

The adsorbent–adsorbate system is made hydrophobic by combination with un-dissociated oleic acid molecules. Such combination may occur through hydrogen bonding of the hydroxide group of HOL as confirmed by the appearance of an absorption band at 2926 cm^{-1} during IR spectral analysis of LS-HOL system. In the pH range 4–10, where the maximal removal of Ni^{2+} ions occurred, adsorption may take place between $Ni(OH)^+$, the predominant species in this pH range, and the surface of LS via hydrogen bonding.

The aggregates of LS-Ni^{2+} being made hydrophobic by combination with un-dissociated oleic acid through hydrogen bonding and/or chemically with oleate anions.

These hydrophobic aggregates are floated to solution surface with the aid of air bubbles.

At pH > 10, the removal of Ni^{2+} ions decreases, which may be attributed to the incapability of adsorption of the negative species, $Ni(OH)_3^-$ and $Ni(OH)_4^{2-}$ and/or negative oleate ions on the negative surface of LS sorbent as confirmed by zeta potential measurements.

4. Conclusions

This investigation presented powdered LS as inorganic sorbent which is abundant in nature, low in cost and have minimal environmental impact for restoration or remediation of natural resources. It is effective in removing Ni^{2+} ions from aqueous solutions, tap water and natural water samples. The experimental results revealed that this simple sorptive-flotation procedure, using LS as a sorbent and oleic acid as a surfactant, succeeded in removing nearly 99% of Ni^{2+} ions from aqueous solutions at pH 7 after shaking for 5 min and at room temperature (~25°C). The sorption of nickel ions onto LS may proceed via cation exchange, precipitation of nickel hydroxide and/or nickel carbonate. The adsorbent–adsorbate system is made hydrophobic by combination with un-dissociated oleic acid molecules perhaps through hydrogen bonding.

Moreover, the nickel ions were essentially held by LS sorbent and would not leach out by acids owing to the solubility of the sorbent. Therefore, the metal-loaded solid waste could be solidified to an environmentally safe form thereby serving the double-fold aim of water treatment and solid waste disposal.

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