

Using Photovoltaic to Remove Heavy Metals from Industrial Water

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Abstract

Heavy metals pollution has become a more serious environmental problem in the last several decades as a result of releasing toxic materials into the environment. The aim of this study is to develop an ecological method for the removal of Ni^{2+} ions from industrial wastewater by an electro coagulation method using aluminum plates and solar cell as a source of D.C current. In this study, different conditions of pH of 4, 6, 7, and 8, current densities of 0.5, 1.0, and 1.5 mA/cm^2 , and nickel ion concentrations of 200, 300, and 500 ppm were investigated during a period of time of 120 minutes to remove nickel ions prepared waste water by electro coagulation. The total removal of nickel ions was (97.5-99.5%), (97- 99%), and (96.67-98.8%) for pH (4-8), current density (0.5-1.5 mA/cm^2) and nickel ions concentration (200-500 ppm), respectively. The results show that the optimum condition of electro coagulation process can be obtained at pH = 8 and current density 1.5 mA/cm^2 when 120 minutes were elapsed.

1. Introduction

Nickel is one of the heaviest elements present in the environment. Usually drinking water contains a concentration of nickel less than 10 $\mu\text{g}/\text{L}$. The high concentration of nickel in drinking water results from corrosion of pipes in the water distribution system that contains nickel in their composition. Also, the increasing of concentration of nickel in ground waters may come from the nature of the lands through which the water passes. The presence of nickel in water exceeding the standard limits approved by the United States Environmental Protection Agency (USEPA) leads to health problems. The most common effects of the high level of nickel in water on human health are allergies and rashes. Absorption of high percentage of nickel concentrations in the human body increases the risk of lung cancer, nasal cancer, throat cancer and prostate cancer. It can also cause heart disorders, asthma and

chronic bronchitis. For these reasons, nickel pollution must be eliminated, and it has become necessary to remove nickel pollution from soil, industrial water, and discarded materials, in addition to drinking water.

Among the most common methods used to remove nickel from water are physical-chemical methods such as adsorption [2], ion exchange [3], precipitation [4] and reverse osmosis [5]. These methods are either ineffective or considered expensive methods, especially when the nickel contaminant is present in high concentrations.

Electrocoagulation-Electroflotation (ECF) technologies include alternative methods for removing pollutants from drinking and industrial waters. This method is characterized by high efficiency and relatively fast compared to traditional methods [6].

Electrocoagulation is a process that involves the formation of suspended and emulsification by passing an electric current in an aqueous medium without adding chemicals as flocculants. Electro coagulation involves using a pair or more of metal electrodes in the form of sheets, and most commonly aluminum or iron electrodes separately or in combination. Anode and cathode pairs are arranged.

The electric current is supplied to the reaction cell through a DC current source to start the reaction. In the case of using electrodes from aluminum plates, the main reactions that take place on the electrode surfaces are electro-coagulation and electro-flocculation [7].

2. The Theory of Electro-Coagulation

The Electro coagulation process involves several chemical reactions and physicochemical phenomena, which result in decomposition. Usually there are three steps that occur in sequential ways, and they are [8]:

1. Formation of coagulants through dissolution of the anode.
2. Coagulants of pollutants then suspended particles and breaking of emulsions.
3. Aggregation of the destabilized material through coagulation or adsorption on element hydroxide.

The colloidal particles that form stable suspended are destabilized by adding a positive ion to a specific element. Aluminum and iron are commonly used widely because they are cheap and have a high valence like aluminum (3+). This positive charge interacts with the negative charge of the pollutants, which leads to press the two diffuse layers which lead to reduce the repulsion between the stable electrical charges of the inner molecules. Thus, coagulation occurs with impurities that are surrounded by the remaining colloidal particles in the aqueous medium.

The electro coagulation process is supplied with current through a DC source. The amount of the dissolving element depends on the amount of current applied from the source. The amount of current can be expressed according to Faraday's law [9]:

$$m_{(\text{theoretical})} = (I.t.M)/(n.F)$$

where: m = Theoretical quantity of electrode material dissolved in gram, I = Current in Ampere, t = Time in second, M = Molar mass of the metal electrode in gram, n = Number of electrons in oxidation / reduction reaction, and F = Faraday's constant, $96,500 \text{ C.mol}^{-1}$.

Anode reaction

1. $\text{Al(s)} \longrightarrow \text{Al}_3^+(\text{aq}) + 3\text{e}^-$
2. $2\text{H}_2\text{O(l)} \longrightarrow \text{O}_2(\text{g}) + 4\text{H}^+ + 4\text{e}^-$

Cathode reaction

1. $2\text{H}^+(\text{aq}) + 2\text{e}^- \longrightarrow \text{H}_2(\text{g})$

2. $2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \longrightarrow \text{H}_2(\text{g}) + 2\text{OH}^-(\text{l})$
3. $\text{Al}^{3+} + \text{H}_2\text{O} \longrightarrow \text{Al}(\text{OH})^{2+} + \text{H}^+$
4. $\text{Al}(\text{OH})^{2+} + \text{H}_2\text{O} \longrightarrow \text{Al}(\text{OH})^{2+} + \text{H}^+$
5. $\text{Al}(\text{OH})^{2+} + \text{H}_2\text{O} \longrightarrow \text{Al}(\text{OH})_3 + \text{H}^+$
6. $\text{Al}(\text{OH})_3 + \text{H}_2\text{O} \longrightarrow \text{Al}(\text{OH})_4^- + \text{H}^+$
7. $2\text{H}_2\text{O} \longrightarrow 4\text{H}^+ + 4\text{e}^- + \text{O}_2(\text{g})$

The concentration of aluminum ions Al^{3+} and the concentration of OH^- hydroxide ions in the solution are variable depending on the value of the acidity function of the reaction medium. In acidic medium and to the limit of an acidity function value equal to $\text{pH} = 3.5$, so the control in the solution is for positive aluminum ions. When the acidity function value increases between $\text{pH} 4$ and 9 , many hydroxylated complexes are formed such as, $\text{Al}(\text{OH})_3$, $\text{Al}_2(\text{OH})_2^{4+}$, $\text{Al}_6(\text{OH})_{15}^{3+}$, $\text{Al}_7(\text{OH})_{17}^{4+}$, $\text{Al}_8(\text{OH})_{20}^{7+}$, $\text{Al}_{13}\text{O}_4(\text{OH})_{24}^{7+}$, $\text{Al}_{13}(\text{OH})_{34}^{5+}$, $\text{Al}(\text{OH})_2^+$, $\text{Al}(\text{OH})_2^+$, and the sediments formed in the solution are aluminum hydroxide and aluminum hydroxide polymers. Figure (1) shows the relationship of the acidity function with aluminum hydroxide compounds [10].

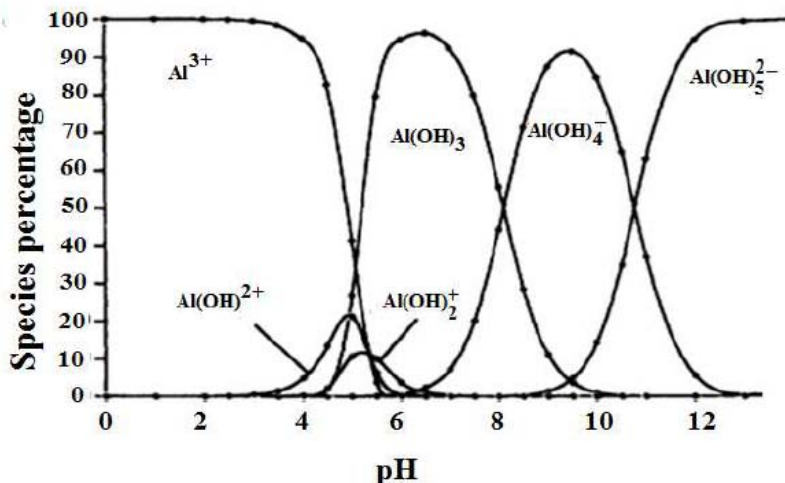


Figure (1). The relationship of the acidity function with the formed aluminum hydroxide compounds [10].

The aluminum hydroxide and poly aluminum hydroxide compounds are produced in the solution when the electric current passes lead to an increase in the efficiency of removing heavy elements. This technique has been successfully applied in treating various types of industrial water, such as discarded by textile factories, landfill leachate operations, and industrial water containing heavy element ions such as copper, zinc and chromium.

In this paper, the removal of nickel ions from water using the electrocoagulation technique was studied at different acidity functions pH , concentration of nickel ions, and current intensity. A solar cell system was used as an alternative source of clean energy to equip the system with DC electrical current.

3. Materials and Method

Nickel sulphate and sodium hydroxide were purchased from B.D.H, while hydrochloric acid was obtained from FLUKA. Solar panel with variable resistance utilised in this study has the specifications shown below:

- Maximum Power (P_{max}): 250 W.
- Voltage at maximum power (V_{mp}): 36 V.

- Current at Max Power (I_{mp}): 7 A.
- Open circuit voltage (V_{oc}): 43.2 V.
- Short circuit current (I_{sc}): 7.7 A.

The other parts of the experiment include:

- Pure aluminum sheets with the dimensions (10×10 cm).
- Rheostat with specifications: $R = 25 \Omega$, $V_1 = 5$ V, $V_2 = 15$ V, and $V_3 = 25$ V.
- pH meter from Jenway (Model 3510 pH meter).
- Heater with magnetic mixer from Buchi's.
- Flame atomic absorption spectroscopy from Buck Scientific (Model 210 VGP).

The atomic absorption spectrophotometer was used to measure the concentration of nickel ions. A standard solution of nickel sulphate at a concentration of 10 ppm was prepared. The design and implementation of a sedimentation system consists of 10 aluminum electrodes with dimensions of 10×10 cm for each plate. The system is arranged in a configuration of alternating anode and cathode pairs, and the distance between one electrode and another is fixed to be 5mm, as shown in Figure (2):

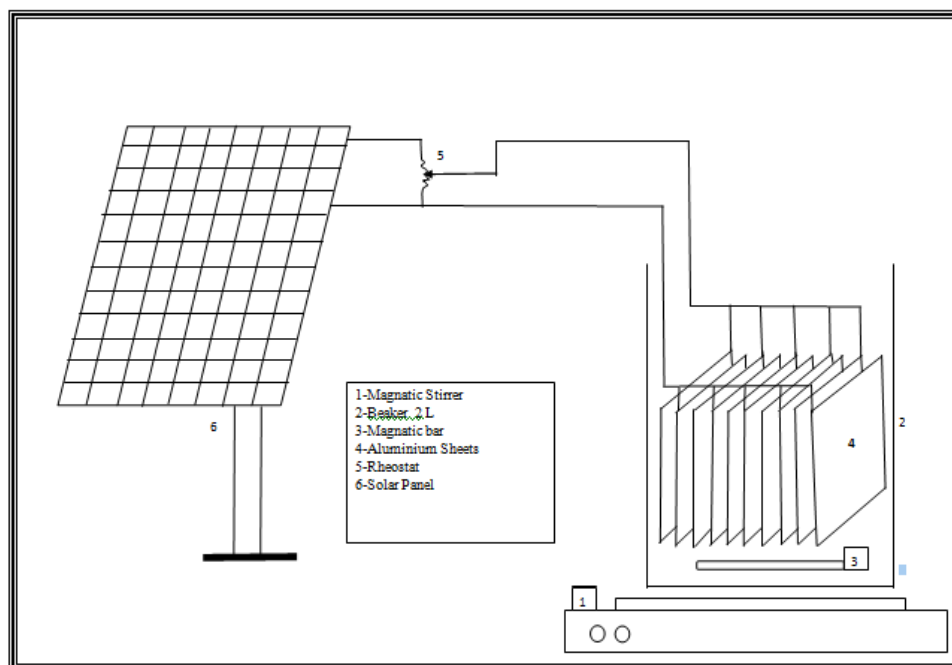


Figure (2). Represents an illustration of the heavy element deposition system.

4. Experiments

4.1 Studying the Effect of Acidity Function on Nickel Removal Efficiency

A standard solution of nickel with a concentration of 200 ppm and a volume of 1500 ml was prepared in a 2-liter glass beaker and the acidity function was modified to be $pH = 8$. The electrodes were submerged inside the solution and connected to the current source represented by the solar cell with a current of $2\text{mA}/\text{cm}^2$. The current was applied for a period of two hours. Samples of the solution were taken at periods time of (15 min, 30 min, 60 min, and 120 min). The residual nickel concentration was measured using a flame atomic absorption instrument. The above experiment was repeated at $pH = 7, 6$, and 4 .

4.2 Studying the Effect of Current Intensity on Nickel Removal Efficiency

A standard solution of nickel with a concentration of 200 ppm and a volume of 1500ml was prepared in a 2-liter glass beaker. The value of the acidity function was fixed at pH = 8. The electrodes were submerged in the solution and connected to the current source represented by the solar cell. A current of $1\text{mA} / \text{cm}^2$ was applied for a period of two hours and samples of the solution were taken at periods time of (15 min, 30 min, 60 min, and 120 min). The residual nickel concentration was measured using a flame atomic absorbent, the above experiment was repeated at current densities: $1\text{mA}/\text{cm}^2$ and $3\text{mA}/\text{cm}^2$.

4.3 Studying the Effect of Nickel Ion Concentration on Nickel Removal Efficiency

A standard solution of nickel with a concentration of 100 ppm and a volume of 1500ml was prepared in a 2-liter glass beaker and the value of the acidity function was fixed at pH = 8. The electrodes were submerged inside the solution and connected to the current source represented by the solar cell and the current value was fixed at $1\text{mA}/\text{cm}^2$ for a period of two hours. Samples of the solution were taken for periods time of (15 min, 30 min, 60 min, and 120 min). The residual nickel concentration was measured using a flame atomic absorber. The above experiment was repeated at the concentration of nickel ion (200 ppm, 300 ppm, and 500 ppm).

5. Results and Discussion

5.1 Effect of Acidity Function (pH)

The acidity function is one of the important factors affecting the deposition of heavy elements by electro-coagulation. The effect of the acidity function was studied at acidity function (4, 6, 7, 8 pH) and a current intensity of $21\text{mA}/\text{cm}^2$ and a solution of 1.5L volume containing nickel ions at a concentration of 200 ppm. All the experiments were conducted at room temperature, it was noted that the highest nickel ions removal at the first 15 minutes, then the removal efficiency decreased with time. The removal values were (93.5%, 98.5%, 97.5%, 99.55%) at (4, 6, 7, 8) pH, respectively. The highest removal was obtained at pH parameter equal to 8, at 120 minutes, and the reason is that the aluminum electrode dissolves in the solution when the electric current passes, forming aluminum ions in the solution, forming several compositions of aluminum compounds - hydroxyl at pH value range (4-8). The type of compound formed depends on the pH value, which helps to remove nickel ions by the method of electro-coagulation as mentioned in previous works [11].

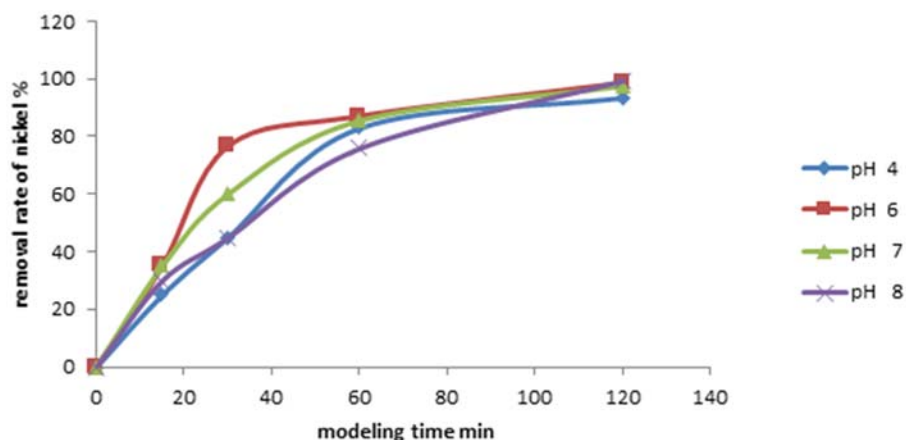


Figure (3). The change in the nickel removal values with the change in the pH and time.

5.2 The Effect of Current Intensity

The current intensity is considered one of the factors affecting on the removal of nickel ions by electro-coagulation method. To study the effect of the current intensity at (0.5, 1.0, 1.5 mA / cm^2) on the removal rate of nickel ions, the acidity function was fixed at pH = 8, a solution of 1.5 L at a concentration of 200 ppm of nickel ion.

Figure (4) shows the effect of removing nickel with an increasing of the current. it has been noticed that the increase of the removal rate with the increase in the intensity of the current sharply at first hour and after 120 minutes of the life of the experiment, we notice that the best removal was obtained at a current intensity of

1.5mA/cm², which is in a good agreement with previous works that refers to increasing the concentration of aluminum hydroxide coagulants with increasing current intensity [12].

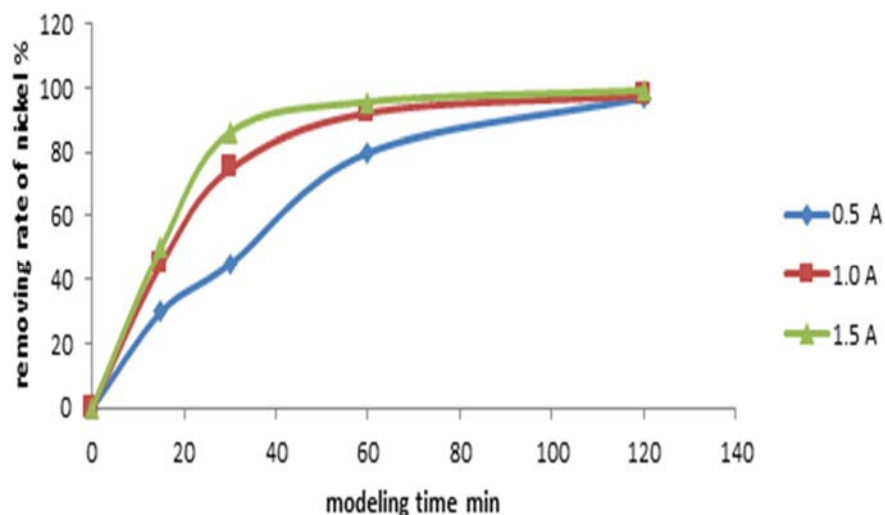


Figure (4). The change in nickel removal rate with current and time.

5.3 The Effect of Ni Ion Initial Concentration

Equations should be centered and in bold as shown in Eq. (1) below. All equations should be numbered. Fonts in Equation Editor (or MathType). Make sure that your Equation Editor or MathType fonts, including sizes, are set up to match the text of your document.

The effect of Ni ion initial concentration on the removal rate was studied using concentrations of nickel ions (200, 300, and 500 ppm) and at a current intensity of 1.0 mA / cm² and an acidity function pH = 8. Table (3) and Figure (5) illustrate the effect of the concentration of nickel ions on the removal rate. The removal rates ranged (98%, 96.7%, and 98.8%) to the concentrations of nickel ions (200, 300, 500 ppm), respectively. the highest removal was at concentration of nickel ions of 500 ppm with a time of 120 minutes which agreement of previous works [13]. The produced sediment rate increases with increasing the concentration of Ni ion in the solution due to dissolution the aluminum electrode with passage of electric current continuously will provide excess amount of aluminum hydroxide compounds which increasing removal of Ni ion as sediment.

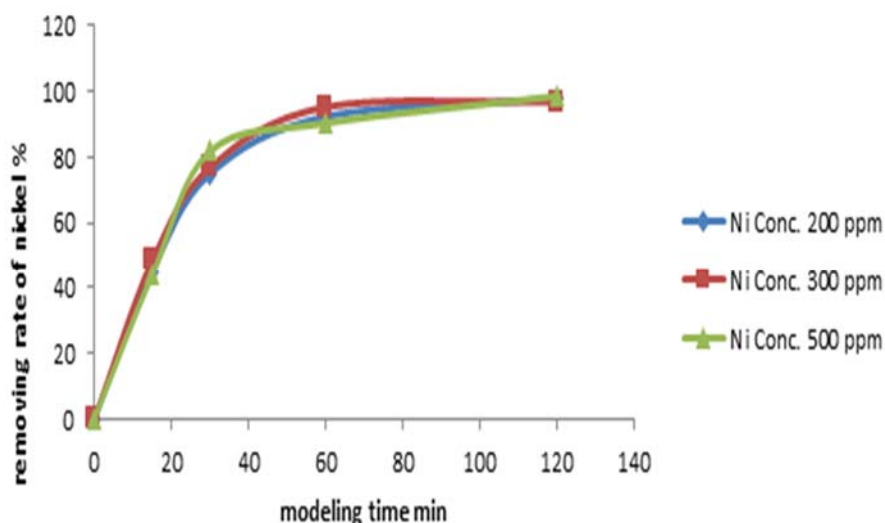


Figure (5). The change in nickel removal rates with concentration and time.

6. Conclusions

The rate of nickel removal increases sharply during the first 60 minutes in all experimental conditions (changing the acidic function, changing the current intensity, changing the concentration of nickel ions) and then it reaches a steady state after 120 minutes of the experimental life. The best removal is pH = 8, with a removal rate of 99.55%. The choice of the neutral pH function corresponds to the determinants of the treated water disposal (6.5 - 8.5 pH). The removal percentage increases with the increase in the current intensity and the best removal was 99.55% at a current strength equals to 1.5 mA/cm². To increase the concentration of aluminum ions dissolved in the solution as a result of the aluminum electrode dissolution when the electric current passes, which produces many aluminum-hydroxyl compounds that help with electro-coagulation. The percentage of removing nickel ions when changing the concentration was close due to the abundance of aluminum ions present in the solution due to the abundance of the surface area of the anode 1000 cm². Through experiments, it has been proven that the use of solar energy as a source of electric current in the electrical coagulation process is successful and efficient.

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