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Investigation of Variables Affecting the Adsorption of Cadmium Ions in Aqueous Solution Using low-cost Adsorbents (Fly Ash)

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A B S T R A C T

This study investigated the effect of some variables on the removal of Cadmium ions from Aqueous solutions using materials produced by some factories and industrial units as an unused or limited-use by-product, such as fly ash. It was tested as an adsorbent for the removal of cadmium ions (Cd (II)). Some variables that directly affect the deionization process were studied, such as pH, required dose, initial metal concentration, contact time, and particle size. Through the experiments conducted and the results obtained, some removal percentages differed based on the studied variable, as the best dose was 3 grams and the best concentration was 300 parts per million, and the removal percentage reached 83%. The remaining prepared concentrations differed, as the best time was 100 minutes, with a particle size of 75 micrometers, and the best pH was 6. The removal percentage changed with temperature, as it was 81% at 25°C and increased to 89% at 55°C. The results showed that cadmium is highly adsorbed on fly ash and can be an economical method for removing cadmium from aqueous solutions..

دراسة بعض المتغيرات المؤثرة على ادمصاص أيونات الكادميوم في المحاليل المائية باستخدام مواد ماصة منخفضة التكلفة (الرماد المتطاير)

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الكلمات المفتاحية:
ايونات الكادميوم
الرماد المتطاير
الاس الهيدروجيني
درجة الحرارة
المحاليل المائية

الملخص

تم في هذه الدراسة اجراء بعض التحقيقات في مدي تأثير بعض المتغيرات في إزالة ايون الكادميوم من المحاليل المائية باستخدام مواد ناتجة عن بعض المصانع والوحدات الصناعية كمنتج ثانوي غير مُستخدَم وغير مكلف او محدود الاستخدام مثل الرماد المتطاير. حيث تم اختُبِاره كمادة مازة لإزالة أيون الكادميوم (Cd (II. دُرِسَت بعض المتغيرات التي تؤثر بشكل مباشر على عملية ازالة الايونات مثل الرقم الهيدروجيني (pH)، والجرعة المطلوبة، والتركيز الابتدائي للمعدن، وزمن التلامس، وحجم الجسيمات ومن خلال التجارب التي أجريت والنتائج المتحصل عليها اختلفت بعض نسب الازالة بناءً على المتغير الذي تم دراسته حيت كانت افضل جرعة عند 3 جرام وافضل تركيز 300 جزء من المليون و بلغت نسبة الازالة 83% واختلفت في باقي التراكيز المحضرة وكان افضل زمن 100 د وحجم جسيمات 75 ميكروميتر وافضل درجة حموضة عند 6 .نسبة الإزالة تغيرت بتغير درجة الحرارة حيث كانت 81 % عند25 درجة مئوية وازدادت الى 89% عند55 درجة مئوية .. اظهرت النتائج أن الكادميوم يمتص بشكل كبير على الرماد المتطاير ويمكن أن يكون طريقة اقتصادية لإزالة الكادميوم من المحاليل المائية.

1. Introduction

Water is a necessary component for all living things, including plants and animals. Water contamination is usually seen as more serious than air and soil pollution because of its vital necessity. Between two and three billion people worldwide lack access to basic sanitation and safe drinking water because of their unique properties and characteristics. Each year, between 3.5 million and 5.5 million people can die from diseases caused by contaminated water. [1]

Toxic contaminants like heavy metals must be reduced in order to combat industrial water pollution. For metal finishing, numerous industrial processes in the coating industry use heavy metals, and their effluents must be treated before being discharged. As environmental regulations have become more stringent, it is necessary in this setting to treat metal-contaminated wastewater in a way that is both cost-effective and efficient [2]. Metal ions are essential for the growth,

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development, and health of living organisms. However, some metal ions are essentially unnecessary and undesirable, and most of these ions are classified as toxic to all living organisms. Therefore, the toxicity of metals depends on their concentration and presence in the environment. Soil has the ability to retain heavy metal ions, which seep into groundwater and water soil solutions, leading to elevated toxic metals concentrations of these ions. As a result, these harmful metals can build up in living tissues and cluster in the food chain. Metals that are include cadmium, which is believed to be one of the most dangerous pollutants today. Due to its negative effects on health, copper is considered a priority pollutant [3]. Two necessary metals that are typically regarded as non-toxic at specific concentrations are zinc and iron [4]. Lead has no known biological purpose and is not a necessary trace element in any living thing. It can have a number of negative health impacts [5].

Although common treatment methods like chemical precipitation and dialysis can remove heavy metals from inorganic wastewater, each process or technology has its unique conditions and capabilities. Recently, adsorption has become a promising alternative therapy option with several advantages. [6]. According to Kurniawan and Babel, adsorption is essentially a mass transfer process in which a substance is transferred from the liquid phase to the surface of a solid because of the solid's high surface reactivity and adsorption capability, and it is linked to chemical and/or physical interactions. Metals like Nickel, Ni (II), Chromium, Cr (VI), Cadmium Cd (II), Zinc Zn (II) [6.7] and Copper, Cu (II) [1.8], can be removed from inorganic effluents through However, the use of activated carbon can be expensive. Utilizing low-cost adsorbents with metal-binding capabilities, like fly ash, has been the focus of increased research in recent years. Natural materials, agricultural waste, and industrial by-products—all of which are easily accessible locally in significant quantities—can be used as inexpensive adsorbents. Some of these materials can be used as absorbent materials after pre-treatment or even used directly without treatment to determine their removal ability. In India [9], Thailand [6], Nigeria [10], Italy [11], and the United States various low-cost materials have been used to investigate economically effective treatment of metal-contaminated wastewater. It has been demonstrated that wool soybean cake sawdust maple sawdust distillery sludge, cocoa husk sugar beet pulp [12, [13], [14].

This article provides an overview of fly ash, an industrial by-product with the ability to bind metals. To highlight its technical application in treating water contaminated with metals, particularly cadmium ions, selected information on pH, required dosage, initial concentration of cadmium ions in solution, temperature and adsorption capacity is discussed.

2. MATERIALS & METHODS

2.1 Preparation of absorbent.

Fly Ash, a byproduct of power plants and cement plants located in and around Al-Khoms, is an undesirable byproduct with very limited uses. It was obtained from the Arab Cement Plant in Zliten. Fly ash is made up of calcium oxide (CaO), iron oxides (Fe_2O_3), alumina (Al_2O_3), and silica (SiO_2). Additionally, it could have traces of carbon., magnesium, sulfur, sodium, and potassium [15.16]. Fly Ash particles were separated using sieves of different diameters between (75-100-150-300-400) micrometers in order to study each size separately.

2.2 Preparation of Solution

Concentrated solutions of cadmium were prepared by diluting 100 mg L^{-1} stock solution prepared from analytical grade aqueous cadmium sulfate Cd (SO_4) $7H_2O$.

Adsorption tests were conducted using batch technology. In 100 ml Erlenmeyer flasks, batch adsorption studies were carried out by combining a fixed volume of aqueous cadmium salt solution with a fixed amount of adsorbent. After that, deionized water was used to dilute the stock solutions to the necessary concentrations (50,150,200,300, and 400 ppm).

2.3 Adsorption Procedure and Measurement

Cd (II) ions were extracted from aqueous solutions using batch adsorption experiments.

A powder (1 -5 g) was weighed into a clean 100 ml conical flask, and a Cd (II) solution (100 mg/L) was added to the flask. pH of the solution was adjusted to the desired value by adding 1 mol HCl or NaOH. The anastomoses were removed and the cadmium ion concentration was determined by Atomic Absorption Spectrophotometry [17,18]. Atomic absorption spectrometry (AAS) was used to determine the amounts of cadmium (II) ions and the concentration after reaching equilibrium.

At the equilibrium status, the adsorption ratio (%) and ion removal capacity (Qe) of the adsorbents were measured, as described in a previous study [1,2]:

$$R\ \% = \frac{(C_i - C_e)}{C_i} * 100 \dots\dots\dots\dots..(1)$$

Where:

R is the removal percentage,
C_i is the initial solution concentration
C_e is the solution concentration at equilibrium.

$$Qe = \frac{(C_i - C_e)V}{m} \dots\dots\dots\dots\dots.(2)$$

Where:

Qe is the adsorption capacity at equilibrium,
C_i is the initial solution concentration,
Ce is the equilibrium concentration,
V is the volume (l),
m is the adsorbent amount (g).

3. RESULTS AND DESCUSSION:

The experiments include some parameters affecting the removal rate of cadmium (II) from aqueous solutions, such as the concentration and particle size of the adsorbent, as well as contact time studies. These are followed by results from studies of the effects of pH, temperature, and mixing speed.

3.1 Effect of Contact Time Variation

Batches of the adsorption procedure were conducted with time intervals varying from 0 to 120 minutes. By altering the contact duration between the adsorbent and the solution made at various concentrations, the impact of contact time on cadmium ion adsorption was assessed. The values (0, 20, 40, 60, 100, and 120 minutes) were subjected to the time. The removal percentage of cadmium (II) from the solution was calculated by using 100 ml of known concentrations of cadmium (II) solutions (50, 150, 200, 300, and 400 ppm), 3 g of adsorbent dose, 75 µm particle size, pH 6, and temperature of 25°C. Figure 1 shows that the maximum removal rate was achieved at 100 min, with the optimum concentration being 300 ppm. At 120 minutes, there was no discernible change in the rate. This does not mean that the other prepared concentrations did not achieve good removal, but rather varying proportions were obtained that were close to each other, but the best of them was the concentration of 300 ppm.

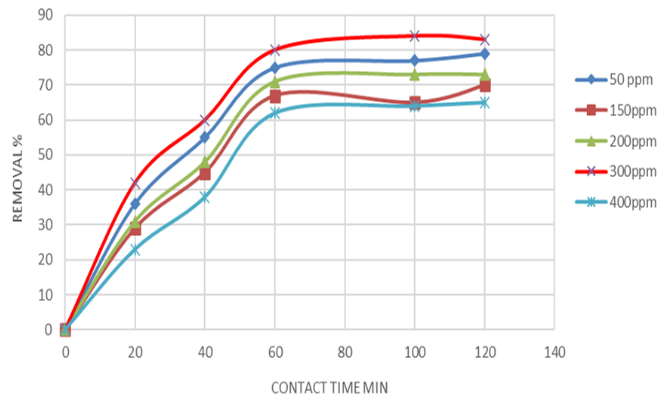

Fig 1. Effect of contact time

3.2 The effect of the Sorbent dosage

The effect of the adsorbent quantity on the adsorption of cadmium (II) (Cd (II)) was studied under known conditions for a contact time of 100 minutes. This was done for 100 ml of a solution containing a known concentration of cadmium (II) (50, 150, 200, 300, and 400 ppm) (Cd (II)), a pH of 6, a temperature of 25°C, and a particle size of 75 µm.

The sorbent dosage was varied from 1 to 4 grams depending on the quantities (1, 2, 3, 3.5, 4.5). Figure 2 shows that the best removal was achieved at a dose of 3 grams for all concentrations, with 50 ppm being the best at the 3-gram dose. This is attributed to the presence of a number of active areas available at the lowest concentrations [19]. ...When the dose of the adsorbent was increased, the amount of removal did not change. Therefore, it was necessary to stop increasing the doses, not increase the time, and stop at 3 grams.

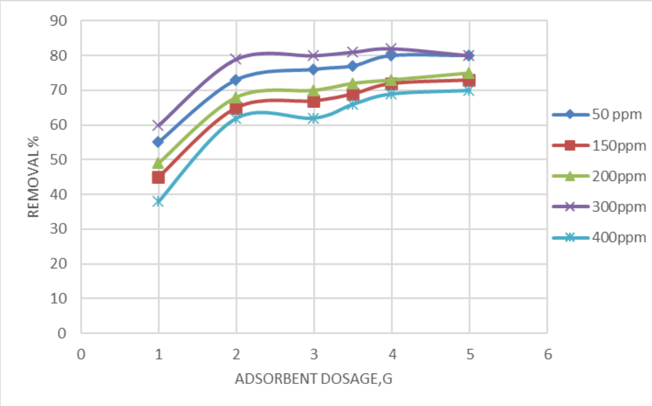

Fig 2. Effect of the amount of fly Ash

3.3 Effect of particle size on cadmium adsorption

The effect of adsorbent particle size on the removal of cadmium (II) from 100 mL of solutions containing known concentrations of cadmium ions solutions (50, 400, and 100 ppm) was studied using a 3 g molecular weight, a temperature of 25°C, a pH at 6, and time of 100 minutes for particle sizes of 75, 100, 150, 300, and 400 µm. Figure 3 shows a graph of the percentage of metal ions removed versus different adsorbent particle sizes. It was observed that the removal rate decreased with increasing particle size. Its ability to effectively remove substances is ascribed to the adsorbent's surface having several active sites. The smallest adsorbent particle size is considered the best size, as it provides a sufficient surface area to accommodate the adsorption of ions.

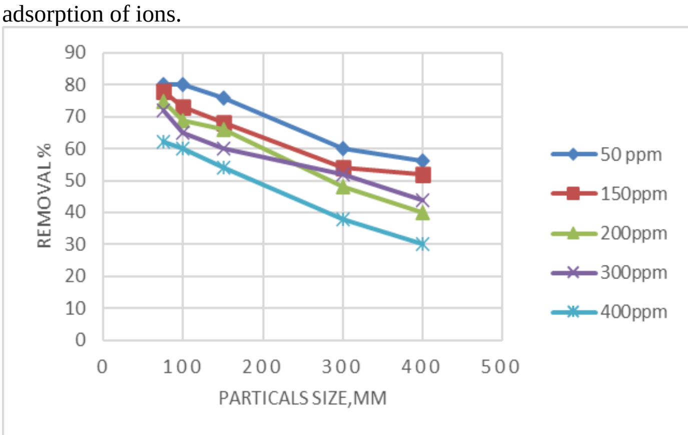

Fig 3: Effect of particle size on cadmium adsorption

3.4 Effect of Initial Cadmium Concentration Variation

The effect of initial Cd (II) ion concentrations on the adsorption efficiency is shown in Figure (4). Different initial concentrations of Cd (II) were used in adsorption testing. used 100 milliliters of solution with a pH of 6, a temperature of 25 ºC, and concentrations ranging from 50 to 400 ppm (50, 150, 300, and 400) for 100 minutes. and the particle size is (75 µm).

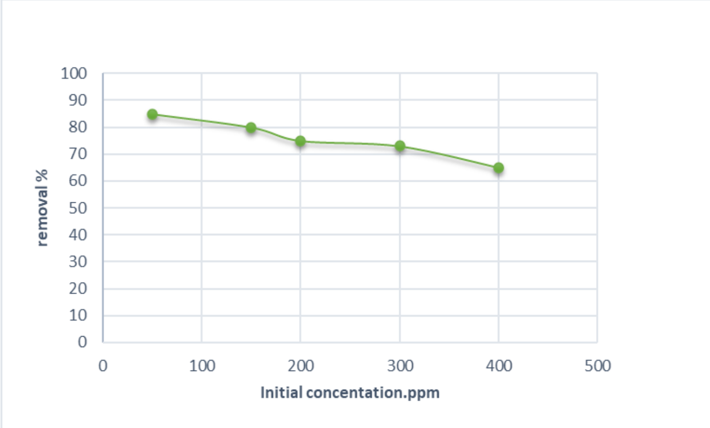

Fig 4: Effect of initial concentration on Cadmium removal

3.5 pH Effect on Cadmium Ion Adsorption

pH is one of the main factors that affecting on adsorption process using molecular weight. Thus, it was investigated how the pH of the starting solution affected the adsorption of cadmium (II) from aqueous solution. This study was conducted under constant conditions, contact time of 100 min, 100 ml of solution containing 300 ppm Cd (II) concentration, 3 g molecular weight with particle size of (75µm), temperature of 25 °C, and pH solution ranging between 4 to 8 (4, 6, 7, and 8). As shown the Figure 5, the amount of cadmium that was adsorbed in the acidic medium increased progressively as the pH was raised from 4 to 6. The difference in absorption rate indicates that the pH effect on the removal process.

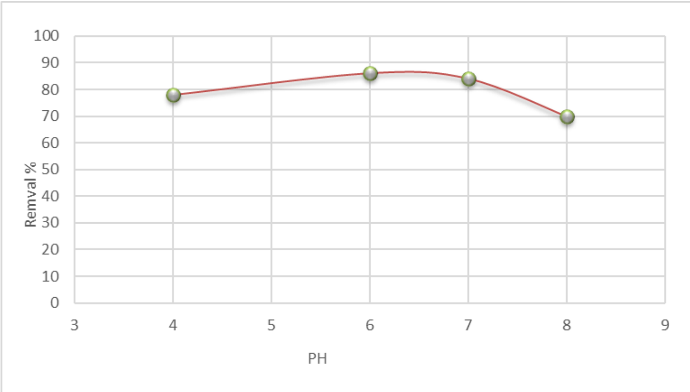

Fig 5. The effect of pH on the removal percentage of Cd (II)

3.6 Effect of Agitation Rate on Cadmium Adsorption

The stirring rate for removing cadmium (II) from 100 ml of prepared solutions was determined based on stirring rates of 100, 200, 250 and 300 rpm using a molecular weight of 3 grams per sample. 300 ppm concentration, and a particle size of (75) µm at 25°C, an initial pH of 6, and a contact time of 100 minutes. Cadmium removal increased with increasing stirring speed, as there was better contact between the sorbent and adsorbent at higher speeds [20]. Therefore, the optimum was 250 rpm.

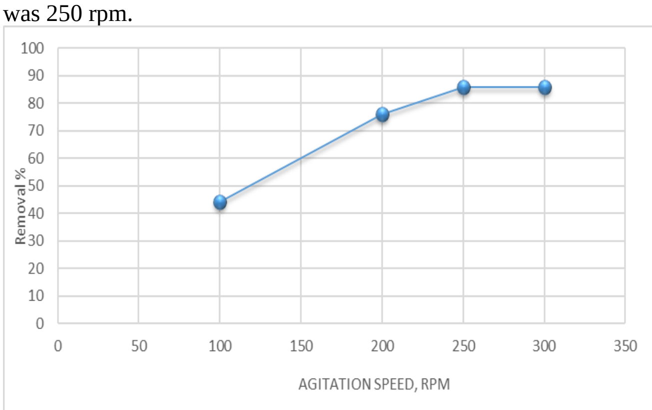

Fig 6. Effect of agitation speed

3.7 Effect of Temperature on Cadmium Adsorption

The of temperature effect on Cadmium (II) adsorption of from 100 mL of solutions with specific concentrations of cadmium (II) ions (300 ppm) was studied using 3 g molecular weight, (75 µm) particle size, initial pH 6 min, and 100 min contact time at temperatures of 25, 35, 45, and 55 °C. A prepared and calibrated water bath was used to obtain the required temperature values for the solutions. Figure 7 shows the results of the removal ratio increase with increasing temperature, implying that the adsorption process was endothermic in nature.

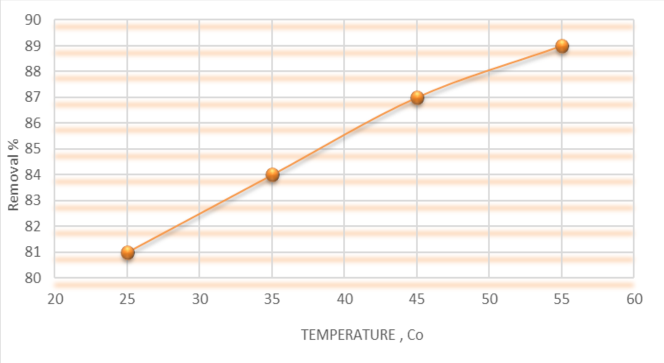

Fig 7. Effect of temperature on the removal percentage of Cd (II)

4. Conclusions

The primary objective of this study was to verify to use of materials or wastes that may be effective in removing some heavy metal ions, such as cadmium ions, present in aqueous solutions in general, and to study some variables that directly affect the removal processes. Fly ash obtained from cement factories was used as an adsorbent capable of removing cadmium (II) ions from waste water and aqueous solutions. Experiments showed that contact time, which is the time the adsorbent dose remains in the solution, affects the removal rate. The best removal was achieved at 100 minutes, and the best concentration was 300 ppm. The pH also had an effective impact on the adsorption process, with the optimum removal rate being at pH 6. Particle size and Temperature also had an effect, as increasing temperature increased the removal rate, making the reaction endothermic. Finally, Fly Ash can be used in the removal of heavy metals ions such as cadmium ions, due to its ease of access, making it suitable for use in wastewater treatment plants and other water sources.

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