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Removal of arsenic and lead with activated carbon from Crescentia cujete L "Huingo" in mining effluents

Remoción de Arsénico y Plomo con carbón activado de Crescentia cujete L "Huingo" en efluentes mineros

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Abstract

The research aimed to evaluate the removal capacity of "Huingo" activated carbon of the heavy metals arsenic and lead in a mining effluent. El estudio fue de tipo aplicado con enfoque cuantitativo y diseño experimental. Six treatments were considered: T0 (control group) and 5 treatments (experimental groups). The doses of 5 g, 10 g and 15 g of powdered and granular activated carbon were considered, and the protocol for wastewater effluent sampling was used. The sample was 50 L of effluent water, kept refrigerated from 4 - 8 °C, and 2 L were taken for initial arsenic and lead concentration analyses. The preparation of the activated carbon began with pre-drying in the open air for 14 days. After that, it was dried in a muffle for 24 hours and once dry, it was crushed and impregnated with 85% phosphoric acid; it was then carbonized at a temperature of 25°C to 1400°C, with a heating rate of 20°C per minute. The activated carbon obtained was ground and washed with distilled water to eliminate impurities. After washing, it was left to dry for subsequent use in the adsorption of heavy metals. Regarding the results, there was an initial concentration of 0.659 mg/L of arsenic and 0.2 mg/L of lead, exceeding the maximum permissible limits. Experimental analyses were carried out and the optimum dose of 15 g of activated carbon powder was found to have a removal value of 85% for arsenic and 88% for lead. Therefore, activated carbon can be an alternative to minimize the negative impacts of heavy metals in the environment.

Keywords: Heavy metals, removal, mining effluent, active carbon.

Resumen

La investigación tuvo como objetivo evaluar la capacidad de remoción del carbón activado "Huingo" de los metales pesados de arsénico y plomo en un efluente minero. El estudio fue de tipo aplicado con enfoque cuantitativo, diseño experimental, se consideró 6 tratamientos; T0 (grupo control) y 5 tratamientos (grupos experimentales) se tomó en cuenta la dosis de 5 g, 10 g y 15 g de carbón activado en polvo y granular, se utilizó el protocolo para la toma de muestras de efluentes de aguas residuales, la muestra fue de 50 L de agua del efluente, se mantuvo refrigerada de 4 - 8 °C, se tomó 2 L para análisis iniciales de concentración de arsénico y plomo, la preparación del carbón activado dio inicio con un presecado al aire libre durante 14 días, posterior a ello se secó en una mufla durante 24 horas, una vez seca, se trituró y se impregnó con ácido fosfórico al 85%, luego se procedió a la carbonización a una temperatura de 25°C a 1400°C, con una velocidad de calentamiento de 20°C por minuto, el carbón activado obtenido se molió y se lavó con agua destilada para eliminar impureza. Después del lavado, se dejó secar para su posterior uso en la absorción de metales pesados. Referente a los resultados hubo una concentración inicial de 0.659 mg/L de arsénico y 0.2 mg/L de plomo sobrepasando los límites máximos permisibles, se procedió a los análisis experimentales encontrándose la dosis óptima de 15 g en polvo de carbón activado con un valor de remoción de 85% para Arsénico y 88% para plomo; por lo tanto, el carbón activo puede ser una alternativa para minimizar los impactos negativos de los metales pesados en el medio ambiente.

Palabras clave: Metales pesados, remoción, efluente minero, carbón activo.

INTRODUCCIÓN

Nowadays, the treatment of tailings water prior to its final disposal has become an essential and extremely important issue. For this reason, many mining companies use different technologies and methods to adequately treat mining effluents.

One of the main phenomena that influences the quality of the aquatic environment is adsorption, a physicochemical regime that allows the elimination of a large number of contaminants present in water. Among the technologies that exist today for the treatment of mining effluents, we find the use of activated carbon. This technology proves its effectiveness in the treatment of water with a high content of heavy metals, using the sustenance of removal (Prieto, 2020).

Peru has great mining potential worldwide due to the abundance of mineral deposits and extensive natural resources. Therefore, mining activity is fundamental for the economic development of the country.

In contrast to Brazil and Chile, in Peru, along with Ecuador and Bolivia, most mining activities are carried out in areas with high population density and in rain basins. This results in a number of significant impacts, mainly related to solid and liquid waste management. In other words, waste management is a crucial issue in these mining areas, as it has a direct impact on the people living there. Therefore, it is essential to address these issues to ensure the safety and well-being of the population and the environment (Espejo, 2024).

Mineral extraction in our country involves significant water consumption in its processes, and the effluents generated contain a variety of contaminants, such as arsenic and lead, which are harmful to biological activity and pollute watercourses. In fact, the toxic metals found are above the Maximum Permissible Limits, such as Arsenic (As), Cadmium (Cd), Mercury (Hg), Lead (Pb), Chromium (Cr), among others (Ministry of the Environment, 2013).

It is important to note that these tailings can have a negative impact on the environment and on the health of people living near mining areas. Therefore, it is crucial that measures are taken to minimize their impact and properly manage these wastes.

Lead is a powerful poison that can have terrible effects on the central nervous system, especially in children. Lead exposure can cause problems in cognitive development, behavioral disorders and growth retardation.

On the other hand, arsenic is highly toxic and its exposure is related to several types of cancer, such as skin, lung and bladder cancer. It can also cause cardiovascular problems, diabetes and neurological damage, as well as skin lesions and damage to the immune system. It is therefore important to take measures to avoid exposure to these toxins and protect our health and well-being (Rodriguez, 2021).

Adsorption is a fascinating process that occurs when atoms, ions or molecules of a substance adhere to the surface of a solid or liquid. This phenomenon is due to the attractive forces between the molecules of the adsorbent and those of the adsorbate. It is a surface process, unlike adsorption where substances are uniformly distributed within another substance (Maza et al, 2023).

Activated carbon is a material widely used in industry due to its incredible adsorption properties. Its high internal surface area, pore distribution and diversity of functional groups allow it to capture a wide range of molecules. In other words, this element is capable of trapping and retaining unwanted substances on its surface, making it a valuable component in multiple industrial processes. From the removal of contaminants in water to the purification of gases and liquids, activated carbon is an important ally in the search for environmental and quality solutions in production (Abdul et al., 2019).

Activated carbon is an amazing material, with a chemical composition that is almost pure, containing about 70 to 80% carbon, 5 to 10% ash, 60% oxygen and 0.5% hydrogen. This chemical mixture makes it very useful for a variety of applications, and makes it one of the most versatile materials in existence. In fact, its purity is comparable to that of diamond, graphite and other types of mineral carbon. Activated carbon is a true chemical wonder that has been used for generations to improve our lives in many different ways (Hagemann et al., 2018).

Milla (2022) explains that activated carbon has a fascinating property: adsorption capacity is a physicochemical phenomenon that occurs when a solid called an adsorbent traps certain molecule, called adsorbates, found in a liquid or gaseous medium. Functional groups are formed during the activation process, when free radicals on the surface of the carbon interact and cause the carbon surface to become chemically reactive. This is what gives activated carbon its adsorptive properties, especially for molecules of a polar nature. Activated carbon is often considered hydrophobic, i.e. it has little affinity for water. This is very important in gas adsorption applications in the presence of moisture or species in aqueous solution. However, the presence of functional groups on its surface means that it can react with water, making the surface more hydrophilic.

The application of activated carbon is a tertiary treatment that aims to improve the quality of the effluent obtained in conventional primary and secondary treatments. It is used in columns packed with granules of the adsorbent material and water is pumped through the filter. As the water flows through the column, chemicals adhere to the porous surface of the granules. When the activated carbon becomes saturated, it must be replaced or cleaned in order to reuse the filter. The cleaning of the spent carbon consists of heating the carbon and pumping clean air through it to get rid of the chemicals. In this way, the efficiency of the filter is guaranteed and a high-quality effluent is obtained (Del Cid, 2023).

According to Zegarra (2021), acid mine drainage, in addition to a low pH, contains a large amount of suspended matter with a high sulfate and metal content (Cu, Pb, Hg, Cd, Ni, Fe, Al, Mn and Zn). All these elements are very detrimental to biological activity and pollute watercourses. It is clear that the high cost of treatment in traditional wastewater treatment plants makes it necessary to look for innovative alternatives to solve this serious problem.

Ledesma (2019) points out that there is a great variety in terms of the use of minerals and metals, and that the method of extraction and location of the minerals and metals generates the so-called tailings. Tailings are highly polluting to water sources, as they contain chemicals used in mining operations, such as acids, sodium cyanide, ionized metals and other chemicals such as acids, alkalis, foams, coagulants, flocculants and suspended solids from mine water.

According to Ramos (2022), heavy metals such as lead, arsenic, mercury, copper and nickel are extremely dangerous and require immediate attention. These metals can accumulate over time and destroy entire ecosystems, as they are highly toxic. Even minute concentrations can persist in the environment and accumulate in living organisms over time. Since there are few pathways for human metabolism or degradation, there is an urgent need to treat the wastewater generated to avoid disastrous consequences.

Some antecedents concerning the study, such as the research by Lagua (2021), proposed to evaluate the capacity of datura seeds to produce activated carbon and its effectiveness as an adsorbent of Lead II and Chromium VI. To achieve this, a carbonization and activation process was carried out with phosphoric acid, and the optimum conditions of dose, pH and time were determined to maximize the removal of the contaminants. The results: 79% removal of lead II and 35% removal of chromium VI, demonstrating the high efficiency of the activated carbon obtained from datura seeds. Therefore, it can be very useful in the search for sustainable and economical alternatives for the removal of heavy metals in water and other pollution media.

Likewise, Roncal and Villanueva (2021) demonstrated the effectiveness of rice husk activated carbon as an adsorbent medium to remove heavy metals present in industrial effluents, such as lead, cadmium and other metals. For this purpose, they carried out a non-experimental cross-sectional approach, which consisted of an exhaustive documentary review. The results obtained showed that rice husk activated carbon was able to remove 96.04% of lead and 95.89% of cadmium present in water, indicating that this method is highly efficient and sustainable for the removal of heavy metals in water. It is concluded the great potential of rice husk as an effective and sustainable removal medium for heavy metal removal in industry.

Tena and Jhames (2019) aimed to determine the degree of effectiveness of coconut shell activated carbon in the absorption of iron and lead from drinking water. The Research method used was a quasi-experimental study: the characterization of raw water has 0.09 mg/L of lead and 0.81 mg/L of iron; tests were performed with 40 g of activated carbon for 1 L of raw water and analyzed in 2 times of 60 and 90 minutes reaching a reduction of 0.02 mg/L of lead (77%

removal) and 0.41 mg/L of iron (49% removal) in an optimal time of 90 minutes, concluding the removal of metals with activated carbon.

Finally, Ponce (2023) evaluated the effectiveness of activated carbon from orange peel as a lead (Pb) adsorbent using an applied methodology with an experimental design of explanatory scope. Different masses of activated carbon, including 0 g, 0.5 g, 1 g, 1.5 g and 2 g, were tested to determine the optimum amount needed to remove lead from contaminated water. The results obtained were that orange activated carbon proved to be a highly effective adsorbent, achieving a lead (Pb) removal rate of more than 94% at the optimum dose of 2g/L. To be more specific, the results were as follows: 0g (0%), 0.5g (93.4%), 1g (94.5%), 1.5g (93.9%) and 2g (93.7%). In conclusion, orange peel activated carbon is a viable and highly effective solution for removing lead from contaminated water.

In this regard, the objective of this study was to evaluate the removal capacity of “Huingo” activated carbon of arsenic and lead heavy metals in a mining effluent.

Therefore, the study is justified, knowing that advances in technology and science have increased human capacity to use natural resources, but have also caused problems in biological, chemical and geological cycles. Conventional methods to treat heavy metal wastes are costly However, Orozco (2023) highlights the potential of environmentally friendly adsorbents to adsorb heavy metals more efficiently and economically. The use of Huingo shell activated carbon as an adsorbent can be beneficial both economically and for the environment. For this reason, the aim is to fill a theoretical gap in scientific knowledge and contribute to the development of alternatives to treat water contaminated with heavy metals.

Advances in technology and science since the industrial revolution have increased the human capacity to use natural resources. On the other hand, conventional methods of treating heavy metal wastes are costly, so the use of environmentally friendly adsorbents may be a more efficient and economical solution for adsorbing heavy metals in industries.

Finally, it is hypothesized that Huingo activated carbon has the capacity to remove arsenic and lead from the mine waste effluent.

METHODOLOGY

Type of research

The type of research was applied, since it seeks to generate concrete results from experimentation. Likewise, a quantitative approach is used to be able to measure the relevance and significance of the results obtained (Hernández *et al*, 2018).

Research Design

The research used a pretest-posttest design with a single group. It is characterized by evaluating the experimental units only twice: before receiving the stimulus and after receiving it, with the objective of establishing an initial reference and determining the effect produced (Pérez, 2020).

Table 1
Experimental conditions

Activated carbon	
Activated carbon dose	5 g
	10 g
	15 g
Type of carbon	Powder Granular
Heavy metals	
Initial and final amount of lead	mg/L
Initial and final amount of arsenic	mg/L

Note. Database

Sample Selection

The protocol for wastewater effluent sampling was considered as established by the Chief Resolution No. 010-2016 National Water Authority. Likewise, the protocol established in Ministerial Resolution No. 273-2013-VIVIENDA for wastewater treatment plant effluent sampling was considered. It is important to note that the sample was taken before the wastewater reaches the receiving body. This ensures that the results of the investigation are accurate and reliable.

A 50 L sample of water was collected from the effluent, kept refrigerated at 4 - 8 °C and transported to the laboratory; 2 L were taken for initial analysis of arsenic and lead concentration. The jar test was applied, with three doses of Huingo activated carbon 5 g, 10 g and 15 g with two rapid mixing speeds 200 rpm for 60 seconds and 60 rpm for 15 minutes. Each dose and type of carbon had three replicates.

Preparation of Huingo activated carbon

The process began with the pre-drying of the raw material in the open air for 14 days, then to eliminate any trace of moisture, it was dried in a muffle for 24 hours, once dry it was crushed and then impregnated with 85% phosphoric acid (Ahiduzzaman and Sadrul, 2016).

The next step was carbonization. It was carried out in a single stage together with activation. A muffle was used and a temperature range of 25°C to 1400°C was applied with a heating rate of 20°C per minute. The samples were placed in crucibles and a temperature from 550°C to 700°C at 50°C intervals was considered. Once the desired temperature was reached, the carbonization process was maintained for 30 minutes. Finally, the activated carbon obtained was ground and washed with distilled water to remove any impurities. After washing, it was allowed to dry for subsequent use in the adsorption of heavy metals (Grima *et al*, 2016; Sandoval *et al*, 2021).

Determination of the removal efficiency of the experimental group

To determine the percentage efficiency, the percentage difference formula was used, taking into account the control group and the experimental groups:

$$\text{Adsorption efficiency } (\%) = \frac{CGC\text{-}CGE}{CGC} \times 100$$

Where:

CGC: Concentration of the control group

CGE: Experimental group concentration

(From their Spanish initials)

Data analysis

A descriptive analysis was carried out to compare the results obtained with the maximum allowable water values. The data were tabulated and graphs were prepared to classify and visualize them clearly. In addition, an inferential analysis with ANOVA was applied to determine the significant differences between treatments.

RESULTAS

Data analysis at descriptive level

Table 2
Concentration of arsenic and lead in the different experimental conditions.

Treatment	Dose (g)	Type	As (mg/L)	Pb (mg/L)
T0 (GC)	0	0	0.659	0.2
T1 (GE)	5	Powder	0.197	0.053
T2 (GE)	5	Granular	0.264	0.071
T3 (GE)	10	Powder	0.131	0.034
T4 (GE)	10	Granular	0.198	0.055
T5 (GE)	15	Powder	0.065	0.014
T6 (GE)	15	Granular	0.132	0.033

Note. Data from Minitab program ver. 19

Table 2 shows the concentration data according to arsenic and lead treatments. The initial value for T0 (control group) was 0.659 mg/L for arsenic and 0.2 mg/L for lead, values that exceed the maximum permissible limits (MPL) established by the Supreme Decree N° 010-2010-MINAM. Likewise, the T5 (experimental group) with a dose of 15 g, powdered activated carbon type, values of 0.065 mg/L for arsenic and 0.014 mg/L for lead were obtained.

Data analysis at the inferential levell

Table 3

Análisis de varianza (ANOVA) en la remoción de arsénico (As).

Source	SC	GL	CM	F	p-value
Model	16.55.9	7	236.5	102.3	0.000
Blocks	0.00	2	0.002	0.65	0.544
Linear	1655.9	3	551.9	238.8	0.000
Carbon Dose	1197.5	2	589.7	259.1	0.000
Type of carbon	458.3	1	458.3	198.4	0.000
Dose x Type	0.001	2	0.005	2.33	0.148
Error	0.02	10	0.002		

Note. Data obtained from the program database Minitab ver. 19

Table 4

Analysis of variance (ANOVA) on lead (Pb) removal.

Source	SC	GL	CM	F	p-value
Model	1535.1	7	219.3	41.8	0.000
Blocks	13.78	2	6.889	1.31	0.311
Linear	1520.3	3	506.7	96.7	0.000
Carbon Dose	1095	2	547.5	104.5	0.000
Type of carbon	425.3	1	425.3	81.1	0.000
Dose x Type	1.03	2	0.51	0.10	0.148
Error	52.3	10	5.23		

Note. Data from Minitab program ver. 19

It is observed that the p-value in Tables 3 and 4 was $\leq \alpha = 0.05$, $(0.0000 < 0.05)$, in such sense there is significant difference between treatments for Arsenic and Lead.

Therefore, the hypothesis that Huingo activated carbon has the removal capacity for arsenic and lead in the mining waste effluent is accepted.

Figure 1

Arsenic removal according to dose and type of activated carbon

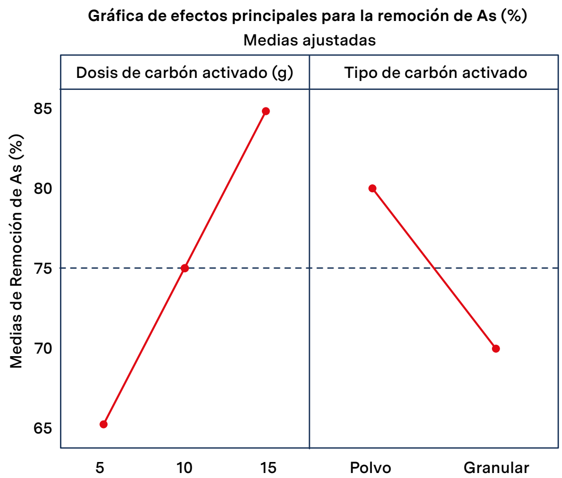

Figure 1 shows the percentage of removal with 85% in a dose of 15 g with powdered activated carbon type.

Figure 2

Lead removal according to dose and type of activated carbon.

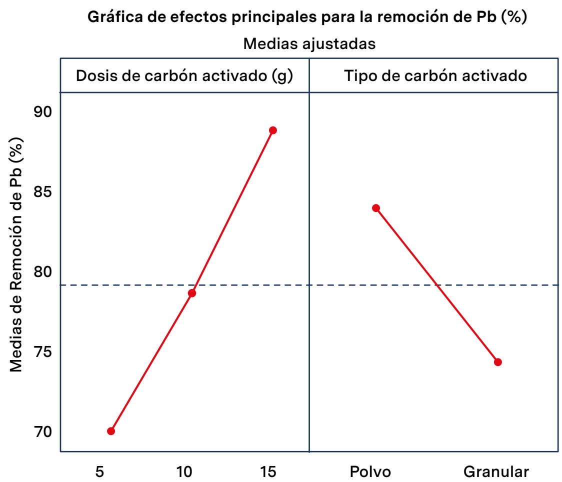

Figure 2 shows the percentage of removal with 88% in a dose of 15 g with powdered activated carbon.

DISCUSSION

In a study conducted by Fiestas y Millones in 2019, they found that the concentration of activated carbon and its application time had a significant impact on arsenic removal, reaching 72%. It is important to note that the initial arsenic level was 0.11mg/L and after application it was drastically reduced to 0.0297mg/L. It should be noted that the present study had a removal rate of 85% at a dose of 15 g and type of powdered carbon, thus showing the removal efficiency of the heavy metal.

In other studies, such as that of Lagua in 2021 and Gonzales and Segovia in 2020, the results were 35% and 48% with a lower value for arsenic removal, probably due to the physical, chemical and biological characteristics of the species they studied, such as water, ions like phosphates, sulfates and silicates can compete with arsenic for adsorption sites on the activated carbon, reducing the effectiveness of arsenic removal.

It is important to emphasize that the type of activated carbon (its surface area, pore size, and functional surface) also affects the arsenic adsorption capacity; activated carbon with a larger surface area and adequate pores can adsorb more arsenic. In addition, the presence of functional groups on the carbon surface can improve or worsen the adsorption of different arsenic species. Arsenic removal with activated carbon depends on the arsenic species present, the water conditions (such as pH and the presence of other ions), and the characteristics of the activated carbon itself; optimizing these factors is crucial to improve arsenic removal efficiency in different contexts (Lee et al, 2021).

Regarding lead, a removal of 88% was obtained in a dose of 15 g and type of powdered carbon. Similar results were obtained from Lee et al, 2021, who reported that activated carbon has efficient metal removal capabilities due to its porous structure, regardless of the species obtained from the product. On the other hand, Ponce et al., 2023 conducted a study on lead removal which resulted in a 94% removal rate.

Likewise, Roncal and Villanueva in 2021 in their research with activated carbon had a removal of 96%. On the other hand, Porras and Martinez in 2019 had a lead removal efficiency of 74% using corn stover activated carbon. In the study by Tena and Jhames in 2019, the removal efficiency of iron and lead was 77%. Finally, in Tubon's research in 2021, activated carbon from fruit residues was used resulting in 47% lead removal. Therefore, it is considered that the chemical and structural composition of fruit residues can vary widely, which can lead to inconsistencies in the quality and efficiency of the activated carbon produced. This variability can negatively affect the ability of the material to adsorb heavy metals consistently (Danish and Ahmad 2018).

Although fruit waste-derived activated carbon is a sustainable and economical option, its efficacy for the removal of heavy metals such as lead may be inferior due to limitations in its surface area, porosity, surface functional groups, activation efficiency, and variability in the raw material (Baoying et al, 2023).

In this sense, activated carbon has a high adsorption capacity due to its large surface area and porous structure, which allows for greater interaction with contaminant molecules. Its surface can be modified to improve its selectivity and adsorption capacity for specific metals, which makes it particularly effective for the removal of lead and arsenic.

CONCLUSIONS

The removal efficiency was evaluated with Huingo activated carbon at a dose of 15 g and powdered carbon type, obtaining values of 85% for arsenic and 88% for lead. The use of activated carbon for the removal of lead and arsenic is crucial due to its high adsorption efficiency, versatility, cost-effectiveness, ease of use and ability to reduce a wide range of contaminants. This contributes significantly to the protection of public health and compliance with environmental regulations.

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