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ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ISSN: 0976-3376

Asian Journal of Science and Technology
Vol. 17, Issue, 10, pp. 14628-14635, October, 2026

RESEARCH ARTICLE

REMOVAL OF COPPER AND LEAD FROM PHYSICO-CHEMICAL ANALYSIS LABORATORY EFFLUENTS BY ELECTROCOAGULATION PROCESS

[1]Nantchiliba, A., [1]Bako, Y. F. R., [2]*Zongo, I. and [1]Tapsoba, I.

[1]Laboratory of Analytical, Environmental and Bio-organic Chemistry (LCAEBiO), Department of Chemistry, UFR/SEA, Joseph Ki-Zerbo University, 03 BP 7021 Ouagadougou 03, Burkina Faso
[2]Laboratory of Natural Products and Environmental Technologies (LABTECH-PRONE), Institute for Research in Applied Sciences and Technologies (IRSAT), National Centre for Scientific and Technological Research (CNRST) 03 BP 7047 Ouagadougou 03, Burkina Faso

ARTICLE INFO

Article History:
Received 18th July, 2026
Received in revised form
20th August, 2026
Accepted 14th September, 2026
Published online 30th October, 2026

Key words:
Electrocoagulation; Aluminum, Copper; Lead, Effluents.

Corresponding author:** ***Zongo, I.

ABSTRACT

The objective of this study is to remove copper and lead by optimizing operating parameters such as pH, electrolysis time and inter-electrode distance using the electrocoagulation process on a pilot scale with aluminum electrodes. During this experiment, the pH was varied between 1.8 and 9; the electrolysis time between 0 and 25 hours and the inter-electrode distance between 20 and 25 cm in order to obtain the best operating conditions. The electrical energy consumed and the operating cost were also evaluated. After treatment, the optimal pH is 5.2; the electrolysis time is 25 hours, the inter-electrode distance is 25 cm, and the electrical energy consumed is estimated at 12.24 KWh/m^3 and the operating cost at 3.48 USD/m^3. The results obtained show that electrocoagulation can be applied on a pilot scale.

Citation: ***Nantchiliba, A., Bako, Y. F. R., Zongo, I. and Tapsoba, I.*** **2023.** " Removal of copper and lead from physico-chemical analysis laboratory effluents by electrocoagulation process*". Asian Journal of Science and Technology*, 17, (10), 14628-14635.

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INTRODUCTION

Water is our most important resource, and adequate quality and quantity are necessary for all areas of life and sustainable development. Although the majority of the planet is covered by water, humans only have access to a tiny amount of fresh water (Abd Al-Hamza and Abd Al-Hamed, 2022). Increasing urbanisation and the expansion of industries such as metallurgical industries, electroplating units, mining operations, electronic manufacturing units, fertiliser industries and leather industries, have led to the release of a considerable amount of wastewater containing high concentrations of trace metal elements (TMEs), in addition to other contaminants (Khan *et al.,* 2023), causing many diseases. There are numerous reports on the health effects of these trace metal elements (TMEs) in water sources. Ingestion of chromium, lead, copper, nickel and cobalt can cause leukaemia, anaemia, hypertension, heart problems and cancer (Drasch *et al.,* 2005). Furthermore, the danger posed by these TME is mainly due to their high level of bioaccumulation in living organisms and their non-biodegradability *(*Aityoub *et al.,* 2020). Cleaning these contaminants from water generally requires their removal. Several decontamination techniques have been developed in research laboratories and industrial sites to eradicate this pollution or at least minimise its effects. These techniques have been tested by researchers around the world, with varying degrees of success. Membrane processes, phytoremediation and adsorption on nanostructures (Sheet *et al.,* 2014; Farsi *et al.,* 2019) are used. Membrane processes are very effective at removing certain charged contaminants, but require costly regeneration or replacement of the resin. Ultrafiltration and reverse osmosis are preferred processes in wastewater treatment, but they are sensitive to harmful substances and can be extremely costly (Kerkulah *et al.,* 2023). Electrocoagulation, on the other hand, is a simple, effective and less costly process that generates less sludge. The electrocoagulation method for wastewater treatment gives better results than conventional methods (Jog, 2018). This technique is interesting and suitable for the treatment of various effluents thanks to its many advantages, including its environmental friendliness, flexibility, efficiency and low cost (Bouaouine *et al.,* 2015). In electrocoagulation, the net surface charge is reduced to such an extent that colloidal particles can come close enough together for Van der Waals forces to hold them together and allow aggregation (Escobar *et al.,* 2006). The introduction of heavy metals into water is a global environmental problem. Heavy metals such as copper, lead and iron are frequently found in industrial wastewater.

Their behaviour varies during electrocoagulation treatment, where interactions between these metals can either promote or limit the efficiency and selectivity of the process. In some countries, such as Mozambique, a prototype small wastewater treatment plant is being installed in Ressano Garcia as part of the Safe Water Africa project. This pilot unit aims to provide drinking water, treating around 10,000 litres per day, using electro coagulation/disinfection technology that generates ozone to neutralise germs (Jan Gäbler and Service for European Research, 2019). Furthermore, a recent study conducted by Stylianou, *et al.* showed significant removal of heavy metals (Stylianou *et al.,* 2022). The results revealed 99.9 % removal for Fe, Zn, Mn and Cu, and 98 %, 96 % and 88 % for Ni, Cd and Cr, respectively. In another study conducted by Ilou *et al.* in 2016, the optimal removal rates for lead, iron and copper were found to be within a pH range of 6 to 8, while a lower pH (below 4) resulted in reduced efficiency due to the redissolution of precipitated metal hydroxides (Ilou *et al.,* 2016). Furthermore, according to the work of Gonzáles Paredes *et al,* (2020), for pH values between 5.15 and 6, the efficiency of heavy metal removal is between 70 and 100 % for metals such as copper. In most of these studies, the estimated costs of treatment have not been detailed, given the influence of various factors, including operating conditions, which are essential to consider, the specific context, the contaminants present in the water and, finally, the total cost of treatment.

In Burkina Faso, the implementation of this treatment is struggling to progress due to the high cost of energy. However, studies have been carried out in our laboratory, preceded by simulations that have proved promising. Zongo *et al,* (2012) treated tannery wastewater by removing chromium, and the results were very satisfactory. They focused on operating parameters, and the energy obtained at the end of their study is estimated at 1.2 KWh/m^3. However, other researchers in Burkina Faso have not ventured into this area, and pilot-scale wastewater treatment is becoming less and less common, if not non-existent, even though large quantities of water are used daily by the population and this resource is in short supply. Biological techniques have been the most widely used in Burkina Faso for several years, particularly in the treatment of organic effluents, and even less so for effluents containing heavy metals. However, the latter are analysed more extensively and their release into the environment is a cause for great concern, given their impact on human and environmental health. The electrocoagulation process should be developed on a pilot scale to treat this water, which can then be released into the environment or used for other purposes, such as watering plants, asphalting roads, etc. Electrocoagulation can also be combined with other techniques for greater efficiency. However, in order to reach this stage, the treatment must first be developed the implementation of this treatment is struggling to progress due to the high cost of energy.

MATERIAL AND METHODS

Presentation of the study site: The wastewater subject to our study was collected within the BUMIGEB in the city of Ouagadougou in the 10th district of the city of Ouagadougou in sector 21 next to the East interchange on the Fada N'Gourma road a few kilometers from Joseph Ki-Zerbo University, in the retention basins installed in a warehouse behind the laboratories. The laboratory has ICP/MS and AAS equipment capable of analysing hundreds of samples per week. The BUMIGEB laboratory receives many wastewater samples from various sources (mines, various other companies, etc.) requiring heavy metal analysis, mainly to determine the presence of gold. After analysis, the wastewater is transported from the laboratories to the retention basins for environmental safety measures. Strong acids such as hydrochloric and nitric acids are widely used in the analysis of this wastewater. At this step, the leachate is very acidic and contains no organic matter. This chocolate therefore constitutes a significant source of environmental pollution if it is not properly treated (Chtioui *et al.,* 2008) before being discharged into the environment.

Table 1. Physical characteristics of wastewater from BUMIGEB basins before and after treatment

Wastewater Characteristics	pH		Conductivity (mS/cm)		Temperature (°C)	
	Initial	Final	Initial	Final	Initial	Final
Values	1.8	6.6	6.64	7.99	25.2	27.3

The metallic elements analysed in the sample are grouped together in Table 2.

Table 2. Concentrations of copper and lead in wastewater from BUMIGEB basins by AAS

Metallic elements	Cu	Pb
Initial concentration (mg/g)	1.323	1.022
Final concentration (mg/g)	0.052	0.000

Description of the experimental set up: The stainless-steel electrocoagulation cell (electrochemical reactor) is cylindrical with a volume of approximately 0.18 m³ and is topped with two aluminum electrodes, one serving as the cathode and the other as the anode. The electrodes measure 50 cm x 20 cm and are 0.2 mm thick. A direct current is applied to the electrodes by a current generator to reduce the mains voltage to 40 V and operating at a current of 5 A. A PM &T WP50 sealed pump, model 160F, ensures the circulation of effluent in the treatment circuit. The pipes attached to the pump heads are SEMILUX 2 *40M, and their inlet and outlet connections are DIA 50 mm. The maximum flow rate of the pump is 6. 10^6 ml/min. A voltage regulator (Voltcraft 11815) is used to reduce the mains voltage from 220 V to a voltage lower than or equal to 40 V. A pH meter coupled with a HANNA brand temperature sensor is used to measure pH and temperature.

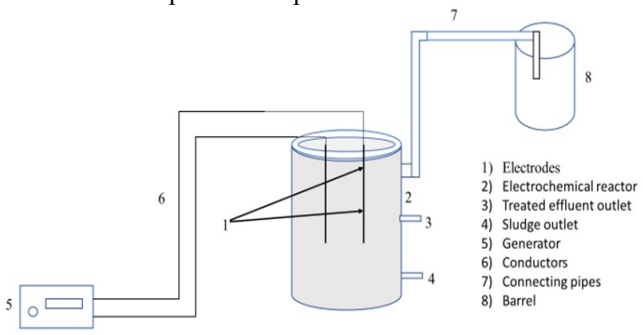


Figure 1. Experimental device

Effluent treatment: 156.62 L of effluent are introduced into the electrochemical reactor. The two aluminum electrodes are immersed in the effluent with an inter-electrode distance of approximately 20 cm/25 cm in order to have a low ohmic drop, avoid fouling, and also ensure homogeneous metal

dissolution. A current of 5 A is delivered by the voltage regulator to the aluminum electrodes, which are immersed in the effluent with an active surface area of 1,444 cm². With a current density of 3.46 mA/cm^2. The effluent is homogenised in two to three minutes using a rod to allow the effluent to mix. Every five hours, a sample of the treated effluent is taken before the pH is measured.

The effluent is collected and left to settle, then filtered using Whatman No. 1 paper. The filtrate is used to perform various physicochemical analyses. At the end of the treatment, the samples are stored at 20 °C before being sent to BUMIGEB for analysis. Before the experiment, the electrodes were first cleaned with distilled water to remove all kinds of impurities, then dried at laboratory temperature and finally weighed. At the end of each experiment, the electrodes were cleaned with tap water and distilled water to remove any residual solid particles from their surfaces, then dried and weighed again.

Electrode reactions: During the electrocoagulation process, the electrochemical reactions involved at the electrodes subjected to direct current are the reduction of water at the cathode followed by the oxidation of aluminum. When aluminum electrodes are used as the anode and cathode in the EC process, the main reactions take place at the anode as follows: (Brahmi *et al.,* 2016)

$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^-$ (anode)

$2\ H_2O_{(l)} \rightarrow O_{2(g)} + 4\ H^+_{(aq)} + 4e^-$

$3\ H_2O_{(l)} + 3e^- \rightarrow 3/2\ H_{2(aq)} + 3\ OH^-_{(aq)}$ (cathode)

$2\ Al_{(s)} + 6\ H_2O_{(l)} + 2\ OH^-_{(aq)} \rightarrow 2\ Al(OH)_4^-{}_{(aq)} + 3\ H_{2(g)}$

Balance equation: $Al^{3+}_{(aq)} + 3\ H_2O_{(l)} \rightarrow Al(OH)_{3(s)} + 3\ H^+_{(aq)}$

Under the right pH conditions, all Al^{3+} ions generated in solution hydrate and then react with water to form mainly $Al(OH)_3$ metal hydroxides. In reality, the metal ions produced may undergo other spontaneous reactions to form various monomeric species such as $Al(OH)^{2+}$, $Al(OH)_2^+$, $Al_2(OH)_2^{(4+)}$, $Al(OH)_4^-$ and polymeric species such as $Al_6(OH)_{15}^{3+}$, $Al_7(OH)_{17}^{4+}$, $Al_8(OH)_{20}^{4+}$, $Al_{13}O_4(OH)_{24}^{7+}$, $Al_{13}(OH)_{34}^{5+}$, which ultimately transform into $Al(OH)_{3(s)}$ according to the complex precipitation kinetics. These amorphous species $Al(OH)_3$ (Brahmi *et al.,* 2016) also known as "flocculation fields" , have a large specific surface area that allows rapid adsorption of pollutants and trapping of colloidal particles through electrostatic forces of the Vander Waals type. This leads to the formation of flocs, which can then be easily separated from the aqueous medium by sedimentation or flotation, both methods being facilitated by the production of dihydrogen (H_2) bubbles and dioxygen (O_2) bubbles (Bouaouine *et al.,* 2015).

Analysis techniques: The samples were analysed by atomic absorption spectroscopy (AAS) using a Shimadzu spectrometer. This requires rigorous sample preparation, precise instrument calibration, optimisation of analytical parameters, and strict quality control procedures to ensure the reliability of the results. Atomic absorption spectroscopy (AAS) is a quantitative analytical technique widely used for the determination of metallic and metalloid elements in various matrices. Shimadzu spectrometers are recognised for their performance and reliability in the analysis of metallic elements.

Preparation of standard solutions and samples and analysis of samples: The preparation of standards is a critical step in obtaining reliable and accurate results (Uddin *et al.,* 2016). These solutions are used to monitor the quality control of the samples to be analysed. There are three main recommended acid digestion methods, but in this study, only nitric acid (HNO_3) was used. The samples were analysed according to the protocol described in the Shimadzu spectrometer manual, and the concentrations obtained and the reduction rates were determined using equation 1 below.

$$\% E = \frac{C_0 - C_1}{C_0} \times 100 \quad \text{(Eq.1)}$$

Where % E, C_o, C_1 are respectively the abatement rate, the initial concentration in mol/L and the final concentration of ions in mol/L of the pollutant.

The electrical energy consumed (EEC) in KWh/m^3 is calculated using equation 2 below:

$$EEC = \frac{UIt}{V} \quad \text{(Eq.2)}$$

Where E: Electrical energy consumed kWh/m³

U: voltage across the electrodes (V)
I: applied current intensity in amperes (A), t: electrolysis time (h).
V: volume of liquid contained in the reactor (m³)
The quantity of dissolved metal C (M) is calculated using the formula in equation (Eq.3):

$$C(M) = \frac{ItM}{ZF.V} \quad \text{(Eq.3)}$$

C(M): quantity of dissolved metal in kg/m^3,
I: current intensity in amperes A,
t: duration of the electrocoagulation process in seconds (s),
Z(Al)=3, Z(Fe)=2
F = Faraday constant (96487 C/mol)
V: volume of solution in the reactor in m^3
The cost of the operation in CFA francs or USD is determined by the following equation 4:

$$C = aC_{electrode} + bC_{energy} \quad \text{(Eq.4)}$$

Where $C_{electrod}(Kg) = m_1 - m_2$;$C_{electrode}$: mass of electrode lost during each test (kg),

m_1 : electrode mass before treatment
m_2 : electrode mass after treatment
C_{energy} = UIt
$C_{energy:}$ energy consumed (kWh), a: unit price of energy (96 FCFA/kWh) b: price per kg of electrode (392 FCFA/kg for aluminum and 130 FCFA/kg for iron).

RESULTS AND DISCUSSION

The effectiveness of the electrocoagulation process in wastewater treatment is significantly affected by pH; the pH of acidic effluents increases, while that of alkaline effluents decreases (Demirci *et al.,* 2015).



Figure 2. Analysis device with Shimadzu spectrometer

The initial pH of wastewater significantly influences the electrocoagulation (EC) process for heavy metal removal. Research indicates that optimal pH levels improve the efficiency of metal ion removal, with varying effects depending on the specific metal involved.

Determination of the appropriate pH for metal removal after five hours: The addition of sodium hydroxide (NaOH) significantly influences the precipitation of copper and lead in contaminated wastewater. This effect is mainly due to the change in pH, particularly its increase, and the multiple chemical interactions that occur during the treatment process.
Analysis of the curve below shows that the copper removal rates are 0.23 % at pH 1.8; 39.56 % at pH 5.2 and 23.5 % at pH 9. Looking at the different values, the best removal rate is obtained at pH 5.2 for copper removal after 5 hours of treatment. The reduction rate of 39.56 % could be explained, on the one hand, by the precipitation of a quantity of copper following the addition of sodium hydroxide to stabilize the pH at around 5. These results are consistent with those obtained by Petsriprasit *et al,* (2010) who achieved a reduction rate of approximately 99 % for copper removal. Our results are below theirs. On the other hand, effluent containing copper and other metals such as lead, sodium hydroxide (NaOH) not only precipitates copper but also interacts with lead and other metals, particularly iron. In the presence of lead, sodium hydroxide forms lead hydroxide, which competes with copper for precipitation (Rao and Raju, 2010).

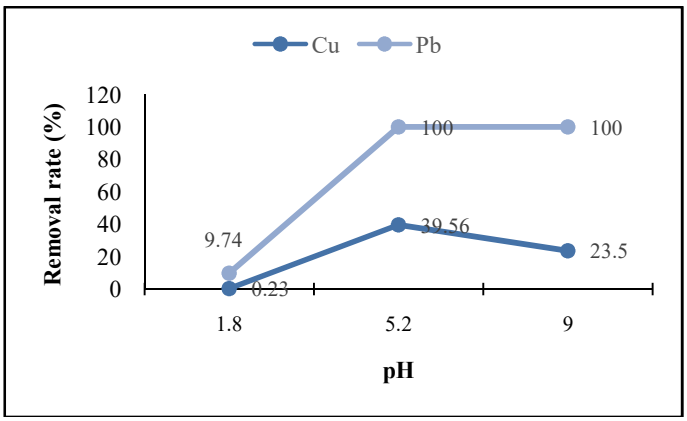


Figure 3. Change in copper and lead removal rates as a function of pH

As for the reduction rate of 0.23 % at pH 1.8 for copper, this could be explained by the fact that in acidic environments (pH < 6), the solubility of metals increases, which leads to a decrease in removal efficiency. Also, at initial pH values between 0 and 5, hydroxylated species do not significantly affect metal removal. This could also explain the low removal rate (0.23 %) at pH 1.8. Our work is supported by that of Abdel-Shafy *et al,* (2022), who showed that electroplating wastewater at pH 2 had low metal removal rates (Abdel-Shafy *et al.,* 2022). The optimal pH levels for copper precipitation are generally above 7, as copper ions can form insoluble hydroxides, thereby improving removal efficiency (Vasudevan *et al.,* 2012). This contrasts with our work, where the removal rate is 23.5 % at pH 9. This removal rate could be explained by secondary reactions, particularly interference. Furthermore, studies show that at pH 8.5, copper removal can be as low as 2.81 % (Yatim *et al.,* 2020). This could explain the abatement rates obtained at pH levels below 6, especially for copper.

The 100 % reduction rate for lead at pH 5.2 and 9 could be explained in part by the addition of sodium hydroxide (NaOH) to the effluent. Referring to the histogram above, it should be noted that despite the addition of sodium hydroxide, effective removal is achieved at pH 5.2. According to studies by Alkizwini *et al,* (2021) maximum lead removal efficiency occurs at pH levels between 5 and 6. On the other hand, increasing the pH to 5 resulted in a decrease in the residual amounts of lead and copper, which can be explained by the increase in the amount of $Al(OH)_3$ coagulant. Aluminum species, such as $Al(OH)_{3(s)}$, are the dominant form in the pH range of 5.0 to 8.5 (Wided *et al.,* 2014). It should be noted that aluminum electrodes are more commonly used to remove inorganic pollutants, but their overall adsorption capacity is lower than that of iron hydroxides in organic wastewater treatment scenarios (Manikandan and Saraswathi, 2022). Furthermore, the order of precipitation of metal hydroxides can be predicted by comparing their solubility constants (K). Compounds with lower K values precipitate first as the pH increases, resulting in sequential precipitation based on their solubility constant. $K(Pb(OH)_2) = 1.43*10^{-20} < K(Cu(OH)_2) = 2.2*10^{-20}$. This is reinforced by the work of Hidmi *et al.,* who showed that the solubility constant of lead hydroxide ($Pb(OH)_2$) is generally lower than that of copper, indicating that lead precipitates before copper (Hidmi and Edwards, 1999).

Furthermore, there may be other species present in the effluent, such as metal oxides, which, according to the work carried out by Basílio *et al,* (2005), have shown the greatest metal retention capacity at very high concentrations. According to the same authors, the adsorption affinity series changes from Pb>Cu>Cr>As to As>Pb>Cu>Cr or As>Cu>Cr>Pb, depending on the material and the concentration of the initial solution. This could explain the rapid precipitation of lead compared to copper. In summary, despite the pH adjustment and the various reactions triggered, the optimal pH for this treatment is 5.2. Although the electrocoagulation process is effective in removing heavy metals, the presence of several metal hydroxides can lead to competition for adsorption sites, which can reduce the overall effectiveness of the treatment. This complexity requires careful control of other operational parameters, including electrode spacing, electrode material and the presence of complexing agents, in order to optimize removal rates.

Effect of time on copper and lead removal with aluminum electrodes: Optimizing the electrolysis time during electrocoagulation is crucial to improving the efficiency of wastewater treatment processes. The aim is to remove as many pollutants as possible while minimising energy consumption

and operating costs. The figures below show the evolution of copper (Figure 4) and lead (Figure 5) removal rates over time.

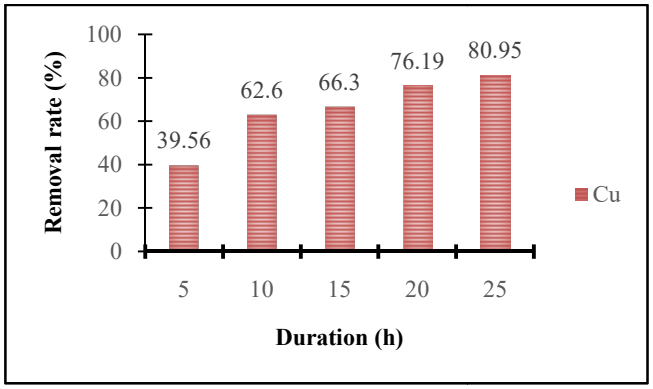


Figure 4. Evolution of the copper removal rate over time. (pH 5.2); electrode: aluminum; current density: 3.46 mA/cm^2

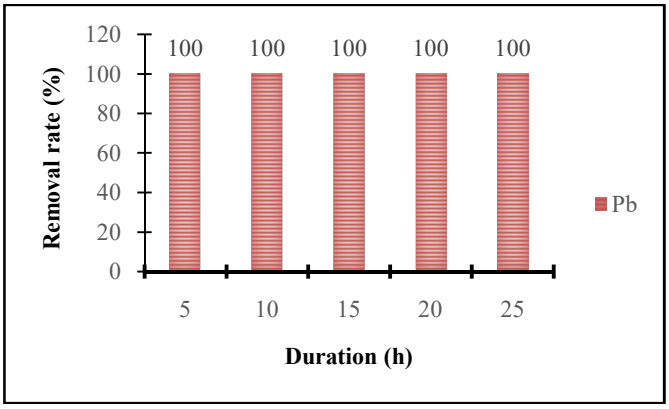


Figure 5. Change in lead removal rate over time. (pH 5.2); electrode: aluminum; current density: 3.46 mA/cm^2

The histogram above (Figure 4) shows that the copper removal rate is 39.56 % after 5 hours of treatment and almost doubles after 10 hours of treatment, increasing slightly to reach 80.95 % after 25 hours of treatment, unlike the lead histogram (Figure 5), where a removal rate of 100 % is achieved after 5 hours of treatment and remains constant until the end of the experiment (25 hours) at pH 5.2. The copper removal rate (80.95 %) could be explained by high concentrations of other metals in the effluent and could lead to competitive adsorption between the different pollutants contained in the effluent, with variable removal rates (Khan *et al.,* 2023) depending on their concentrations and interactions unlike the lead removal rate, which is 100 %. On the one hand, various reactions, in particular interference between heavy metals such as copper, iron, lead and chromium, would have a major impact on the performance of the electrocoagulation (EC) system. Indeed, the presence of several heavy metals in the effluent can modify the electrochemical processes, thus affecting the efficiency of removal and the operational parameters where, according to some authors, copper and lead are removed more efficiently than cadmium in certain processes (Kumarasinghe *et al.,* 2009).

Furthermore, it should be noted that the adsorption of divalent metal ions such as zinc and iron ions in the presence of aluminum hydroxides is less effective in the presence of hydrogen carbonate ions, as the latter prevent the formation of stable metal hydroxides necessary for effective adsorption. Furthermore, the presence of hydrogen carbonate ions can attenuate pH variations, which has an impact on the dissolution rates of the aluminum electrode and on the formation of metal hydroxides, which can hinder the effective removal of certain metals (Doggaz *et al.,* 2019). Furthermore, the formation of aluminum hydroxide $Al(OH)_3$ during electrocoagulation improves the removal of heavy metals by providing active sites for adsorption. According to the work of Chien-Hung *et al,* (2020), this process facilitates both adsorption and coprecipitation, particularly for metals such as Ni (II), while Cr (VI) does not compete for the same adsorption sites (Huang *et al.,* 2020). The parameters were discussed above, and to observe the evolution of the removal rate, the inter-electrode distance was evaluated at pH 1.8 and 5.2.

Effect of inter-electrode distance on copper and lead removal at pH 5.2: The distance between electrodes in the electrocoagulation process is an important parameter that significantly influences the efficiency of heavy metal removal. This parameter affects the intensity of the electric field, ion transport and all the electrochemical reactions that occur between the electrodes. Careful optimization of the distance between electrodes can reduce treatment time and electrode dissolution while increasing the overall kinetics of the reactions that occur there and the dispersion of flocs, thereby improving the efficiency of contaminant removal. This parameter influences on the one hand the speed of ion transport, which is essential to the efficiency of coagulation and sedimentation processes. On the other hand, this parameter affects ion diffusion and concentration gradients. By carefully considering these factors, it is possible to design systems that maximise efficiency and energy density. Optimising this parameter also reduces energy consumption. Analysis of Figures 6 and 7 below show that after 5 hours of treatment, the copper removal rates for electrode distances of 20 and 25 cm are respectively 39.56 % (Cu1) and 65.21 % (Cu2) respectively. These removal rates increase to reach, 80.95 %, and 100 % respectively after 25 hours of treatment. The best reduction rate is obtained for an inter-electrode distance of 25 cm. This reduction rate could be explained by an increase in the intensity of the electric field between the electrodes, promoting better migration of ions towards the electrodes and improving the efficiency of metal ion removal (Kamaraj *et al.,* 2015). According to the work of some authors, specific electrode configurations and an optimal inter-electrode distance have achieved removal rates of up to 99.98 % and 99.88 % for lead and copper, respectively (Varma *et al.,* 2021).

For the histogram (Figure 7) showing lead removal, the rate observed is 100 % after 5 hours of treatment and remains constant until the end of treatment (25 hours) for both electrode distances (20 cm and 25 cm). This rate could be explained by a suitable electrode spacing allowing for optimal lead removal. Deviations from this range may reduce removal efficiency due to changes in species and coagulant load (Khan *et al.,* 2023). The best removal rate obtained for copper corresponds to an inter-electrode distance of 25 cm, and as both pollutants were treated with the same inter-electrode distance, the best removal rate for lead is 100 % despite obtaining the same rate with an electrode spacing of 20 cm, which could be due to several factors, including the addition of sodium hydroxide and the solubility constant of lead compared to that of copper.

The diffusion and migration processes between electrodes during electrocoagulation are essential for optimising the

removal of contaminants from water. These processes involve the movement of ions and molecules influenced by concentration gradients and electric fields, which can significantly affect the efficiency of EC treatment. Near the electrodes, the concentration of pollutants decreases as treatment progresses. And the production of hydrogen bubbles at the cathode promotes mechanical agitation within the liquid. This results in the diffusion of pollutants, which migrate from areas of high concentration to areas of low concentration, and is essential for transporting pollutants to the electrode surface (Acosta Niño *et al.,* 2013). Ions also move in response to an electric field, which can lead to change imbalances that affect overall mass transport (Rasouli *et al.,* 2015).

According to some authors, a small distance between electrodes increases the intensity of the electric field, promoting better ion migration towards the electrodes, which improves the efficiency of metal ion removal (Kamaraj *et al.,* 2015). According to the same authors, a large distance between electrodes can result in a weaker electric field, which could cause short circuits (Setyawati *et al.,* 2021), thereby reducing the efficiency of ion migration towards the electrodes. One study found that reducing the inter-electrode distance from 9 mm to 3 mm increased the reaction rate and improved fluoride removal efficiency, achieving a residual concentration of 1.5 mg. L^{-1} (Martínez-Villafañe *et al.,* 2022).

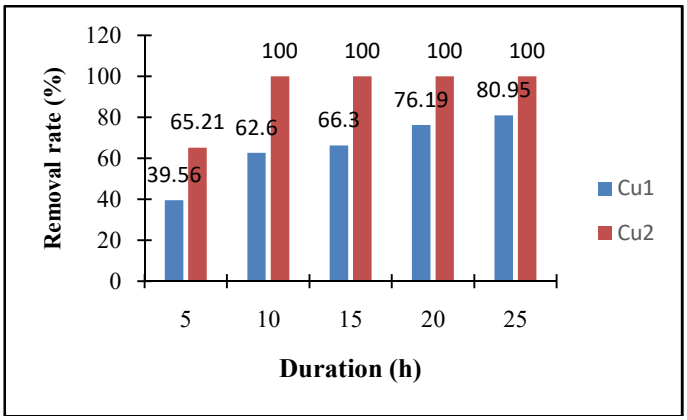


Figure 6. Evolution of the abatement rate over time at pH 5.2 die= 20 (Cu1) & 25 cm (Cu2)

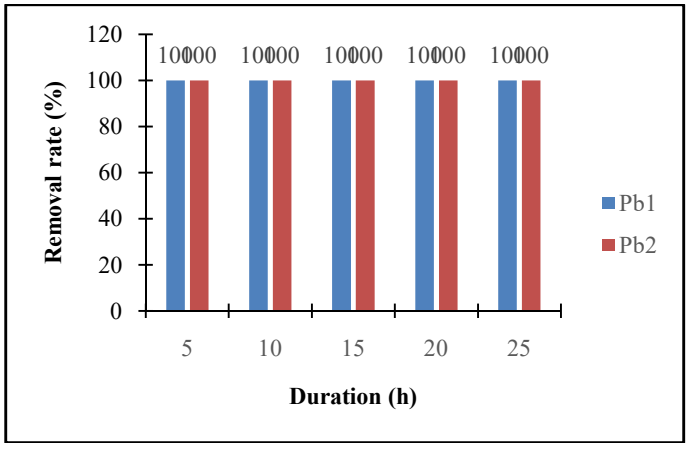


Figure 7. Evolution of the abatement rate as a function of time at pH 5.2 die= 20 (Pb1) & 25 cm (Pb2)

Electrical energy consumption and operating costs: Energy consumption is a key factor influencing the efficiency and cost-effectiveness of the EC process. The electrical energy consumed during electrocoagulation (EC) processes for heavy metal removal varies significantly depending on operating parameters such as current density, pH and treatment duration, but electrode consumption and electrical energy consumption determine the cost of the operation. At the end of our treatment, the electrical energy consumed is estimated at 12.24 KWh/m³. The operational cost is approximately 1964.98 CFA francs /m³ or 3.48 USD/m³. A comparison between the studies conducted by Bassam Aji et *al.* (Al Aji *et al.,* 2012) and our own, which removed copper, zinc, nickel and manganese at an estimated operating cost of 3.77 USD/m^3 shows that our results are lower than theirs. All these results also depend on operating conditions.

CONCLUSION

In light of this study, effluents from the BUMIGEB basins in the city of Ouagadougou were treated using the electrocoagulation process on a pilot scale using aluminum electrodes. The impact of operating parameters such as pH, electrolysis time and interelectrode distance was evaluated on the removal of copper and lead, and the energy allocated to this experiment was calculated. Removal efficiency is influenced by these different parameters (pH, electrolysis time and inter-electrode distance). The optimal values obtained are 5.2, 25 hours and 25 cm respectively, corresponding to reduction rates of 100 % for copper after 25 hours of treatment and 100 % for lead after 5 hours of treatment at the same pH using aluminum electrodes. The electrical energy consumed is approximately 3.48 USD/m^3. With this treatment, the abatement rate varies depending on the pollutants present in the solution. With a view to exploring other operating parameters such as current density, the abatement rates can be improved. Pilot-scale electrocoagulation is therefore proving to be an alternative for the treatment of wastewater contaminated with heavy metals.

Acknowledgement:

Our thanks go to the engineer who designed the pilot unit (electrochemical cell) and to BUMIGEB for authorising the water sampling.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.

Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects

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