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جامعة وهران 2 محمد بن أحمد
Université d'Oran 2 Mohamed Ben Ahmed

معهد الصيانة و الأمن الصناعي
Institut de Maintenance et de Sécurité Industrielle

Department of Industrial Safety and Environment

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VALORIZING METAL WASTE FOR WASTEWATER TREATMENT BY ELECTROCOAGULATION

Presented and publicly supported by:

Amelsi Abdelillah Mohammed El amine & Bounaga Abdelali Hakim

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WASTEWATER TREATMENT BY ELECTROCOAGULATION

ABSTRACT:

This study focuses on the treatment of landfill leachate using the electrocoagulation process. Leachate samples were collected from the EPIC CET landfill center and subjected to a series of electrocoagulation experiments under varying conditions. The manipulations involved the use of different electrode materials, including aluminum, graphite, and recycled tomato can rectangles, as well as different leachate types both fresh and mature.

Throughout the experiments, key electrocoagulation performance indicators were measured, including pH, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD₅), Total Dissolved Solids (TDS), and electrical conductivity. The results were analyzed and compared against regulatory standards to assess the efficiency of the treatment process under each condition.

Findings revealed that treatment performance varied significantly depending on the electrode material and the maturity of the leachate. While some improvements were noted, especially when using graphite electrodes, many parameters remained above acceptable limits, particularly COD and BOD in most cases. The study concludes that electrocoagulation holds promise as a treatment method for leachate but requires careful optimization of materials and operating conditions to ensure compliance with environmental standards.

Keywords: EC, Electrocoagulation, Leachate, Sewage, Wastewater, BOD, COD, TDS, pH,

.

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ABRIVIATION LIST

EC : Electrocoagulation Alphanotique

TDS : Total Dissolved Substances

BOD : Biological Oxygen Demand

COD : Chemical Oxygen Demand

GENERAL INTRODUCTION

"Knowledge is not given but earned with effort, as the gold is purified by fire."

Khalil Gibran

In an era where environmental sustainability is no longer a choice but a necessity, the treatment of wastewater particularly from highly polluted sources like landfill leachate stands as one of the most pressing challenges. With increasing urbanization, population growth, and industrial activity, the generation of complex effluents has reached critical levels, demanding innovative, efficient, and adaptable treatment solutions.

Among the various types of wastewater, landfill leachate is particularly difficult to manage due to its highly variable and concentrated load of organic matter, heavy metals, and persistent pollutants. Traditional treatment methods often fall short in addressing these complex compositions. This has led to growing interest in electrochemical technologies, and in particular, electrocoagulation, as a promising alternative or complementary approach.

Electrocoagulation is a relatively simple yet powerful technique that relies on the in-situ generation of coagulant agents by dissolving sacrificial electrodes under an electric current. Its ability to remove suspended solids, reduce organic load, and neutralize various contaminants without the need for chemical additives makes it especially attractive for treating difficult effluents such as leachate.

The present work is part of this ongoing effort to explore sustainable water treatment technologies. It aims to evaluate the performance of electrocoagulation in treating leachate under different experimental conditions, using various electrode materials and analyzing the outcomes through key parameters such as pH, BOD, COD, TDS, conductivity, and density.

Through methodical experimentation, analysis, and reflection, this study seeks not only to understand the behavior and limitations of the electrocoagulation process but also to contribute to the broader field of environmental engineering by providing practical data and insights. In doing so, it embraces the idea that meaningful knowledge is built through effort, experimentation, and critical inquiry as essential today as ever in the pursuit of sustainable solutions for our planet's future.

This work of our finals contains 4 chapters, the first chapter is a general introduction about wastewater, the second chapter summarizes the treatment method chosen for this project (Electrocoagulation), the third chapter is about the materials and methods used for this work and finally chapter4 is about the discussion of the results obtained from this work.

CHAPTER I : Wastewater

I.1 Introduction:

Over the past two decades, water quality specialists and environmental authorities have shown growing concern over the presence of emerging contaminants (ECs) in marine and aquatic ecosystems. These substances are now frequently detected in surface waters, including hospital wastewater (HPWW), as well as residues from cosmetics and personal care products, endocrine-disrupting compounds, and pesticides, all of which have been associated with adverse ecological impacts.

One of the main pathways through which ECs enter aquatic environments is sewage discharge. The ability to manage and control these contaminants largely depends on how they behave and are removed during wastewater treatment and within the natural environment. Research has shown that over 200 types of ECs can be found in river waters worldwide, generally at concentrations ranging from nanograms to micrograms per liter. Despite these low concentrations, ECs can negatively affect human health and aquatic organisms, including alterations in mineral balance, metabolic activity, and reproductive function.

Numerous studies have raised alarms about the continued discharge of ECs into wastewater treatment systems, citing risks such as the proliferation of antibiotic-resistant genes, interruption of microbial biodegradation processes, and broader ecological disturbances. Nonetheless, the fate of certain ECs and the effectiveness of treatment technologies in removing them are still not fully understood.

Typically, EC removal in wastewater treatment plants (WWTPs) occurs via three primary mechanisms: volatilization, biodegradation, and sorption to suspended solids. However, the dominant removal pathway can vary significantly depending on the compound and system conditions, making it essential to identify which mechanisms are most effective in each case. Despite the large number of studies conducted, findings on removal efficiency and primary removal mechanisms have often been inconsistent. Factors such as hydraulic retention time, sludge Age, and seasonal variations in influent composition all contribute to this variability

(Noguera-Oviedo & Aga, 2016). (Riva et al., 2019), (Khan et al., 2021b), (Juliano & Magrini, 2017), (Ng et al., 2021), (Primel et al., 2017), (Margot et al., 2015). (Murray et al., 2010). (Varsha et al., 2022). (Ahmed et al., 2021). (Rout et al., 2021). (Cao et al., 2017).

I.2 The definition of WasteWater :

As it is found in the dictionary its water that has been used (as in a manufacturing process) : sewage

Or by other means:

Wastewater (or **waste water**) is water generated after the use of freshwater, raw water, drinking water or saline water in a variety of deliberate applications or processes. Another definition of wastewater is "Used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff / storm water, and any sewer inflow or sewer infiltration". In everyday usage, wastewater is commonly a synonym for sewage (also called domestic wastewater or municipal wastewater), which is wastewater that is produced by a community of people.

As a generic term, wastewater may also describe water containing contaminants accumulated in other settings, such as:

- **Domestic Wastewater:** This refers to wastewater generated from households, including water from kitchens, bathrooms, and laundry. It consists of **blackwater** (excreta, urine, and faecal sludge) and **greywater** (water from washing, bathing, and cooking). Domestic wastewater often contains organic matter, nutrients, pathogens, and household chemicals.
- **Industrial Wastewater:** This type of wastewater originates from various industrial processes, such as manufacturing, mining, and chemical production. It can contain **heavy metals, toxic chemicals, oils, and organic pollutants**, depending on the industry. Industrial wastewater requires specialized treatment before being discharged into the environment.

Agricultural Wastewater: This includes wastewater from farming activities, such as irrigation runoff, livestock waste, and fertilizer residues. It often contains **pesticides, nutrients (like nitrogen and phosphorus), sediments, and organic matter**. If not managed properly, agricultural wastewater can contribute to water pollution and eutrophication..

I.3 The origin of wastewater

The production of waste from human activities is unavoidable. A significant part of this waste will end up as wastewater. The quantity and quality of wastewater is determined by many factors. Not all humans or industries produce the same amount of waste. The amount and type of waste produced in households is influenced by the behaviour, lifestyle and standard of living of the inhabitants as well as the technical and juridical framework by which people are surrounded. In households most waste will end up as solid and liquid waste, and there are significant possibilities for changing the amounts and composition of the two waste streams generated. For industry similar considerations apply. The design of the sewer system affects the wastewater composition significantly. In most developing

countries separate sewer systems are used. In these the storm water is transported in trenches, canals or pipes.

I.4 Sources of water pollution

I.4.1 Domestic wastewater sources:

Blackwater: For blackwater, two modes of effluent collection are considered: classic collection of whole excretion and water from toilets, and selective collection from source separating toilets which are usually composed of a faecal bin and an [2]urine diverter. Unlike classical toilets, source-separating toilets allow a separate collection of yellow water (flush water and urine) and brown water (flush water or not, faeces and toilet paper). Contributions considered as accidental, such as cleaning water in toilets, cigarette butts, etc. are also taken into account.

Greywater: Greywater includes various emission sources. Effluent characteristics are linked to appliances used and to individual patterns: kitchen sink, dishwasher, washing machine, bathroom washbasin, shower, and bath. These uses are divided under two headings: (i) greywater from food-related activities and cleaning (kitchen and laundry activities), and (ii) greywater from personal care, bathroom effluents.



Figure 1 Domestic wastewater diagramme

I.4.2 Industrial wastewater sources:

Unlike domestic sewage, industrial wastewater varies widely depending on the sector. Heavy industries, such as chemical manufacturing and metallurgy, discharge wastewater laden with toxic organic compounds (e.g., phenols, benzene), heavy metals (e.g., mercury, lead, chromium), and acidic or alkaline effluents. The textile industry, for instance, releases synthetic dyes and chlorinated compounds, many of which are carcinogenic and resistant to conventional treatment methods.

Food processing industries, including dairy plants and slaughterhouses, generate wastewater with high organic loads, including proteins, fats, and carbohydrates, which deplete oxygen levels in receiving waters. Mining operations produce acid mine drainage (AMD), characterized by low pH and high concentrations of sulfates, iron, and arsenic, posing severe risks to aquatic life and groundwater quality.

Power plants contribute thermal pollution through cooling water discharges, which can alter local ecosystems, while coal ash leachate introduces toxic elements like selenium and mercury into water systems (EPA, 2020). The environmental repercussions of industrial wastewater are profound, often leading to bioaccumulation of heavy metals in aquatic organisms, soil contamination, and long-term ecological damage.

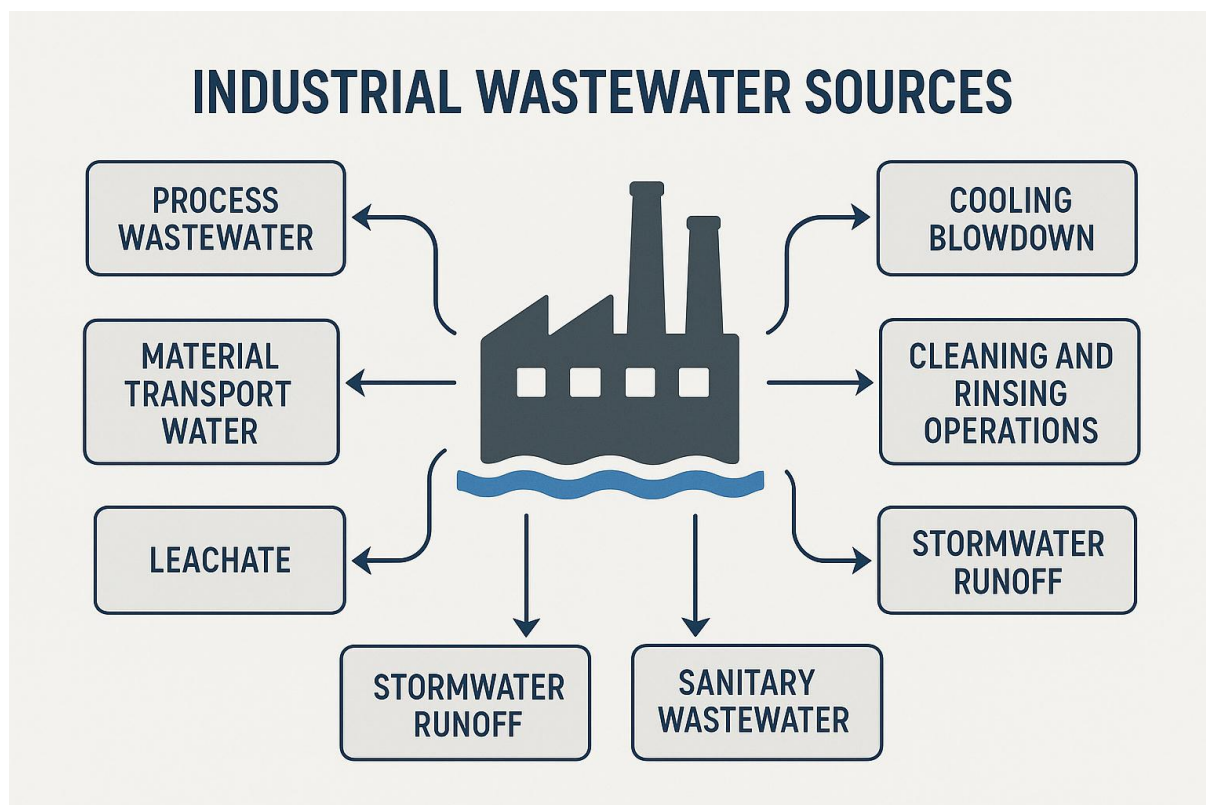


Figure 2 Industrial wastewater sources

I.4.3 Agriculture wastewater sources:

Agricultural activities generate wastewater through irrigation runoff, livestock operations, and aquaculture. Irrigation return flows carry excess fertilizers, particularly nitrates and phosphates, into

rivers and lakes, fueling algal blooms and creating dead zones where aquatic life cannot survive. Pesticides and herbicides, such as atrazine and glyphosate, are also washed into water bodies, where they act as endocrine disruptors and pose risks to human health.

Livestock farming is another major contributor, with manure lagoons releasing ammonia, methane, and pathogens like *E. coli* and *Cryptosporidium* (USDA, 2021). The overuse of antibiotics in animal husbandry has led to the emergence of antibiotic-resistant bacteria, which can spread through water systems (WHO, 2018). Aquaculture, while a vital food source, discharges uneaten feed, feces, and residual antibiotics, further stressing aquatic ecosystems.

Additionally, soil erosion from agricultural fields increases sediment loads in water bodies, smothering habitats and reducing water clarity.

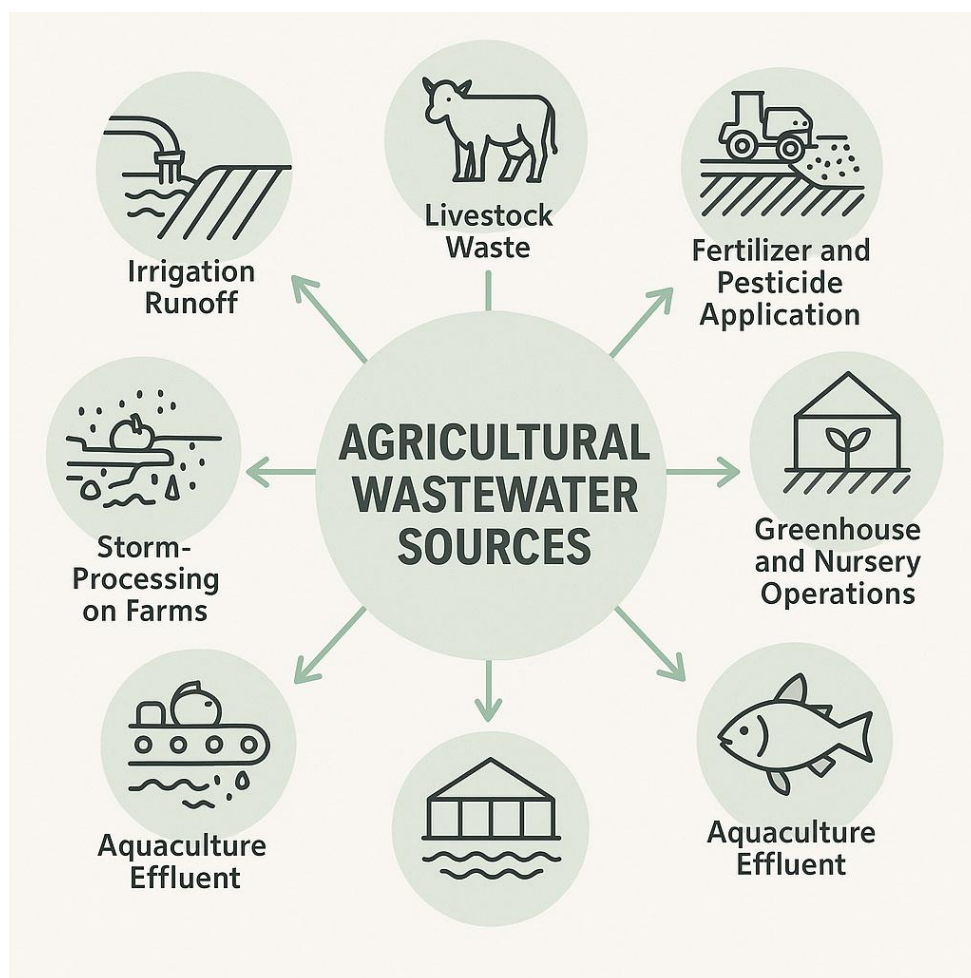


Figure 3 Agriculture Wastewater sources

(Eckenfelder, 2000), (Tchobanoglous et al., 2003), (Johnson & Hallberg, 2005), (EPA, 2020), (Dixit et al., 2015), (Mateo-Sagasta et al., 2017), (Boyd & McNevin, 2015), (Pimentel & Burgess, 2013)

While the term wastewater encompasses all used water from domestic, industrial, and agricultural sources, the term sewage refers more specifically to the subset of wastewater transported through sewer systems, primarily generated by households and urban activities. This distinction is critical as we now turn to focus on sewage's unique composition and challenges...

I.5 Sewage characteristics

I.5.1 Sewage types:

There are three types of wastewater, or sewage: domestic sewage, industrial sewage, and storm sewage. Domestic sewage carries used water from houses and apartments; it is also called sanitary sewage. Industrial sewage is used water from manufacturing or chemical processes. Storm sewage, or storm water, is runoff from precipitation that is collected in a system of pipes or open channels.

Domestic sewage is slightly more than 99.9 percent water by weight. The rest, less than 0.1 percent, contains a wide variety of dissolved and suspended impurities. Although amounting to a very small fraction of the sewage by weight, the nature of these impurities and the large volumes of sewage in which they are carried make disposal of domestic wastewater a significant technical problem. The principal impurities are putrescible organic materials and plant nutrients, but domestic sewage is also very likely to contain disease-causing microbes. Industrial wastewater usually contains specific and readily identifiable chemical compounds, depending on the nature of the industrial process. Storm sewage carries organic materials, suspended and dissolved solids, and other substances picked up as it travels over the ground.

I.6 Principal pollutants

I.6.1 Organic material :

The amount of putrescible organic material in sewage is indicated by the biochemical oxygen demand, or BOD; the more organic material there is in the sewage, the higher the BOD, which is the amount of oxygen required by microorganisms to decompose the organic substances in sewage. It is among the most important parameters for the design and operation of sewage treatment plants. Industrial sewage may have BOD levels many times that of domestic sewage. The BOD of storm sewage is of particular concern when it is mixed with domestic sewage in combined sewerage systems (*see below*).

Dissolved oxygen is an important water quality factor for lakes and rivers. The higher the concentration of dissolved oxygen, the better the water quality. When sewage enters a lake or stream, decomposition of the organic materials begins. Oxygen is consumed as microorganisms use it in their

metabolism. This can quickly deplete the available oxygen in the water. When the dissolved oxygen levels drop too low, trout and other aquatic species soon perish. In fact, if the oxygen level drops to zero, the water will become septic. Decomposition of organic compounds without oxygen causes the undesirable odours usually associated with septic or putrid conditions.

I.6.2 Suspended solids :

Another important characteristic of sewage is suspended solids. The volume of sludge produced in a treatment plant is directly related to the total suspended solids present in the sewage. Industrial and storm sewage may contain higher concentrations of suspended solids than domestic sewage. The extent to which a treatment plant removes suspended solids, as well as BOD, determines the efficiency of the treatment process

I.6.3 Inorganic compounds:

Domestic sewage contains compounds of nitrogen and phosphorus, two elements that are basic nutrients essential for the growth of plants. In lakes, excessive amounts of nitrates and phosphates can cause the rapid growth of algae. Algal blooms, often caused by sewage discharges, accelerate the natural aging of lakes in a process called eutrophication.

I.6.4 Microbes:

Domestic sewage contains many millions of microorganisms per gallon. Most are coliform bacteria from the human intestinal tract, and domestic sewage is also likely to carry other microbes. Coliforms are used as indicators of sewage pollution. A high coliform count usually indicates recent sewage pollution.

I.6.5 BOD and COD:

Organic matter is the major pollutant in wastewater. Traditionally organic matter has been measured as BOD and COD. The COD analysis is 'quick and dirty' (if mercury is used). BOD is slow and cumbersome due to the need for dilution series. The COD analysis measures through chemical oxidation by dichromate the majority of the organic matter present in the sample. COD measurements are needed for mass balances in wastewater treatment. The COD content can be subdivided in fractions useful for consideration in relation to the design of treatment processes. Suspended and soluble COD measurement is very useful. Beware of the false COD measurement with permanganate,

since this method only measures part of the organic matter and should only be used in relation to planning of the BOD analysis. The theoretical COD of a given substance can be calculated from an oxidation equation. For example, theoretical COD of ethanol is calculated based on the following equation: $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ or 46 g of ethanol requires 96 g of oxygen for full oxidation to carbon dioxide and water. The theoretical COD of ethanol is thus $96/46 = 2.09$. The BOD analysis measures the oxygen used for oxidation of part of the organic matter. BOD analysis has its origin in effluent control, and this is what it is most useful for. The standard BOD analysis takes 5 days (BOD₅), but alternatives are sometime used, BOD₁, if speed is needed and BOD₇ if convenience is the main option, as in Sweden and Norway. If measurement of (almost) all biodegradable material is required, BOD₂₅ is used. It is possible to estimate the BOD values from the single measured value.

In this work we intent to measure BOD₅

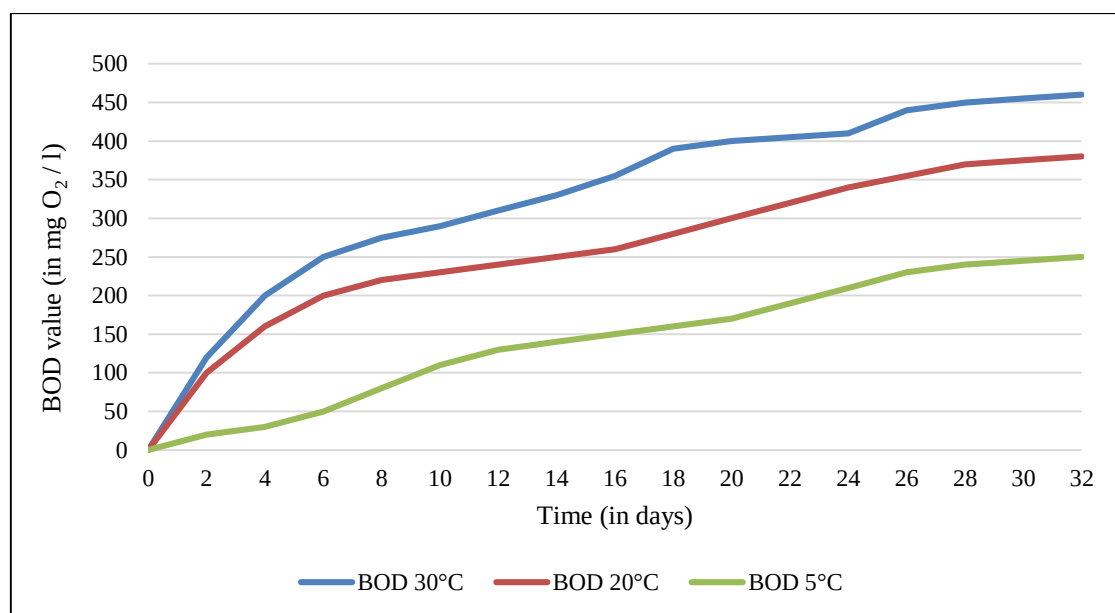


Figure 4 : The BOD analysis result depends on both test length and temperature. Standard is 20°C and 5 days.

I.7 The Algerian regulation concerning Wastewater:

The regulation of wastewater in Algeria has undergone significant transformation over the past decades, reflecting the country's evolving environmental priorities and alignment with international standards. The legal framework has progressively developed from basic provisions to comprehensive regulations governing wastewater quality, treatment, and discharge.

The earliest environmental legislation, **Law 83-03 of 1983**, laid initial groundwork for water pollution control but lacked specific wastewater quality standards. A pivotal shift occurred with the enactment of **Law 03-10 in 2003**, which established a modern water policy framework. This legislation explicitly defined wastewater as "any water altered by human activity" and introduced the fundamental requirement for treatment prior to discharge into natural environments. The subsequent Law 05-12 of 2005 on environmental protection further reinforced these provisions, mandating industrial facilities to implement proper wastewater treatment systems.

The regulatory framework was substantially strengthened through implementing decrees that specified technical requirements. **Decree 07-149 of 2007** established general discharge standards for key parameters including biochemical oxygen demand ($\text{BOD}_5 \leq 30 \text{ mg/L}$), chemical oxygen demand ($\text{COD} \leq 90 \text{ mg/L}$), and total suspended solids ($\text{TSS} \leq 30 \text{ mg/L}$). More stringent, sector-specific regulations followed with Decree 11-125 of 2011, which imposed tailored limits for various industries, particularly addressing hydrocarbons ($\leq 5 \text{ mg/L}$) and heavy metals such as cadmium, lead, and mercury (ranging from 0.1 to 1 mg/L depending on the metal and industrial activity).

Algerian standards for domestic sewage treatment incorporate bacteriological controls, with fecal coliform limits set at $\leq 2,000 \text{ CFU/100 mL}$, while maintaining pH requirements between 6.5 and 8.5. For agricultural reuse of treated wastewater, Algeria has adopted guidelines aligned with World Health Organization recommendations, particularly regarding nutrient content and pathogen levels.

The regulatory system demonstrates international influences, notably through compliance with Mediterranean Action Plan standards for coastal discharges. However, implementation challenges persist, including uneven enforcement and infrastructure gaps, particularly in rural areas. Recent policy developments, including the 2020 National Sanitation Plan, aim to address these issues with ambitious targets for expanding treatment coverage to 80% of wastewater by 2030.

This evolving regulatory landscape reflects Algeria's commitment to balancing industrial development with environmental protection, while progressively harmonizing its standards with international best practices in wastewater management. The framework continues to adapt to emerging challenges, particularly in light of climate change impacts and increasing water scarcity concerns.

I.8 Characteristics of wastewater:

Algeria's regulatory approach to wastewater management establishes comprehensive quality standards that address a wide range of physicochemical, organic, and toxicological parameters. The framework, primarily governed by Decrees 07-149 (2007) and 11-125 (2011), sets specific limits for various wastewater characteristics based on its origin and intended disposal or reuse.

I.8.1 pH levels:

Algerian standards mandate a neutral to slightly alkaline range of 6.5-8.5, which is particularly important for industrial effluents where extreme pH values are common - textile industry wastewater often exhibits highly alkaline conditions (pH 9-12) due to dyeing processes, while mining operations frequently produce acidic discharges (pH 2-4) from sulphide oxidation.

I.8.2 Electrical Conductivity:

Though not strictly limited, serves as an important indicator of salinity, with desalination plants and agricultural runoff being major contributors to elevated levels that can impact soil quality and aquatic ecosystems.

I.8.3 BOD and COD:

wastewater treatment plants must achieve BOD₅ levels below 30 mg/L and COD under 90 mg/L, while industrial sectors face slightly more lenient but still restrictive limits (BOD₅ ≤ 50-100 mg/L depending on industry type). These standards are particularly challenging for high-load industries like breweries, where raw wastewater can contain BOD₅ concentrations of 1,000-2,000 mg/L from fermentable sugars, or pharmaceutical manufacturers dealing with complex organic compounds that push COD levels above 1,000 mg/L.

I.8.4 Total suspended solids (TSS):

Are capped at 30 mg/L for domestic effluents, a standard that food processing facilities often struggle to meet due to the particulate nature of their waste streams, which may contain 200-500 mg/L of organic solids from slaughtering or dairy operations.

I.8.5 The oil and grease parameters :

Limited to 5 mg/L, primarily targets petroleum refineries and automotive service industries where hydrocarbon contamination is prevalent. In terms of dissolved solids, while no universal discharge limit exists, the guideline of 1,500 mg/L for agricultural reuse addresses salinity concerns, particularly relevant for oil refinery effluents that often contain 3,000-5,000 mg/L TDS from process waters and brine streams.

I.8.6 Microbiological standards:

For wastewater reuse in agriculture align with WHO guidelines, requiring faecal coliform counts below 2,000 CFU/100 mL and helminthic egg concentrations not exceeding 1 egg/L for unrestricted irrigation.

These biological parameters are especially critical in Algeria's water-scarce context, where treated wastewater represents an increasingly important resource for agricultural production. The country's regulatory evolution reflects both local environmental priorities and international influences, particularly from Mediterranean partnerships and WHO recommendations, though challenges remain in consistent enforcement and addressing emerging contaminants not yet covered by existing legislation. Future regulatory developments are expected to focus on industrial wastewater recycling mandates and the incorporation of new parameters for micro pollutants as Algeria continues to balance economic development with environmental protection in its water management strategies.

Algerian Ministry of Water Resources (2021). National Sanitation Strategy, Official Journal of the Algerian Republic (JORA); Decree 11-125 (2011), Decree 07-149 (2007), WHO (2018). Guidelines for Safe Wastewater Use in Agriculture.

I.9 Risks of Wastewater

I.9.1 Wastewater overflow risks and hazards on human factor:

Contact with wastewater can occur when effluent or untreated wastewater overflows or is improperly discharged, resulting in seepage onto the property. The common cause of on-site wastewater overflows is the failure, or inadequate maintenance and servicing of the OWMS.

Wastewater contains dissolved and suspended biological matter that can contain many microorganisms that may be harmful to humans, animals, and the environment. These microorganisms can include viruses, bacteria, protozoa, fungus, and parasitic organisms.

Contact with wastewater or its products can expose people to harmful microorganisms that can cause illnesses such as:

- gastroenteritis (diarrhoea or vomiting)
- giardiasis and cryptosporidiosis (severe stomach cramps, diarrhoea, or vomiting)
- viral infections such as hepatitis (liver infections)
- Infections of the skin or eyes.

Due to technological and economic limitations, waste products such as sewage and manure generated in livestock farming lack comprehensive scientific and centralized treatment. This leads to the exposure of various contaminants in livestock wastewater, posing potential risks to both the ecological environment and human health. This review evaluates the environmental and physical health risks posed by common pollutants in livestock wastewater and outlines future treatment methods to mitigate these risks. Residual wastes in livestock wastewater, including pathogenic bacteria and parasites surviving after epidemics or diseases on various farms, along with antibiotics, organic wastes, and heavy metals from farming activities, contribute to environmental damage and pose risks to human health. As the livestock industry's development increasingly impacts society's future negatively, addressing the issue of residual wastes in livestock wastewater discharge becomes imperative. Ongoing advancements in wastewater treatment systems are consistently updating and refining practices to effectively minimize waste exposure at the discharge source, mitigating risks to environmental ecology and human health. This review not only summarizes the "potential risks of livestock wastewater" but also explores "the prospects for the development of wastewater treatment technologies" based on current reports. It offers valuable insights to support the long-term and healthy development of the livestock industry and contribute to the sustainable development of the ecological environment.

I.10 Typology of contaminants in wastewater:

I.10.1 Microbial hazards:

Raw wastewater may contain plenty of human microbial pathogens, including bacteria, helminths, protozoa and viruses. Employment of untreated or partially treated wastewater vegetable irrigation may cause the transmission of infectious microorganisms to the products end users and farm workers.

Epidemiological and clinical studies have revealed a significant risk of helminthiasis like ascariasis and giardiasis, enteropathogenic infections like cholera, typhoid, shigellosis, *H pylori* and *E coli* infection, Listeriosis, Salmonellosis, enterovirus infections like rotavirus and poliovirus among others which have been shown to directly correlate with inadequate wastewater treatment.

I.10.2 Leachate wastewater:

Leachate is a highly contaminated liquid that forms when water percolates through waste materials, primarily in landfills, dissolving and transporting various pollutants. This complex wastewater poses significant environmental and public health risks due to its variable composition, which depends on factors such as waste type, landfill age, and climatic conditions.

The formation of leachate begins with water infiltration through waste layers, initiating biological, chemical, and physical processes. In municipal solid waste landfills, organic matter decomposition produces volatile fatty acids, resulting in young leachate (less than five years old) characterized by acidic pH (4.5–6.5), high biochemical oxygen demand (BOD₅ often exceeding 10,000 mg/L), and elevated ammonia nitrogen concentrations (500–2,000 mg/L).

As landfills mature (beyond ten years), leachate becomes more alkaline (pH 7.0–8.5) with lower biodegradability (BOD₅ /COD ratio below 0.2) but accumulates persistent pollutants like humic substances and heavy metals including lead, cadmium, and arsenic.

Industrial waste landfills generate even more hazardous leachate containing toxic organic compounds, heavy metals, and high salt concentrations.

I.10.3 The environmental risk:

Are severe, leachate can contaminate groundwater resources, degrade soil quality through salinity and metal accumulation, and cause eutrophication in surface waters due to nutrient loading. Human health impacts include exposure to carcinogenic compounds like benzene and polycyclic aromatic hydrocarbons (PAHs).

Algeria's regulatory framework addresses leachate management through several key instruments. Decree 11-125 (2011) establishes discharge limits for parameters like chemical oxygen demand (COD $\leq$ 250 mg/L) and heavy metals (cadmium $\leq$ 0.1 mg/L, lead $\leq$ 0.5 mg/L). Law 01-19 (2001) requires technical measures such as landfill liners and leachate collection systems.

However, challenges remain in addressing emerging contaminants and ensuring consistent enforcement across landfill sites.

- **Case studied in Algeria:**

- Oued Smar Landfill (Algiers):
- Challenge: High COD (15,000 mg/L) and NH₃ -N (1,200 mg/L).
- Solution: Sequential anaerobic-aerobic treatment + chemical precipitation.
- Outcome: COD reduced to <500 mg/L (meeting Decree 11-125 standards).

Table 1 Key pollutants in leachate

Settings	Typical concentration	Regulatory Limits (in Algeria)
COD	2,000–60,000 mg/L	≤ 250 mg/L (Decree 11-125)
NH ₃ -N	500–3,000 mg/L	≤ 10 mg/L (irrigation reuse)
Heavy Metals (Cd, Pb)	0.1–10 mg/L	≤ 0.1–0.5 mg/L
Chloride (Cl ⁻)	1,000–5,000 mg/L	≤ 1,500 mg/L

I.11 Conclusion

In summary, this chapter provided a general overview of wastewater, outlining its origins, types, and main sources, including domestic, industrial, and agricultural activities. It highlighted the complexity and variability of wastewater composition, which directly influences the choice of treatment methods. This foundational understanding is essential for addressing the environmental challenges posed by wastewater and sets the stage for exploring appropriate and innovative treatment techniques, such as electrocoagulation, discussed in the following chapters.

Kjeldsen, P., et al. (2002). "Landfill Leachate: A Review of Composition and Environmental Fate." *Waste Management*, 22(1), 3-23,

Algerian Ministry of Environment (2011). Decree 11-125 on Industrial Effluent Standards. Official Journal of the Algerian Republic No. 37.

Renou, S., et al. (2008). "Landfill Leachate Treatment: Review and Opportunity." *Journal of Hazardous Materials*, 150(3), 468-493,

Aziz, S. Q., et al. (2010). "Leachate Treatment by Coagulation-Flocculation." *Environmental Technology*, 31(1), 25-33.

Ould-Chikh, K. (2015). *Leachate Management in Algerian Landfills*. University of Algiers Press.

CHAPTER II : ELECTROCOAGULATION

II.1 Introduction

One of the major challenges facing mankind today is to provide clean water to a vast majority of the population around the world. The need for clean water is particularly critical in Third-World Countries. Rivers, canals, estuaries and other water-bodies are being constantly polluted due to indiscriminate discharge of industrial effluents as well as other anthropogenic activities and natural processes. In the latter, unknown geochemical processes have contaminated ground water with arsenic in many countries. Highly developed countries, such as the US, are also experiencing a critical need for wastewater cleaning because of an ever-increasing population, urbanization and climatic changes. The reuse of wastewater has become an absolute necessity. There is, therefore, an urgent need to develop innovative, more effective and inexpensive techniques for treatment of wastewater. A wide range of wastewater treatment techniques are known which includes biological processes for nitrification, denitrification and phosphorous removal; as well as a range of physico-chemical processes that require chemical additions. The commonly used physico-chemical treatment processes are filtration, air stripping, ion-exchange, chemical precipitation, chemical oxidation, carbon adsorption, ultrafiltration, reverse osmosis, electrodialysis, volatilization and gas stripping. A host of very promising techniques based on electrochemical technology are being developed and existing ones improved that do not require chemical additions. These include electrocoagulation, electroflotation, electrodecantation, and others. Even though one of these, electrocoagulation, has reached profitable commercialization, it has received very little scientific attention. This process has the potential to extensively eliminate the disadvantages of the classical treatment techniques. Moreover, the mechanisms of EC are yet to be clearly understood and there has been very little consideration of the factors that influence the effective removal of ionic species, particularly metal ions, from wastewater by this technique. In this brief review, we wish to address these issues.

II.2 Definition of Electrocoagulation(EC)

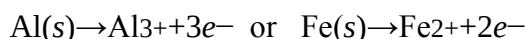
Electrocoagulation involves dissolution of metal from the anode with simultaneous formation of hydroxyl ions and hydrogen gas occurring at the cathode. Electrocoagulation has been proposed since before the turn of the century with Vik et al. (1984) describing a treatment plant in London built in 1889 (for the treatment of sewage by mixing with seawater and electrolyzing). In 1909, in the United States, J.T. Harries (Vik et al., 1984) received a patent for wastewater treatment by electrolysis with sacrificial aluminium and iron anodes. Matteson et al. (1995) describe a device of the 1940's, the "Electronic Coagulator" which electrochemically dissolved aluminium (from the anode) into solution, reacting this with the hydroxyl ion (from the cathode) to form aluminium hydroxide. The

hydroxide flocculates and coagulates the suspended solids purifying the water. A similar process was used in Britain in 1956 (Matteson et al., 1995) for which iron electrodes were used to treat river water.

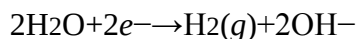
II.3 Electrocoagulation process:

Electrocoagulation (EC) is an electrochemical water treatment technology that employs sacrificial metal electrodes and direct current (DC) to remove contaminants through coagulation, flotation, and sedimentation. The process begins with the immersion of electrodes—typically aluminium (Al) or iron (Fe)—into the contaminated water. When a DC voltage is applied, the anode undergoes oxidation, releasing metal ions (e.g., Al^{3+} or $\text{Fe}^{2+}/\text{Fe}^{3+}$) into the solution. Simultaneously, the cathode facilitates the reduction of water molecules, producing hydrogen gas (H_2) and hydroxide ions (OH^-). These reactions are fundamental to the process:

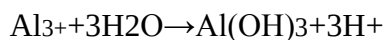
At the anode:



At the cathode:



The released metal ions hydrolyse in water to form metal hydroxides such as $\text{Al}(\text{OH})_3$ or $\text{Fe}(\text{OH})_3$, which act as coagulants. For example, aluminium ions react with water to form amorphous aluminium hydroxide:



These hydroxides neutralize the surface charges of colloidal particles (e.g., suspended solids, oils, or organic matter), destabilizing them and promoting aggregation into larger flocs. This process, known as charge neutralization, is followed by sweep coagulation, where hydroxide flocs physically enmesh smaller particles.

Hydrogen gas generated at the cathode enhances contaminant removal by attaching to flocs and buoying them to the surface (electroflotation). Larger flocs settle via gravity (sedimentation), after which the sludge is removed through skimming or filtration. The efficiency of electrocoagulation depends on several factors, including current density, pH, water conductivity, electrode material, and hydraulic retention time. For instance, higher current densities increase coagulant dosage but may lead to excessive energy consumption or electrode passivation due to oxide layer formation (Mollah et al., 2001). Optimal pH ranges vary by electrode material: aluminium performs best near neutral conditions (pH 6–8), while iron is more effective in slightly acidic environments (pH 5–7).

Electrocoagulation is versatile and has been applied to treat industrial wastewater from textiles, food processing, and petroleum industries, as well as to remove heavy metals (e.g., arsenic, chromium) and degrade organic pollutants like dyes and pesticides (Chen, 2004). Its advantages include minimal

chemical usage, compact design, and adaptability to diverse contaminants. However, challenges such as electrode passivation, sludge management, and energy costs for low-conductivity waters remain limitations (U.S. EPA, 2000).

Mollah, M. Y. A., Schennach, R., Parga, J. R., & Cocke, D. L. (2001). Electrocoagulation (EC) — science and applications. *Journal of Hazardous Materials*,
 Chen, G. (2004). Electrochemical technologies in wastewater treatment. *Separation and Purification Technology*,
 U.S. EPA. (2000). *Electrocoagulation in Water Treatment*. EPA/625/R-00/001.

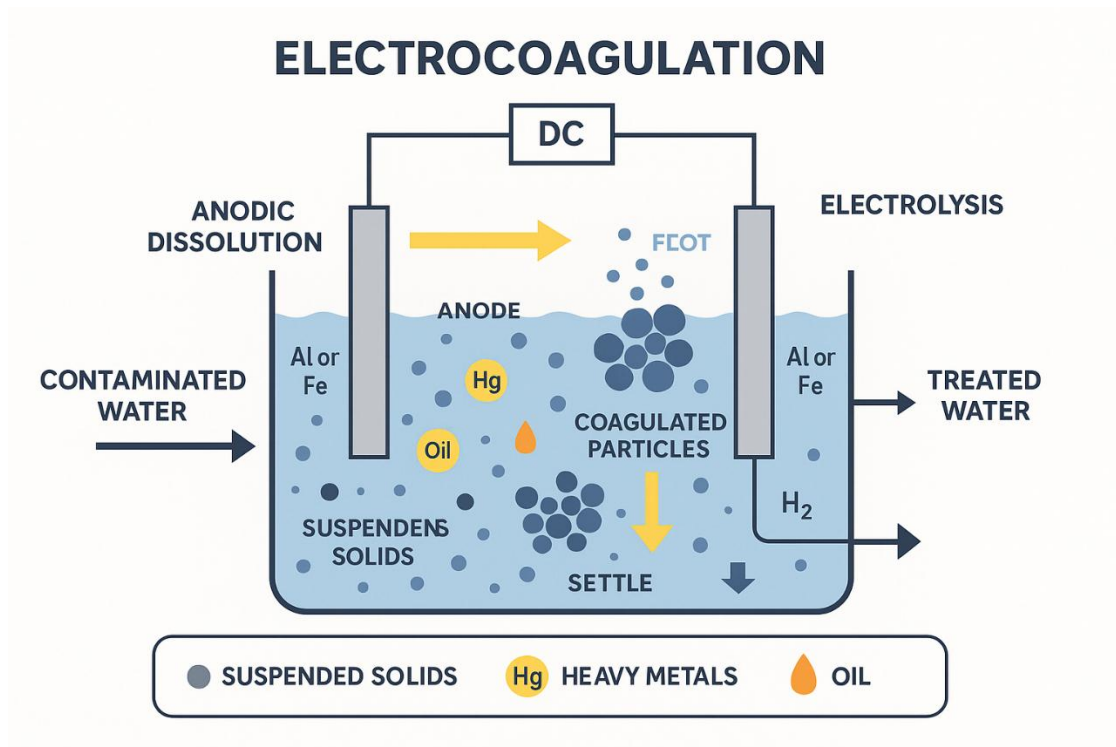


Figure 5 : Description of electrocoagulation process

II.4 Optimal Settings for Electrocoagulation (EC) Process:

The efficiency of electrocoagulation depends on several operational parameters, including electrical intensity, voltage, electrode material, and reaction time. Below are the typical settings used in research and industrial applications:

II.4.1 Current density (Electrical intensity)

Current Density (Electrical Intensity)

- **Range:** 5–150 mA/cm² (in our experiment we use from 150-300 mA/cm²).
- **Effect:**

Higher current density increases coagulant release (more Al^{3+} or Fe^{2+} ions) but may lead to excessive energy consumption, Too low current density results in insufficient coagulation.

II.4.2 Voltage

- **Range:** 5–30 V (typically 5–15 V for most systems).
- **Effect:**

Higher voltage increases reaction rate but also energy costs, Optimal voltage depends on water conductivity (lower voltage for high-conductivity wastewater).

II.4.3 Electrode Material

- **Aluminium (Al):**

Preferred for organic pollutants (dyes, oils, organic matter).

Reactions:



II.4.4 pH range

- **Aluminium electrodes:** 6–8 (neutral to slightly alkaline).
- **Effect:**

Extreme pH (<4 or >9) can dissolve hydroxides, reducing efficiency.

II.4.5 Electrode Configuration:

- **Monopolar (parallel):** Electrodes alternate (anode-cathode-anode...).
- **Bipolar (series):** Only outer electrodes connected to power; inner ones polarize.
- **Optimal spacing:** 5–20 mm (too close causes short-circuiting; too far increases resistance).

II.4.6 Reaction time

- **Range:** 120-180 minutes (depends on pollutant concentration).

- **Effect:**

Longer time improves removal but increases energy costs.

Typical treatment time: **10–30 min** for industrial wastewater.

II.4.7 Conductivity and Energy consumption

- **Conductivity:** > **1000 $\mu\text{S/cm}$** (if low, add NaCl or other electrolytes).
- **Energy consumption:** **0.5–10 kWh/m³** (depends on current density and pollutant load).

II.4.8 Temperature

- **Optimal range:** **20–40°C**.
- **Effect:**

Higher temperatures increase reaction rates but may cause electrode corrosion.

Table : 2 Summary of optimal settings

Parameter	Typical Range
Current Density	10–60 mA/cm ²
Voltage	5–15 V
pH (Al electrodes)	6–8
pH (Fe electrodes)	5–7
Reaction Time	10–30 min (120-180 min)
Electrode Spacing	5–20 mm
Conductivity	>1000 $\mu\text{S/cm}$

Mollah, M. Y. A., et al. (2001). *Journal of Hazardous Materials*, Chen, G. (2004). *Separation and Purification Technology*, U.S. EPA (2000). *Electrocoagulation in Water Treatment*

II.5 Pollutant conditions for the manifestation of the EC process:

Landfill leachate presents a complex wastewater that can be effectively treated by electrocoagulation when its composition falls within certain parameters.

For optimal treatment performance, the leachate should ideally contain moderate to high concentrations of organic matter, typically characterized by a COD (Chemical Oxygen Demand) ranging between 500-10,000 mg/L. The presence of biodegradable organic compounds is particularly favorable, as indicated by a BOD/COD ratio exceeding 0.3, which suggests better treatability. Heavy metal contamination, including common pollutants like lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), and zinc (Zn), responds well to electrocoagulation treatment due to the effective removal mechanisms available.

The process shows good efficacy for leachate containing significant amounts of ammonia nitrogen ($\text{NH}_3\text{-N}$) and phosphates (PO_4^{3-}), both of which can be removed through various electrochemical pathways. Suspended solids in the range of 200-2,000 mg/L are also well-suited for treatment, as the electrocoagulation process effectively aggregates these particles. The presence of some salinity is actually beneficial, with optimal treatment occurring when conductivity exceeds 1,000 $\mu\text{S/cm}$, as this improves current efficiency without requiring excessive energy input.

However, certain leachate characteristics may require pretreatment or make electrocoagulation less suitable. Extremely high total dissolved solids ($\text{TDS} > 20,000 \text{ mg/L}$) can pose challenges and may necessitate dilution prior to treatment. Similarly, leachate containing high concentrations of refractory organic compounds, such as humic substances, might show limited treatment efficiency with electrocoagulation alone and could benefit from combined treatment approaches. The presence of certain complex organic pollutants may also reduce overall treatment effectiveness when using electrocoagulation as a standalone process. Understanding these composition parameters is crucial for determining whether electrocoagulation represents an appropriate treatment solution for a given landfill leachate and what modifications or additional treatment steps might be necessary to achieve the desired effluent quality.

Table 3 : Ideal pollutant characteristics for EC

Parameter	Ideal Range for EC Treatment	Notes
COD	500–10,000 mg/L	Higher values may require pretreatment or extended treatment time
BOD/COD ratio	>0.3	Indicates better biodegradability and treatability
Heavy metals	Present (Pb, Cd, Cr, Ni, Zn, etc.)	EC is particularly effective for metal removal (80–99% efficiency)
Ammonia (NH₃ -N)	Up to 1,200 mg/L	Moderate removal (30–60%); may need complementary processes for higher loads
Phosphates (PO₄³⁻)	Present	Excellent removal (80–95%) with Fe/Al electrodes
Suspended solids (TSS)	200–2,000 mg/L	Easily removed via flocculation and sedimentation
Conductivity	>1,000 µS/cm	Low conductivity may require electrolyte addition (e.g., NaCl, Na ₂ SO ₄)
pH	5–8	Adjust to 6–7 for Al electrodes; 5–7 for Fe electrodes
Problematic Cases		
TDS	>20,000 mg/L	May require dilution or pretreatment
Refractory organics	High concentrations	Poor removal; consider EC + advanced oxidation (e.g., ozone, H ₂ O ₂)
Complex organics	Humic acids, some pesticides	Partial removal; may need activated carbon polishing

II.6 Conclusion

This chapter presented the fundamental principles of electrocoagulation, detailing its mechanism, key operational parameters (such as current density, electrode material, and treatment time), and its relevance in wastewater treatment. Additionally, it explored the physico-chemical characteristics of landfill leachate, emphasizing its complex and variable composition depending on its age and origin. The understanding of both the electrocoagulation process and the nature of the leachate is crucial for designing effective treatment strategies, and serves as the technical foundation for the experimental work described in the next chapter.

Chen, G. (2004). Separation and Purification Technology, Comninellis, C. (1994). Electrochimica Acta, EPA (2000). Electrocoagulation in Water Treatment, Ghanbari et al. (2014). Journal of Environmental Management, Holt et al. (2005). Water Research, Khandegar & Saroha (2013). Journal of Environmental Chemical Engineering, Kobya et al. (2006). Journal of Hazardous Materials, Mollah et al. (2001, 2004). Journal of Hazardous Materials, Rajeshwar & Ibanez (1997). Environmental Electrochemistry, Türgay et al. (2011). Journal of Hazardous Materials, Umar et al. (2010). Waste Management

CHAPTER III : METHODS AND MATERIALS

III.1 Introduction

This chapter outlines the materials, equipment, and methodologies employed in the investigation of wastewater treatment through the electrocoagulation process. The objective of this section is to provide a comprehensive and transparent account of the experimental procedures, ensuring the reproducibility and scientific integrity of the work. The approach adopted integrates both theoretical principles and practical considerations specific to electrocoagulation, a technique known for its effectiveness in removing various pollutants from wastewater.

III.2 Discription of Oran’s Technical Landfill Centre:



Figure 6 Technical landfill

The **Technical Landfill Center (TLC)** in **Hassi Bounif, Oran**, is a dedicated waste management facility designed to handle solid waste, particularly materials that are not recyclable or cannot be effectively valorized. Inaugurated in **2012**, this center plays a pivotal role in managing the region’s waste stream, receiving approximately **14,000 tons of waste daily** from **14 different municipalities**.

Spanning an area of **89 hectares**, the center includes **six engineered landfill cells** specifically constructed for safe waste disposal. Although originally designed with a projected operational lifespan of five years, the center reached full capacity within just three years due to the unexpectedly rapid accumulation of waste. This premature saturation highlights the pressing need for more efficient waste management systems and strategic planning to accommodate population growth and increasing waste volumes. As one of the **three main waste treatment centers in the Oran region**, the Hassi Bounif TLC is central to regional efforts to manage and contain municipal solid waste. It facilitates the

reception, storage, and management of waste, thereby supporting public hygiene, reducing health risks, and mitigating environmental impact.

At the site, solid waste is systematically transported and deposited into designated areas, where rigorous protocols are followed to prevent contamination of soil and groundwater. Environmental



Figure 7 Leachat Pool

control measures, such as **daily waste covering** and **biogas collection** from decomposing waste, are implemented to minimize ecological harm. In addition, the facility is equipped with **air and water quality monitoring systems** to ensure emissions and effluents comply with environmental and public health regulations.

It is important to note that **Technical Landfill Centers** are generally regarded as a **last-resort solution** in the waste management hierarchy, used when alternatives such as recycling, energy recovery, or waste minimization are not viable or sufficient for certain waste types.

In this context, the Hassi Bounif TLC plays a vital role in the region’s solid waste management infrastructure, offering a **controlled and monitored solution** for disposing of non-recoverable waste while striving to minimize its environmental footprint.

III.3 Materials Used

III.3.1 Leachate:

on this work we used two different types of leachate

- **Mature leachate(500ml):** this leachate was stocked for over 5 years in a tank, it has no smell such as the young leachate
- **Young leachate(500ml):** this was the topic of the search, it has the ordinary smell (toxic and can provoke headache if exposed to it for a long period of time)

III.3.2 Electrodes

the variety of electrodes used allowed us to see what type of materials used works best for this treatment

- **Aluminium recycled from Tomato cans (Manip01):**

Poste 01: $T = 99^{\circ}\text{C}$, $A = 9$, $I = 1.7\text{A}$

Poste 02 : $T = 50^{\circ}\text{C}$, $A = 2$, $I = 1.34\text{A}$

Poste 03: $T = 90^{\circ}\text{C}$, $A = 3$, $I = 2.34\text{A}$

Poste 04: $T = 60^{\circ}\text{C}$, $A = 4$, $I = 2\text{A}$

Poste 05: $T = \text{amb}$, $A = 0$, $I = 3.24\text{A}$

- **Graphite (Manip02):**

Poste 01: $T = \text{amb}$, $A = 8$, $I = 2\text{A}$

Poste 02 : $T = \text{amb}$, $A = 2$, $I = 1.6\text{A}$

Poste 03: $T = \text{amb}$, $A = 9$, $I = 1.63\text{A}$

Poste 04: $T = \text{amb}$, $A = 2$, $I = 1.64\text{A}$

Poste 05: $T = \text{amb}$, $A = 2$, $I = 1.6\text{A}$

- **Alluminium (Manip03):**

Poste 01: $T = \text{amb}$, $A = 2$, $I = 1.7\text{A}$

Poste 02 : $T = \text{amb}$, $A = 2$, $I = 3\text{A}$

Poste 03: $T = \text{amb}$, $A = 2$, $I = 3\text{A}$

Poste 04: $T = \text{amb}$, $A = 2$, $I = 1\text{A}$

Poste 05: $T=\text{amb}$, $A=2$, $I=1.7\text{A}$

- **Graphite (Manip04)**

Poste 01: $T=\text{amb}$, $A=2$, $I=3.1\text{A}$

Poste 02 : $T=\text{amb}$, $A=2$, $I=3.09\text{A}$

III.3.3 Laboratory DC Power Supply:

After a 500ml sample is taken we do the assembly, we place the 500ml sample of the leachate in a bowl and we submerge the electrodes (anode and cathode) supplied from the power supply in it, we charge the electrodes with an electrical intensity up to 3Am (only 1Am is deadly, we had to be extra careful on this work) and we set a timer for 2 hours.

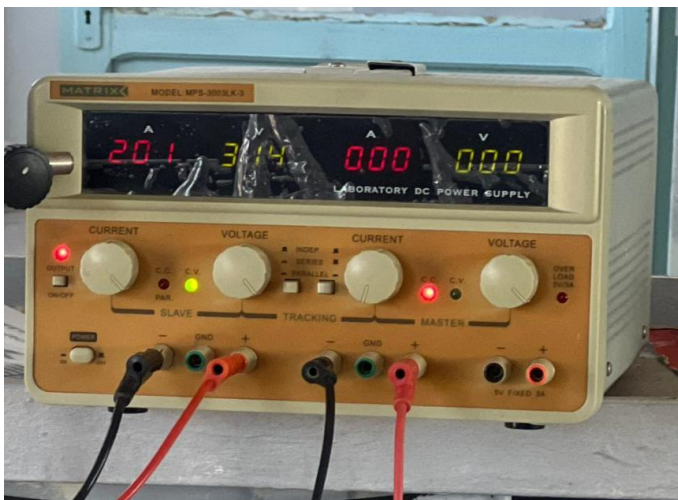
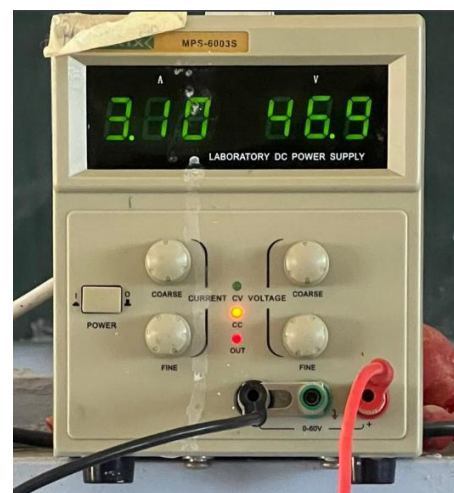


Figure 8 Power Supply

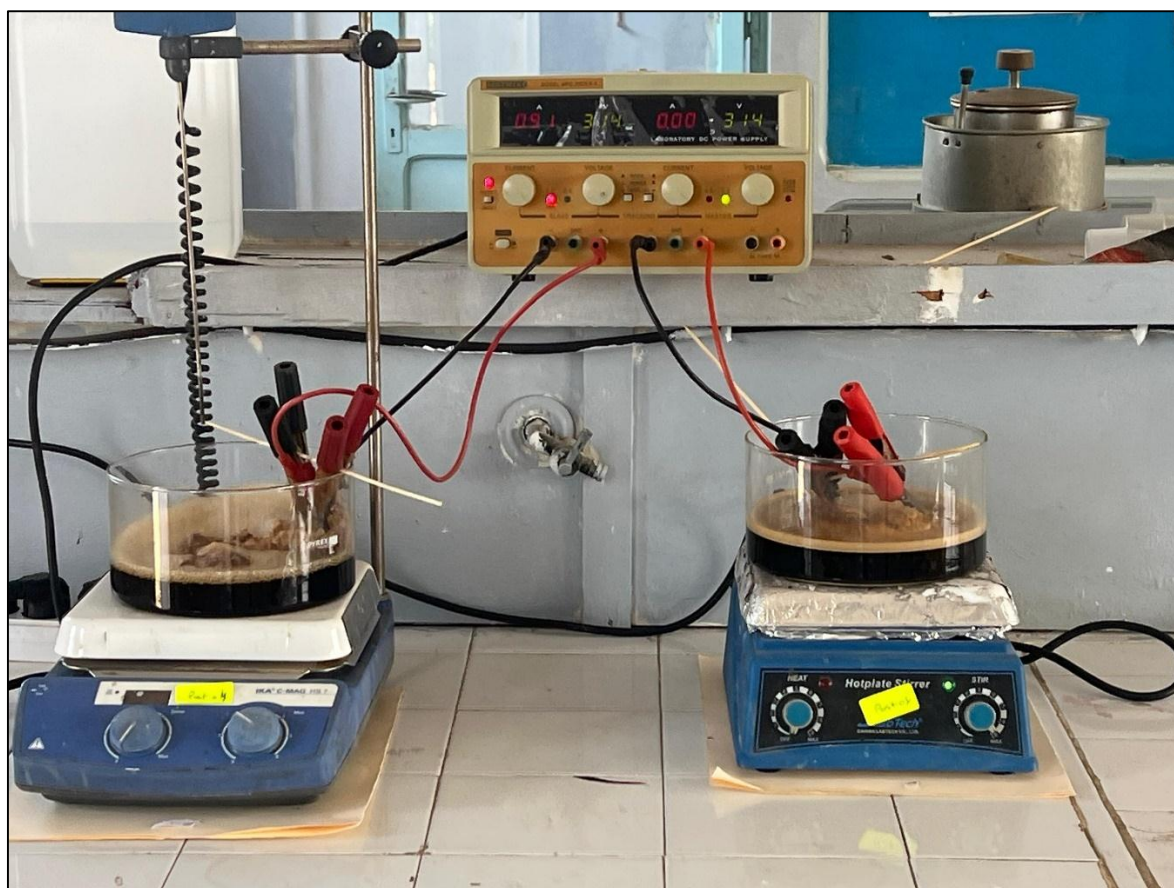


Figure 9 Experimental protocol for EC

III.3.4 Agitator:

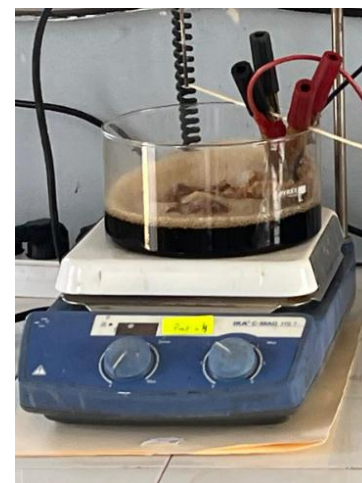


Figure 10 Agitators

Some of the manipulation were done under different temperature and agitation settings

III.3.5 Centrifuge:

A bench-top centrifuge (model DM0412P) was used to separate suspended solids from the wastewater samples prior to analysis. The centrifuge operates at adjustable speeds and

time settings in this study, samples were centrifuged at 2690 rpm for 20 minutes. This step ensured the removal of particulate matter and to weight the TDS, allowing for more accurate measurement of parameters such as COD, turbidity, and conductivity in the supernatant. Proper balancing of sample tubes was maintained during operation to ensure consistent and safe centrifugation.



Figure 11 Centrefuge

After putting the 12 samples in the centrifuge, its then taken to be filtered using 2 pumps and filter sheets to extract the TDS, then the filtered sample are taken to calculate the density after the filtration process, after that we measure the pH level and the EC using a conductometers and pH meter

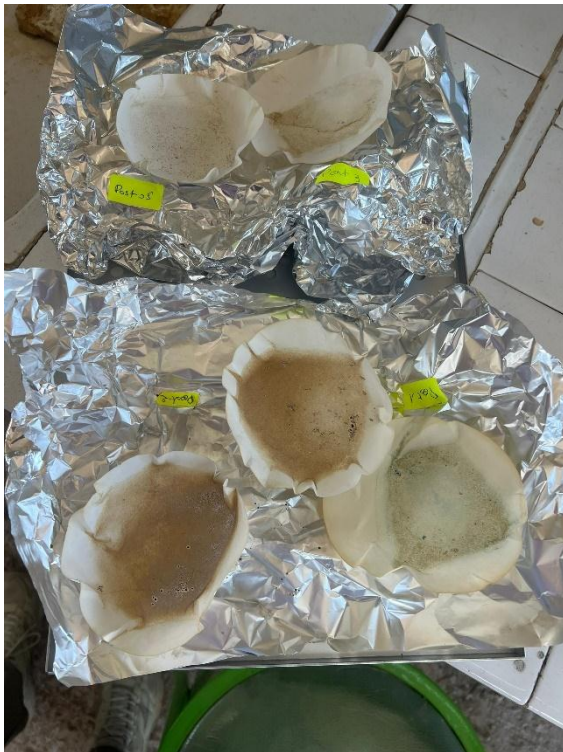


Figure 12 TDS weights



Figure 13 Conductivimeter

After this part we go straight to measure the BOD (Biological Oxygen Demand) using what we call Oxitops.

III.3.6 OxiTop:

OxiTop® is a manometric BOD measuring system developed by WTW (a Xylem brand). It measures the oxygen consumption by microorganisms during the decomposition of organic matter over a set incubation period (usually 5 days for BOD₅).

- BOD bottles are filled with the wastewater sample and a nitrification inhibitor (if required).
- A microbial seed may be added if the sample has low microbial activity.
- A rubber stopper containing a CO₂ absorber (e.g., NaOH pellets) is placed inside the bottle cap.
- The OxiTop® head is then screwed onto the bottle.
- As microbes consume oxygen, CO₂ is produced and absorbed by the NaOH.
- This causes a pressure drop in the sealed bottle, which the OxiTop head measures.
- The device records pressure changes, which are converted into mg/L of BOD.

COD protocol:

- 2,5ml Sample (50 times diluted)
- 1,25ml K₂Cr₂O₇
- 0,12g HgSO₄
- 3,75ml catalyst H₂SO₄+Ag₂SO₄

COD equals:

$$\frac{8000 \times C_{fe} (V_{blanc} - V_{eq}) \times 50}{2,5}$$

Where :

V_{blanc} : death salt volum needed for the Destiled water

V_{eq} : death salt volum needed for leachate sample

C_{fe} : HgSO₄

The samples after that are placed in the COD machine that increases the Temperature up to 120 C°

After 5 hours, the samples are then taken for the dosage.

We add 50ml of distilled water and add about 3 drops of the colour indicator and then we add the salt of death NH₄ SO₄ drop by drop until the sample colour changes to a reddish colour

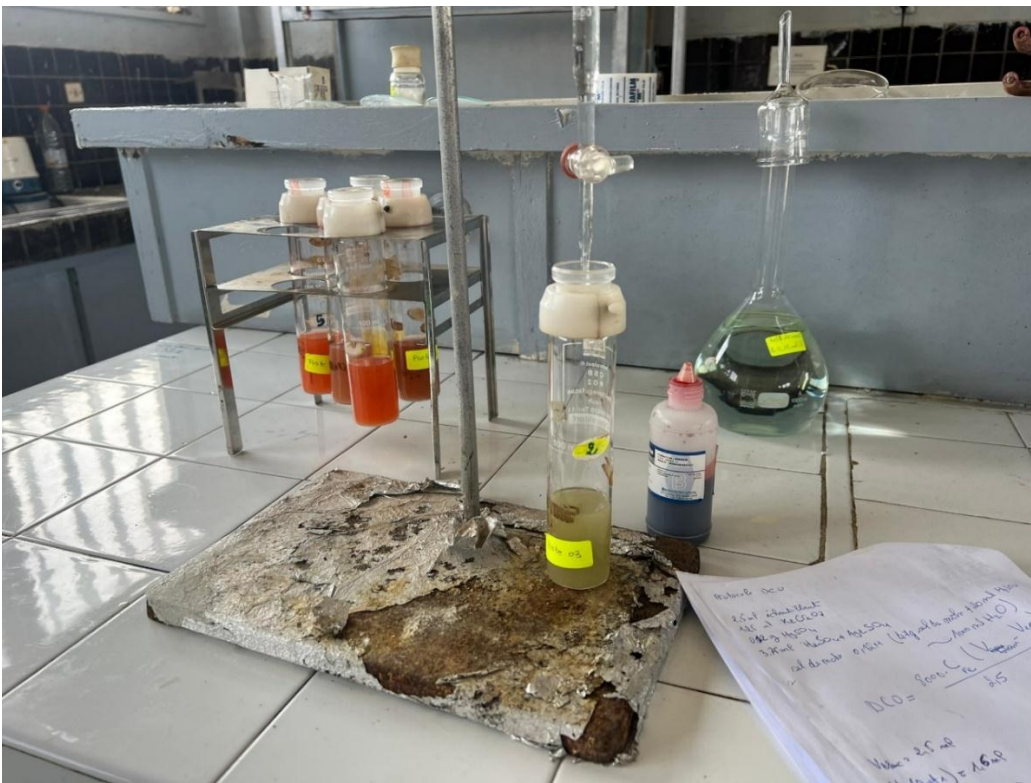


Figure 14 COD determination protocol (Dosage)

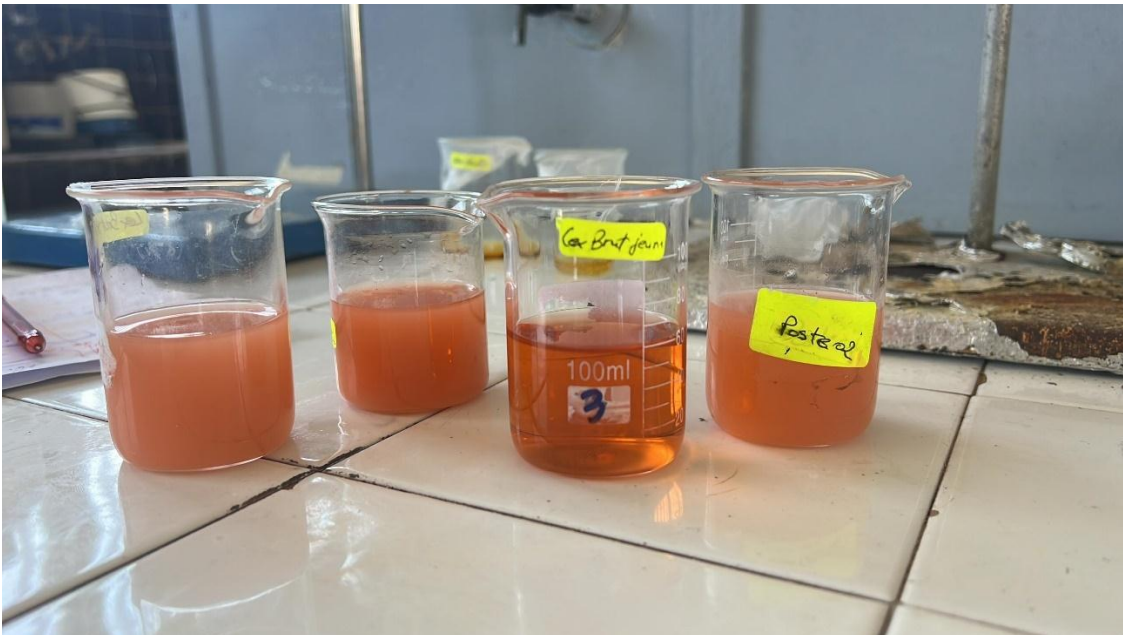


Figure 15 Leachate samples for COD

III.4 Conclusion:

This chapter detailed the materials, instruments, and experimental procedures employed in the treatment of wastewater using the electrocoagulation process. The characterization of raw wastewater, selection of appropriate electrodes, and setup of the electrocoagulation reactor were carefully planned to ensure reproducibility and efficiency. Analytical techniques, including BOD measurement using the OxiTop system and physicochemical analyses such as COD, TDS, and electrical conductivity, were carried out in accordance with established standards. Together, these methods provided a comprehensive framework for evaluating the effectiveness of electrocoagulation in treating wastewater and laid the foundation for the analysis and interpretation of results presented in the following chapters.

CHAPTER IV : RESULTS AND DISCUSSION

IV.1 Introduction

This chapter presents the experimental results obtained from the treatment of wastewater using the electrocoagulation (EC) process, followed by a critical analysis and interpretation of these findings. The performance of the treatment was assessed through several key physicochemical parameters, including pH, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand over 5 days (BOD₅), Total Dissolved Solids (TDS), and electrical conductivity. These parameters were measured both before and after treatment in order to evaluate the efficiency and behavior of the system under various operating conditions.

IV.2 pH results discussion

Manipulation01 :

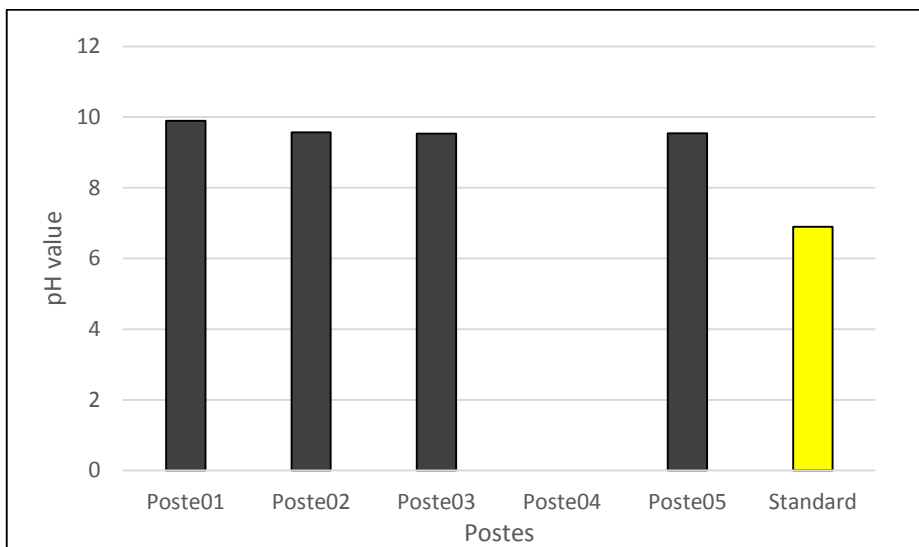


Figure 16 pH level Manipulation1

Manipulation02 :

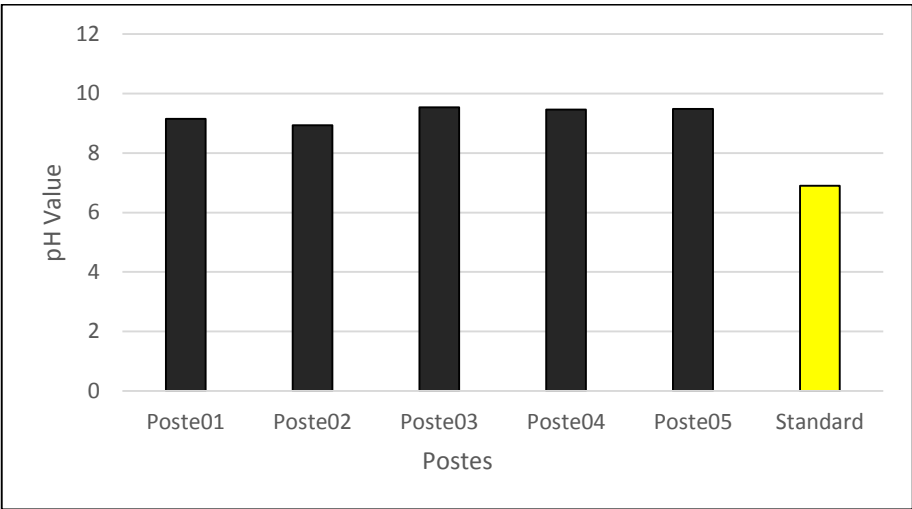


Figure 17 pH level, Manipulation2

Manipulation03 :

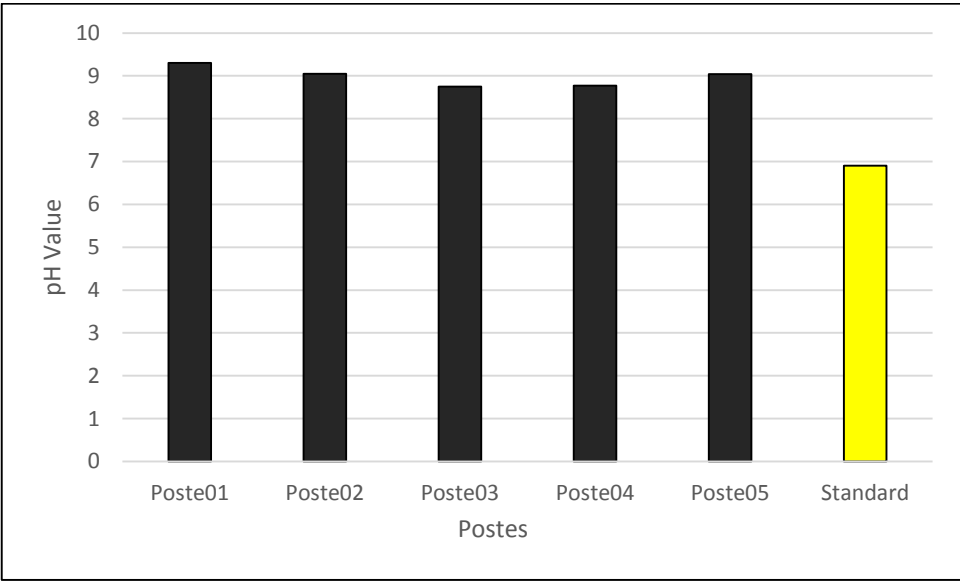


Figure 18 pH level, Manipulation3

Manipulation04 :

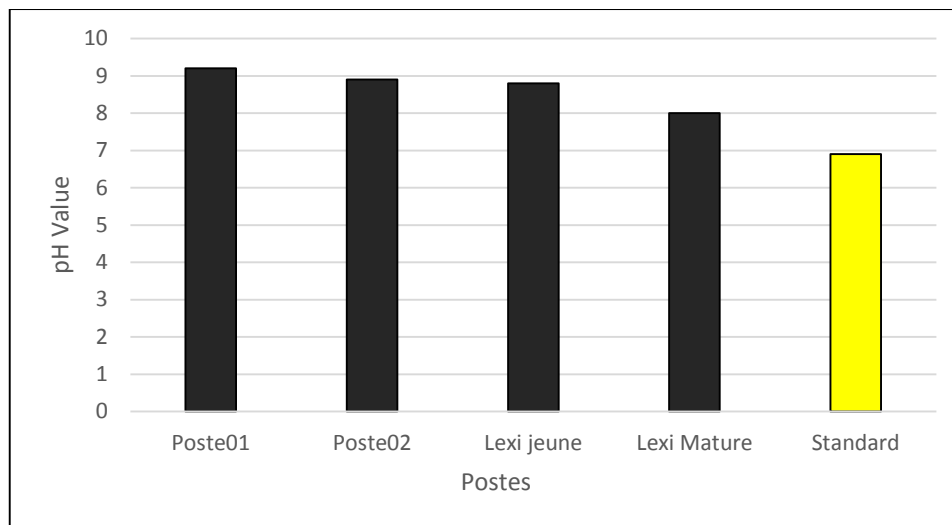


Figure 19 pH level, Manipulation4

The pH values recorded across all experimental manipulations ranged between 8.0 and 9.9, which indicates an alkaline character of the leachate samples. Some values exceed the standard regulatory value of 8.5, generally recommended for treated effluents intended for discharge or reuse. However, contrary to what is commonly observed in electrocoagulation processes, the treatment did not significantly alter the pH levels. This observation suggests that the elevated pH values are primarily due to the intrinsic characteristics of the raw leachate rather than the effect of electrocoagulation.

To better understand this behavior, pH levels were also measured in both fresh (new) raw leachate and mature raw leachate, revealing that the alkaline nature was already present before any treatment. This is consistent with the known composition of landfill leachate, which evolves over time. New leachate often exhibits a higher concentration of easily biodegradable organic matter, which can lead to acidic or near-neutral pH values, while mature leachate typically contains more refractory compounds and undergoes ammonification, which increases the concentration of ammonia and results in a more alkaline pH.

The results indicate that the leachate used in this study was likely in a mature phase, where the high pH is a result of long-term anaerobic degradation and ammoniacal nitrogen accumulation. As such, the electrocoagulation process did not significantly modify the initial pH, either because of a lack of reactive species in the matrix or due to the system's natural buffering capacity.

From a regulatory and environmental perspective, these findings imply that while electrocoagulation may be effective in removing pollutants, pH adjustment may still be necessary before discharge or reuse, particularly when the raw leachate already falls outside the recommended pH range. This reinforces the idea that characterization of the raw effluent is essential in designing an effective and compliant treatment strategy.

In conclusion, the observed pH values reflect the original chemical state of the leachate, particularly its maturity stage, rather than the influence of the electrocoagulation process itself. This highlights the importance of understanding the evolutionary stage of leachate in planning appropriate treatment and post-treatment steps.

IV.3 Discussion of the BOD results :

Manipulation01 :

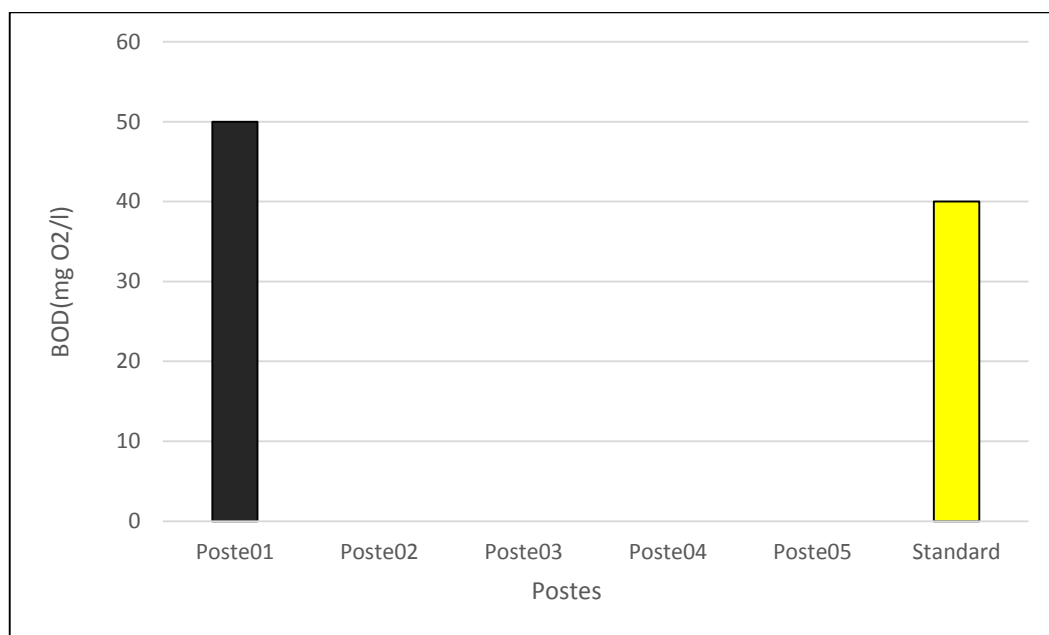


Figure 20 BOD level, Manipulation1

Manipulation02 :

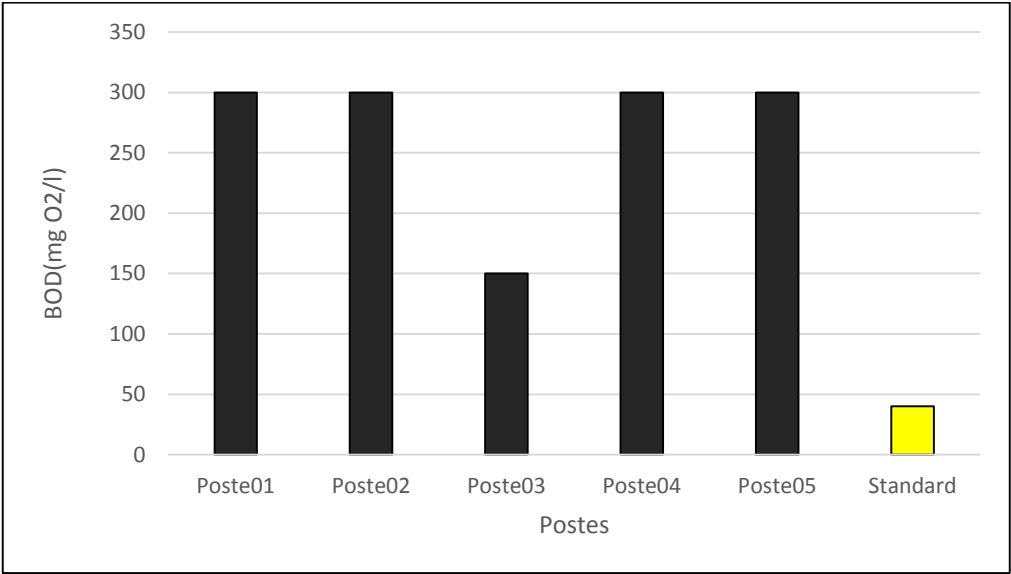


Figure 21 BOD level, Manipulation2

Manipulation03:

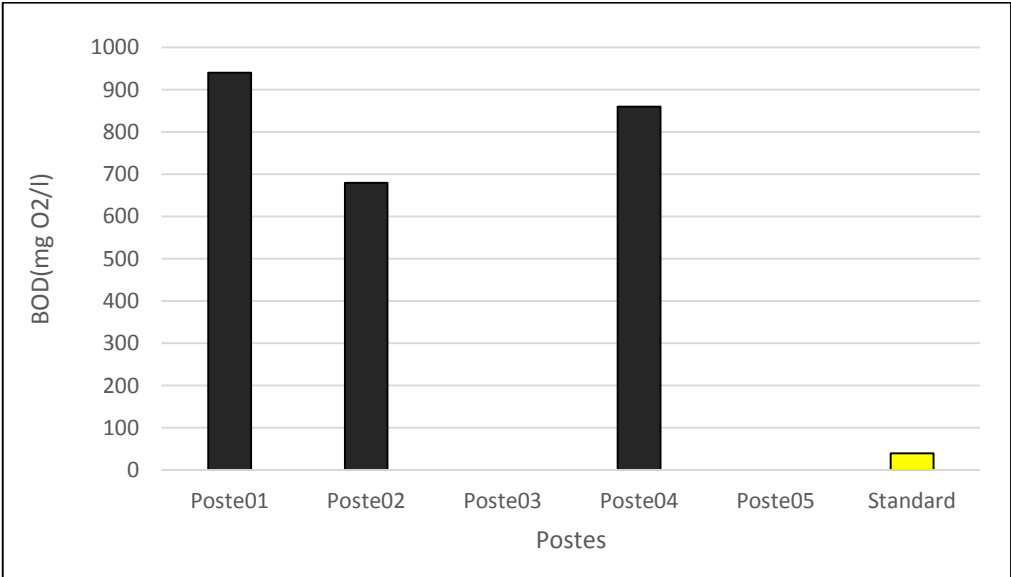


Figure 22 BOD level, Manipulation3

Manipulation04:

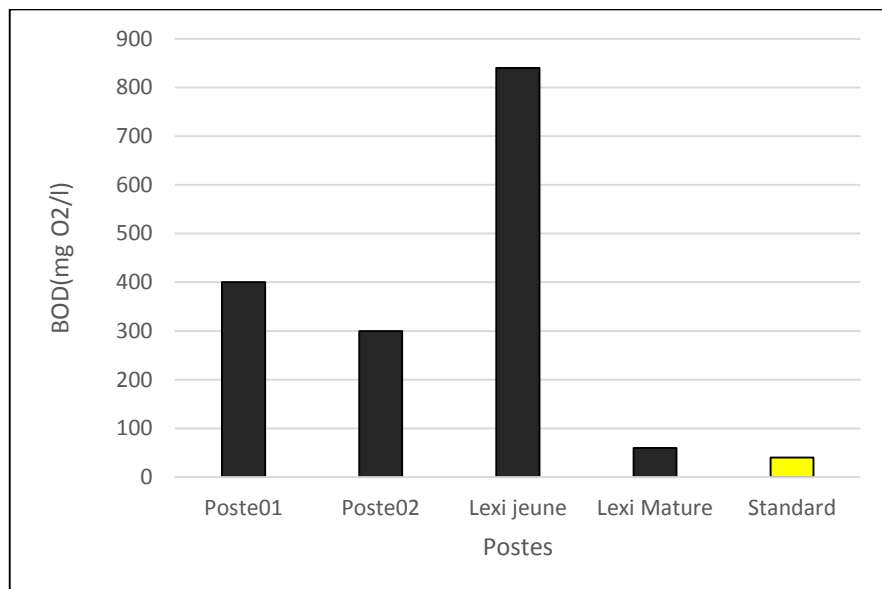


Figure 23 BOD level, Manipulation4

The Biochemical Oxygen Demand (BOD_1) values measured after treatment ranged from 150 mg O_2 /L to 940 mg O_2 /L, significantly exceeding the standard discharge limit of 40 mg O_2 /L for most manipulations. These results indicate that, in general, the electrocoagulation process alone did not effectively reduce the biodegradable organic load of the leachate to meet regulatory requirements. This can be attributed to the complex and variable composition of the raw leachate, especially in its mature form, which is often dominated by refractory organic compounds that are difficult to remove by coagulation processes.

The only exception to this trend was observed in Manipulation 01 (Poste01), where the BOD_5 value was exactly 50 mg O_2 /L, meeting the accepted standard. This notable difference is primarily due to the nature of the leachate used in this test: a mature raw leachate aged approximately five years. Mature leachates, which have undergone extensive anaerobic degradation over time, tend to have lower concentrations of biodegradable organic matter. Over several years, easily degradable compounds are broken down, and only refractory or slowly biodegradable substances remain. As a

result, the initial BOD load of such mature leachates is often lower than that of fresh or younger leachates, which explains the reduced BOD in this particular manipulation.

This outcome underscores the importance of leachate age and composition in determining treatment efficiency. While electrocoagulation showed limited ability to reduce BOD in more recent or less stabilized leachates, the naturally low BOD in mature leachate samples made the process appear more effective in Manipulation 01. However, it is important to note that this result does not necessarily reflect a higher treatment efficiency, but rather a lower initial pollution load.

In conclusion, the high BOD values in most tests highlight the limitations of electrocoagulation as a standalone method for reducing biodegradable organic matter in leachate, particularly in its early stages of formation. Conversely, the low BOD observed in the manipulation using mature leachate emphasizes how the natural aging of landfill leachate can influence both the starting composition and the apparent effectiveness of treatment processes. These findings suggest that tailoring treatment approaches to leachate age is essential for optimizing performance and ensuring regulatory

IV.4 Discussion of the COD results :

Manipulation01 :

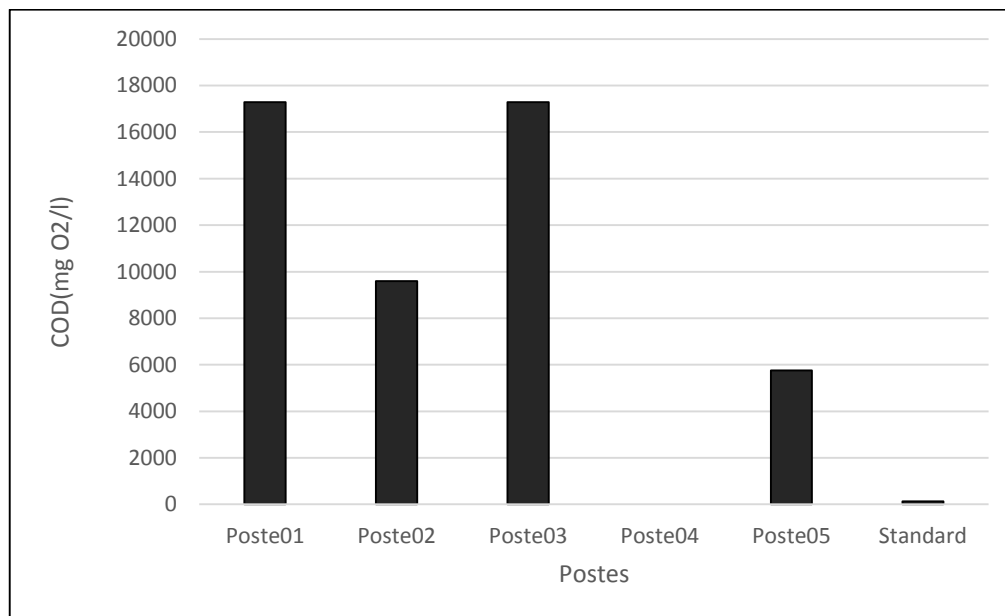


Figure 24 COD levels Manipulation1

Manipulation02:

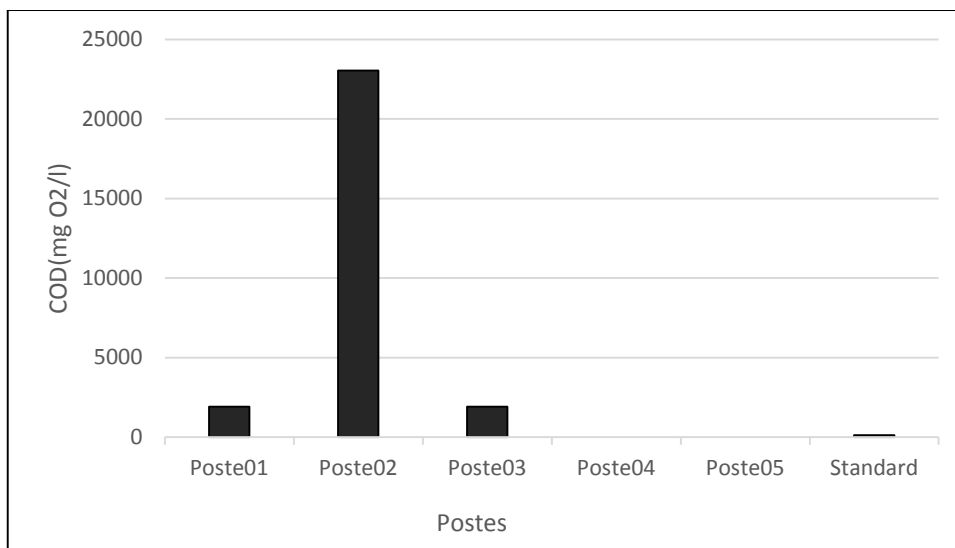


Figure 25 COD levels Manipulation2

Manipulation03:

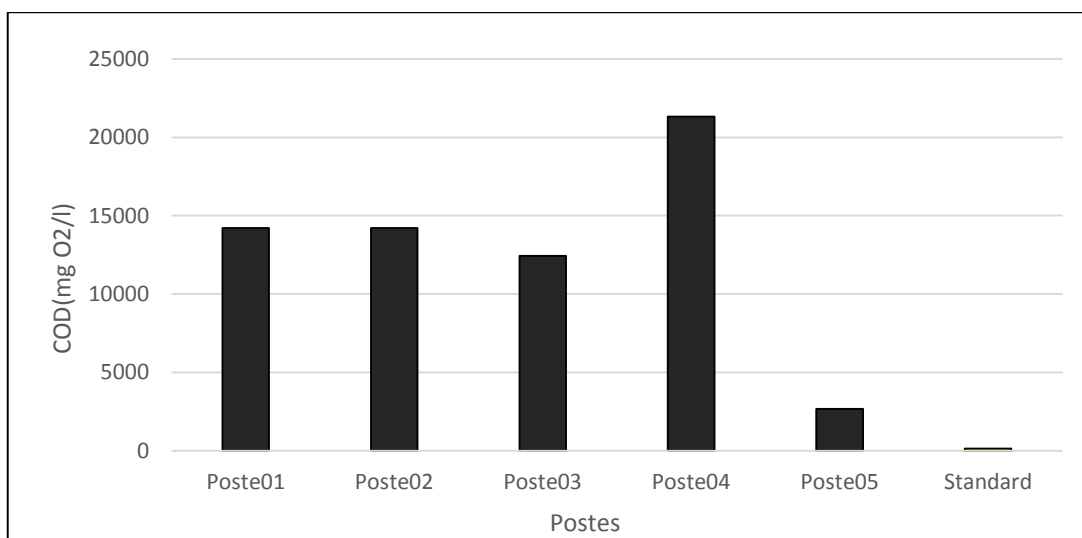


Figure 26 COD levels Manipulation3

Manipulation04:

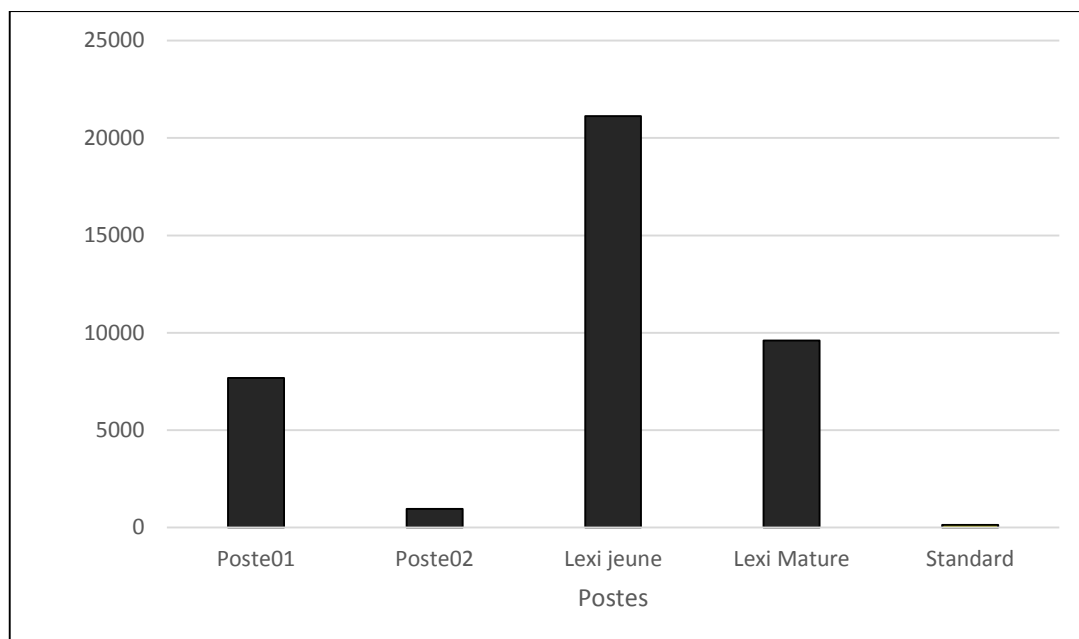


Figure 27 COD levels Manipulation4

The Chemical Oxygen Demand (COD) values obtained after treatment through electrocoagulation showed exceptionally high levels, ranging from 960 mg O₂ /L to 21120 mg O₂ /L, significantly exceeding the regulatory discharge standard of approximately 150 mg O₂ /L. These results reflect the extremely high organic and oxidizable pollutant load present in the leachate, particularly in its more recent or immature stages.

COD is a critical parameter as it represents not only biodegradable but also non-biodegradable (refractory) organic matter, which is especially prevalent in landfill leachate due to the complex and variable nature of its composition. The majority of the tested samples remained far from regulatory compliance, indicating that the electrocoagulation process as applied in those conditions had limited impact on reducing total organic content. This inefficiency can be attributed to several factors:

The high initial pollutant load overwhelmed the capacity of the generated coagulants to aggregate and remove organic matter effectively.

The electrode material, electrical conditions, or reaction time in these manipulations may not have been optimal for COD removal.

Leachate, particularly from municipal landfills, contains a wide range of persistent compounds (e.g., humic substances, fulvic acids, surfactants) that are resistant to physical-chemical treatments like electrocoagulation.

However, a relatively better performance was observed in Manipulation 04, specifically at Poste02 and Poste03, where COD values dropped to 960 mg O₂ /L. While still far above the regulatory threshold, this level is significantly lower than in other manipulations, some of which exceeded 20,000 mg O₂ /L. The key distinguishing factor in Manipulation 04 was the use of graphite electrodes.

Graphite, as a non-metallic and inert electrode material, may offer certain advantages in terms of stability, reduced passivation, and enhanced surface interactions. While graphite does not release coagulant metal ions like aluminum or iron, it can promote electrochemical oxidation reactions, contributing to partial degradation or breakdown of complex organic molecules, especially when combined with the formation of oxidizing agents like hydrogen peroxide or hydroxyl radicals at the anode surface.

Although the COD values in Manipulation 04 still do not meet the standards, the notable reduction compared to other tests suggests that graphite electrodes may offer a complementary oxidation mechanism to support pollutant breakdown, particularly in systems with high organic loads. These findings suggest that electrode material plays a critical role in electrocoagulation performance, and that hybrid approaches combining coagulation and electrooxidation might be more effective for treating complex leachates.

IV.5 Discussion of the TDS results:

Manipulation01:

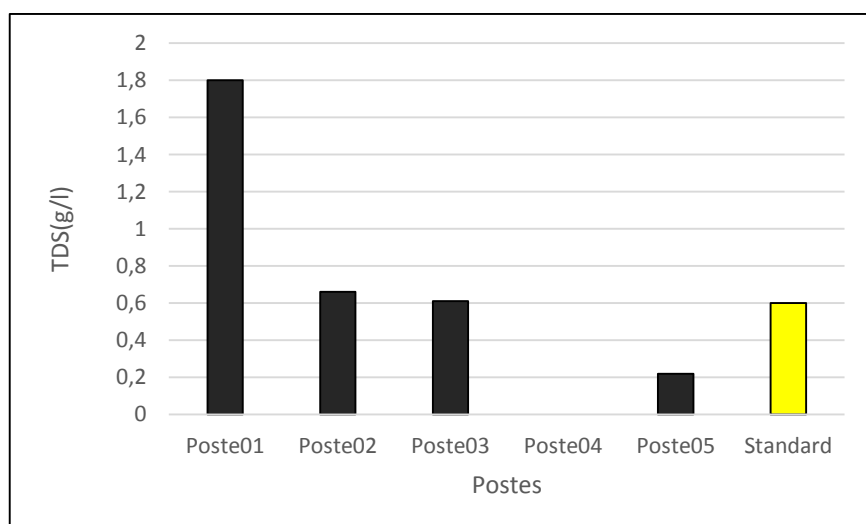


Figure 28 TDS values Manipulation1

Manipulation02:

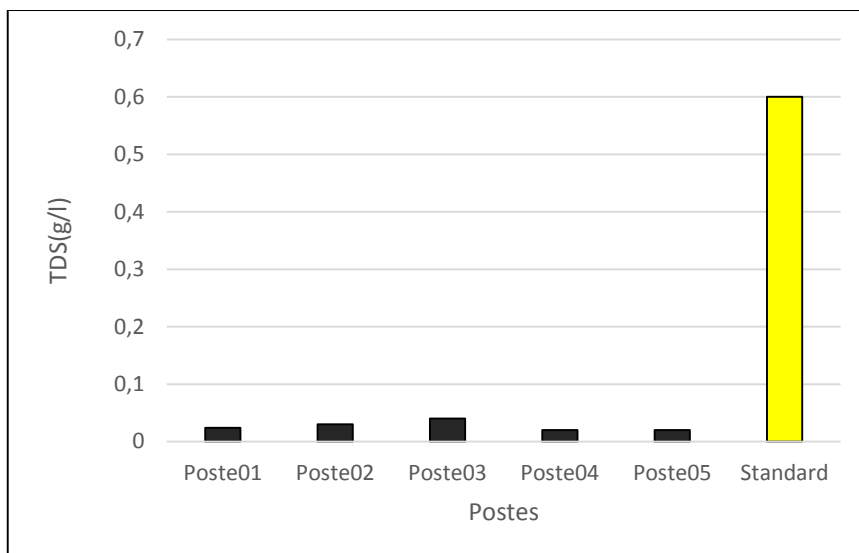


Figure 29 TDS Values Manipulation2

Manipulation03:

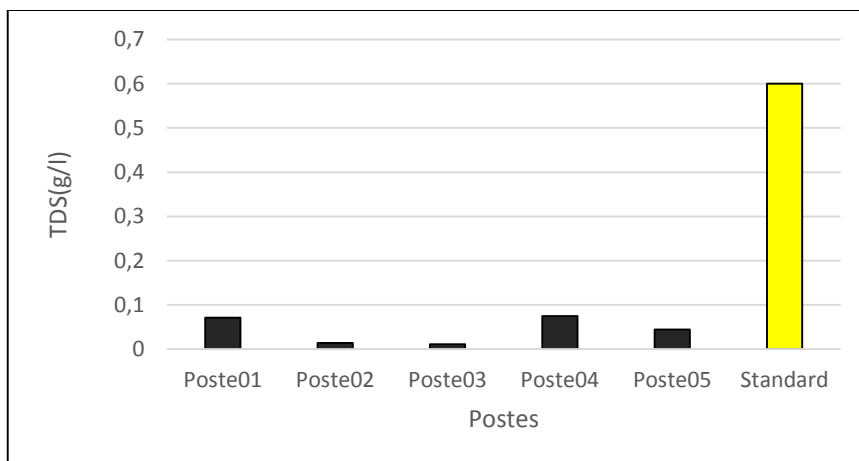


Figure 30 TDS Values Manipulation3

Manipulation04:

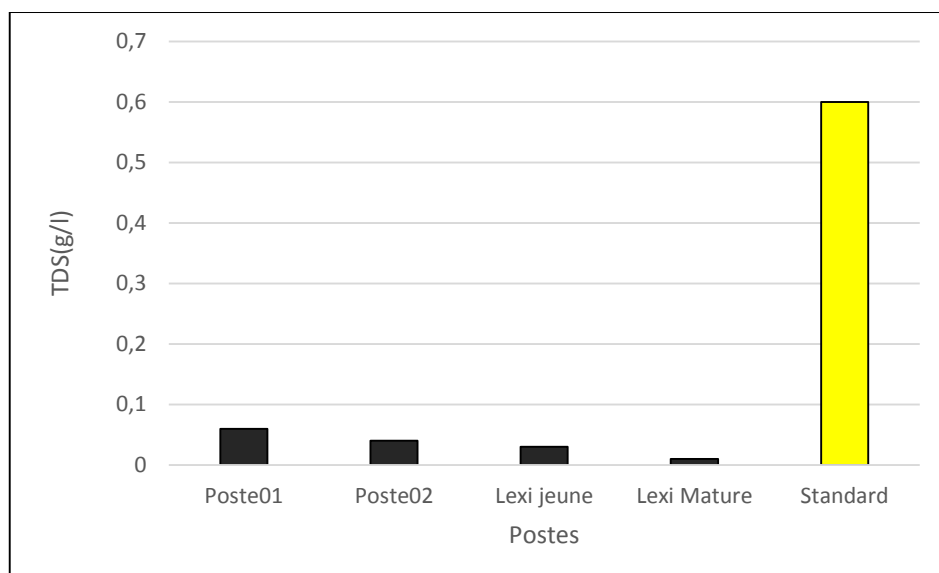


Figure 31 TDS Values Manipulation4

The Total Dissolved Solids (TDS) values measured across the various electrocoagulation manipulations ranged from 0.01 to 0.6 g/L, which falls within or below the commonly accepted standard limit of 0.6 g/L for treated wastewater. These values were measured after centrifugation, ensuring that only dissolved substances (not suspended particles or flocs) were considered. This step adds precision to the results, confirming that the electrocoagulation process, in most cases, did not contribute significantly to the solubilization of additional materials.

However, a notable outlier was observed in Manipulation 01, where the TDS reached 1.8 g/L, significantly exceeding the standard. This spike in dissolved solids is directly linked to the electrode material used during the experiment — metal rectangles cut from tomato cans. These makeshift electrodes were visibly degraded during electrocoagulation, releasing metal ions and other soluble materials into the water, which remained in solution even after centrifugation. This behavior confirms that the electrochemical corrosion of the cans contributed to an elevated TDS in the treated effluent. Tomato cans, commonly made of tin-plated or coated steel, are not designed for electrochemical durability. When used as electrodes, these materials corrode rapidly under current, leaching elements such as iron, tin, or coating residues into the leachate. The resulting increase in dissolved inorganic content raises the TDS and potentially introduces undesirable ions into the effluent.

By contrast, the other manipulations — which used more suitable and stable electrodes such as iron, aluminum, or graphite — showed TDS values between 0.01 and 0.6 g/L, well within the standard. These results suggest that when proper materials are used, electrocoagulation does not significantly increase the salinity or dissolved load of the treated water.

IV.6 Discussion of the density results :

Manipulation01:

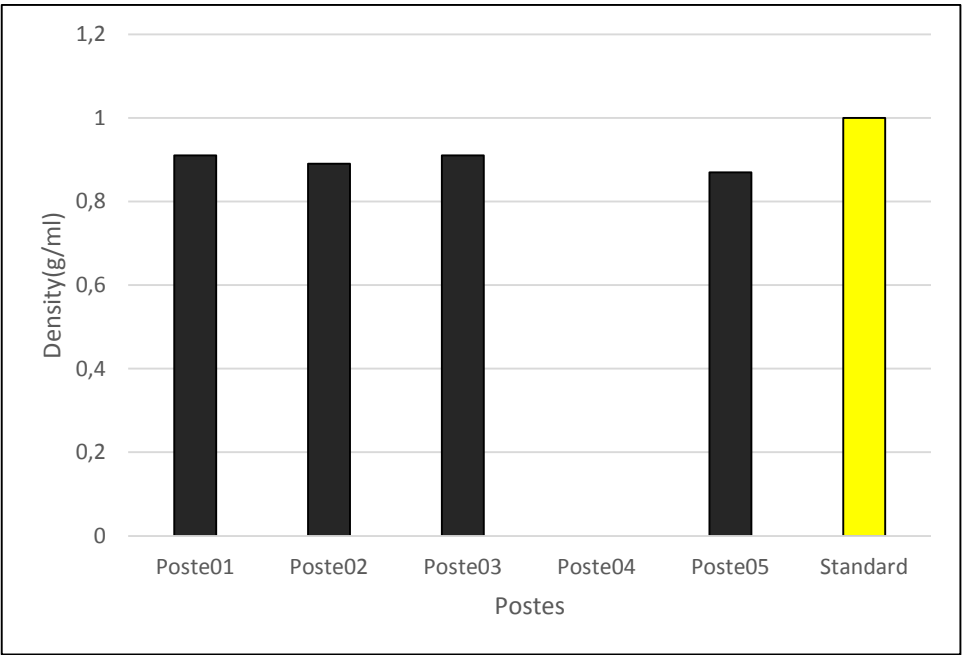


Figure 32 Density Values Manipulation1

Manipulation02:

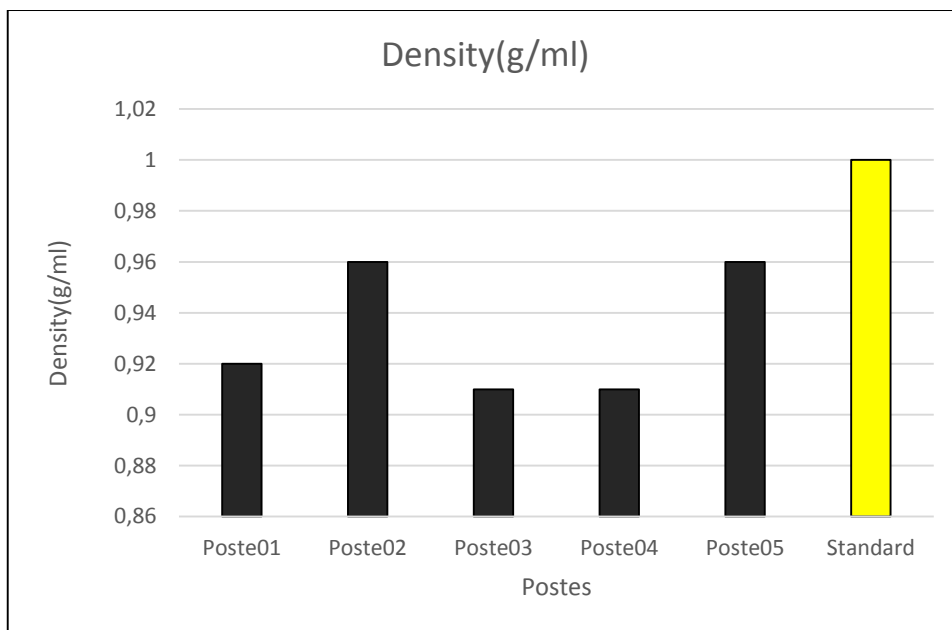


Figure 33 Density Values Manipulation2

Manipulation03:

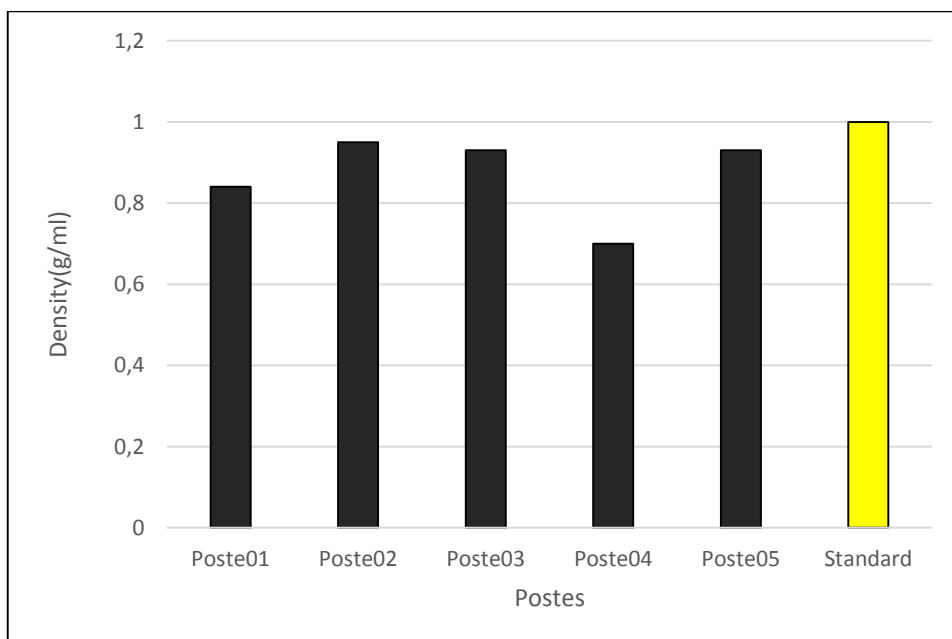


Figure 34 Density Values Manipulation3

Manipulation04:

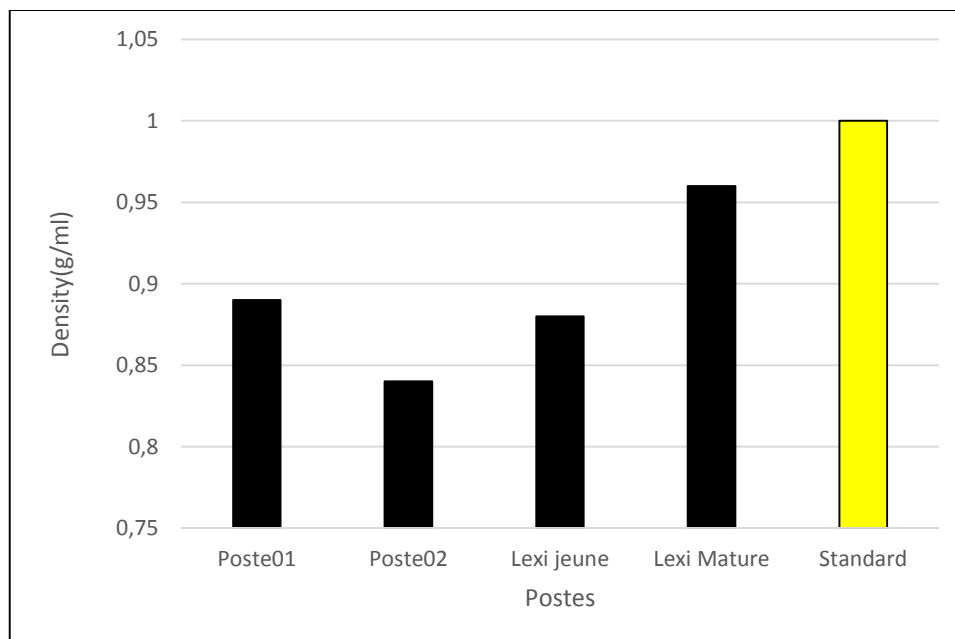


Figure 35 Density Values Manipulation4

The density of the treated leachate samples, measured after electrocoagulation, showed relatively minor variation, with values ranging between 0.8 and 0.9 g/cm³, compared to the standard reference value for clean water or compliant effluent, which is typically around 1 g/cm³. These values suggest that the treatment process did not significantly alter the bulk composition of the leachate in terms of its mass-to-volume ratio.

However, a more detailed observation reveals that Manipulation 2 consistently produced higher density values, with all corresponding posts exceeding 0.9 g/cm³. This is a noteworthy trend, especially when compared to other manipulations, and becomes more relevant considering that graphite electrodes were used in this particular test series.

Graphite, being a chemically inert and stable electrode material, does not corrode or dissolve into the treated solution. As a result, it avoids introducing metallic by-products or residues that might otherwise reduce or disrupt the fluid's uniformity. Instead, graphite's primary role may have been to enhance the coagulation-oxidation synergy in the system, possibly promoting the aggregation and removal of suspended matter more effectively, leading to a clearer, denser liquid phase with fewer entrapped gases or suspended solids.

By contrast, in manipulations using metal electrodes (such as iron, aluminum, or even tomato cans in Manipulation 01), corrosion and the formation of sludge or microbubbles during the electrochemical reactions could have led to lower bulk density, either by introducing suspended particles or by creating a more heterogeneous fluid with air pockets or less cohesive structure.

The relatively higher density values in Manipulation 2 may also suggest a better phase separation after treatment — where solids settled more efficiently and the liquid phase became more concentrated and homogeneous, thus increasing the measured density. Though all values remained under the theoretical maximum, the upward trend supports the hypothesis that graphite may help enhance post-treatment fluid quality.

GLOBAL CONCLUSION

The objective of this study was to evaluate the effectiveness of electrocoagulation as a treatment method for landfill leachate, by applying it under various operating conditions and analyzing key physico-chemical parameters. A series of manipulations were carried out using different types of leachate (new and mature), various electrode materials (including iron, aluminum, graphite, and recycled materials like tomato cans), and performance was assessed based on pH, BOD, COD, TDS, conductivity, and density.

The results demonstrated that electrocoagulation can significantly influence certain water quality parameters, but its efficiency varies strongly depending on the electrode material, leachate composition, and treatment conditions. While the pH remained relatively stable and slightly alkaline throughout all manipulations — largely influenced by the natural maturity of the leachate — parameters such as BOD and especially COD remained well above regulatory discharge limits in most cases. However, Manipulation 01 for BOD and Manipulation 02 for COD showed

comparatively better results, particularly when graphite electrodes were used, indicating the potential advantage of alternative electrode materials in enhancing treatment efficiency.

TDS values were generally within acceptable limits, except in the case of Manipulation 01, where the use of non-standard electrodes (tomato cans) resulted in excessive metal dissolution and a significant rise in dissolved solids. Similarly, density measurements showed only minor variations, but a slight improvement was noted in Manipulation 02, again suggesting that graphite may promote more stable and homogeneous treated effluents.

Overall, the study highlights that while electrocoagulation is a promising and adaptable technique, especially for complex effluents such as leachate, its effectiveness is highly dependent on the optimization of process parameters and the selection of suitable electrode materials. In its current form, the treatment process may require complementary or post-treatment steps, such as filtration or biological processes, to meet strict discharge standards — particularly for persistent pollutants like COD.

This work contributes to the growing body of knowledge on electrochemical wastewater treatment, offering insights into the behavior of different leachates and the critical influence of electrode materials, and serves as a foundation for future improvements and scale-up applications in landfill leachate management.

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