

Industrial Wastewater Treatment: Efficient Management and Reuse by means of Batch Recirculation Electrocoagulation

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Abstract—In the last few decades the exponential urban growth and the development of new technologies have been demanding more resources from the earth. The minerals extraction and the following production processes that are part of the elaboration chains have been contaminating the air with emission gases, as well as the soil and especially bodies of water with dangerous chemicals. In this paper, the water treatment processes are approached with the purpose of providing information about the different methods and solutions to treat wastewater effectively and efficiently. Therefore, an innovative treatment, the batch recirculation electrocoagulation (BRE) process, for certain kinds of wastewater which are difficult to clean, is presented and analyzed in terms of cost-effectiveness, efficiency, and efficacy. It is expected that this work might help other researchers to do their investigations by giving more information about the wastewater issue. Thus, there will be more contributions and further research about green alternatives to combat wastewater contamination consequences.

Keywords: wastewater treatment, water scarcity, contamination, electrocoagulation, energy efficiency.

Resumen— En las últimas décadas el exponencial crecimiento poblacional y el desarrollo de nuevas tecnologías han demandado más recursos del planeta. La extracción de minerales y los procesos de producción posteriores que son parte de las cadenas de elaboración han estado contaminando el aire mediante la emisión de gases, así como el suelo y especialmente masas de agua con químicos peligrosos. En este escrito, los tratamientos de agua son abordados con el propósito de proveer información acerca de los diferentes métodos y soluciones para tratar aguas residuales de manera efectiva y eficiente. Por consiguiente, un nuevo tratamiento de electrocoagulación con recirculación por lotes, que sirve para ciertos tipos de aguas residuales, las cuales son difíciles de tratar, es presentado y analizado en términos de costo-efectividad, eficiencia y eficacia. Se espera que este escrito sea de ayuda, a través de brindar información sobre aguas residuales para que otros investigadores puedan realizar sus respectivos trabajos. Así, habrá más contribuciones y más investigaciones sobre alternativas ecológicas para combatir las consecuencias de la contaminación de las aguas residuales.

Palabras clave: tratamiento de aguas residuales, escases de agua, electrocoagulación, eficiencia energética.

I. INTRODUCTION

In our current society, wastewater pollution from the industrial sector has tremendously increased in recent years and has posed severe environmental and health problems in

many countries worldwide. Each one of us needs clean water to sustain life and perform other daily activities, such as cooking, maintaining personal hygiene, or irrigating the garden. However, lack of effective water treatment and poor management of water sources caused by wastewater discharge to the environment without sufficient treatment has contributed to the high concentration of organic matter and hazardous compounds in the water.

Although industries are important for a country's economy, the consequences of pollution cannot be ignored. Clean water must be ensured as the United Nations states in its Sustainable Development Goals (SDGs), concretely in SDG #6 "Clean water and sanitation" [1]. Moreover, SDG #12 "Responsible consumption and production" [1] is closely related to this because the industry sector is the main pollution source, so it is important to reduce its toxic emissions [2, p. 5-12].

Despite their contamination, factories must continue with the production processes for economies to run properly, so the problem must be addressed without compromising these processes. Considering this, the engineering field can contribute to their sustainability by somehow managing some aspects of the manufacturing process. The answer is a correct wastewater treatment.

The best proposal is a system which works with an innovative technology: the Batch Recirculation Electrocoagulation (BRE) process. In a few words, this option is promising because it only implies electrical energy, less infrastructure and the water does not need pre or post treatment.

The purpose of this paper is to analyze different ways to recycle industrial wastewater and to discuss the BRE process in detail. In order to achieve this aim, firstly, the contamination types will be explained and differentiated, and its consequences will be mentioned. Secondly, the most common methods to treat water will be approached and the viability of each one will be analyzed. In the third place, a the BRE system, which utilizes new technology, will be discussed. Then, this system will be rated in terms of viability and efficiency. It is expected that this work might help other researchers to do their investigations by giving more information about the wastewater issue. Thus, there will be more contributions and further research about green alternatives to combat wastewater contamination consequences.

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II. CONTAMINATION PROBLEMS CAUSED BY WASTEWATER

The industrial sector is extremely related to water consumption. Most industries need clean water to complete their production processes, but they contaminate this water, which means that they also pollute the environment in many ways.

Each problem is very harmful, and the situation gets worse if many of these problems occur simultaneously. Such problems are mentioned below.

A. *Clean Water scarcity*

The problem with water contamination is that industries release the water used in the manufacturing process. Companies release water to bodies of water near the area to get rid of these black waters [3, p. 16]. These situations make the water no longer fresh, because releasing a small amount of wastewater contaminates large volumes of clean water.

B. *Harmful effects on aquatic life*

The aquatic life severely suffers because of water contamination. Most of the times, pollution makes the area uninhabitable for all kinds of aquatic living beings, which leads to other consequences [3, p. 15]. For example, if the people of the area earn money by fishing and selling it, this area is no longer good for this kind of activity.

C. *Release of harmful chemicals and components into the air and soil.*

Water contamination is connected to soil contamination and air pollution. Water is capable of going through the soil where the plants are, making them absorb toxic components present in the dirty water and resulting in dead flora. Moreover, air contamination occurs when black waters are abundant in little rivers or lakes, making them unlivable. In addition to that, wastewater brings bad smell or even the air becomes toxic [3, p.15-17].

III. CHARACTERISTICS OF THE INDUSTRIAL WASTEWATER

The production processes entail several contamination problems and each one contains its own characteristics. However, they can be summarized as follows.

A. *Physical characteristics*

1) *Water temperature*

Temperature is an important physical characteristic, which can modify the ecosystem depending on its value., but if the value is different from that, the ecosystem becomes more likely to suffer [4, p. 7] [5, p. 4]. When the average value changes around one or two degrees with respect to standard values, it can be significant.

2) *Total suspended solids (TSS)*

TSS can affect surface water quality. The measure of TSS can indicate the toxicity and physical effects on aquatic environments. High rates of TSS can affect the opacity of water and the light cannot cross to bottom of the water body [3, p. 9].

3) *Total dissolved solids (TDS)*

TDS is a measure of the dissolved content of organic and inorganic substances present in a body of water. If its value is high, it can affect the taste, the corrosion properties of water and the color of water. Also, TDS is measured in part per million (ppm) and it is an important aspect to analyze to confirm if the water is clean [4, p. 10].

B. *Biochemical characteristics*

1) *Biological oxygen demand (BOD)*

BOD refers to the quantity of dissolved oxygen that microorganisms use to degrade and mineralize organic matter in water under aerobic conditions. Microorganisms use this oxygen to degrade and mineralize organic matter in water under aerobic conditions [4, p. 10].

2) *Chemical oxygen demand (COD)*

COD is a measure of the oxygen present in the organic content. It is an assessment used to measure the degree of pollution from organic substances in water [4, p. 11].

3) *Ph*

It is a measure of the acidity and alkalinity of the water. The optimum Ph to ensure aquatic life is between 6.5 and 8.2. Therefore, a value out of these limits can severely affect aquatic life and the development of ecosystems [4, p. 6].

IV. ANALYSIS OF METHODS FOR WATER TREATMENT

Finding a suitable solution is not an easy task and there are many paths to follow according to the situation. Such task must be done analyzing many of the actual options.

There are many water treatment alternatives that are known globally. The most known methods include physical, biological, and chemical methods [4, p. 2-3].

A. *Physical methods*

The physical method includes the most common ways to treat wastewater [2, p. 2]. They can be summarized as follows.

- The adsorption process, which uses porous materials such as activated carbon, absorbs wastewater. The disadvantage is that there is risk of blocking the system.
- The electrolytic method consists of anodic oxidation and cathode reduction, and it is produced by applying voltage. It is mostly used for heavy metals present in the wastewater.
- The membrane separation process is a new treatment. It entails using a membrane to separate the impurities present in the water.
- Magnetic separation uses a magnetic field to attract the heavy metals present in the water. Although this treatment is rather inefficient, better results can be obtained by adding coagulants.

B. *Chemical methods*

Chemical methods are based on the principle of chemical reactions to make the water easy to treat. They include:

- The flocculation method, which is precipitation adding a coagulant because it is not easy to separate

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impurities by using the conventional physical method.

- The neutralization method means adjusting the pH value of the industrial water to make it less toxic.
- The redox method includes the combination of the ozone oxidation method, photocatalytic method, and dioxygen water method. All of them are meant to decompose organic and inorganic components in industrial wastewater.

C. *Biological methods*

Biological methods are the newest type of solution to this problematic issue. This method uses a plant method which is capable of cleaning water using plants or algae, microbial decomposition, and biofilm technology to correctly treat wastewater. It is effective to treat ammonia and it is low cost [2, p. 2-3]. However, the process needs a very controlled place to be done because it can be easily affected by external agents.

Once the different methods are explained, it is important to justify why they are not the best option. All the methods mentioned before are dependent on the environmental conditions or they have some restrictions [2, p. 5]. Also, they must be combined to obtain better results and large infrastructure is needed to apply these chemicals to concrete water cleaning processes. As well as this, a viable option should embrace sustainable development, which is not guaranteed by the previous methods.

V. INNOVATIVE WASTEWATER TREATMENT METHOD

The industrial sector needs to improve the efficiency of wastewater treatment to ensure sustainable development and reduce the pollution in the environment. In addition, it is essential to implement a system or treatment that can be implemented everywhere, being low cost and without the use of expensive chemicals.

For this reason, research into the latest systems to improve wastewater is needed. The best option seems to be a new system which has better results specifically for industrial wastewater.

The new solution to this problem consists in implementing an industrial wastewater treatment with almost zero waste. This solution is the batch recirculation electrocoagulation (BRE) process. However, before explaining the characteristics and operations of BRE, the foundation of the process, which is Electrocoagulation (EC), will be introduced. Considering that BRE represents an improvement and adaptation of EC, it is important to develop it. The next section is about this treatment, its advantages and why it is highly versatile.

A. *EC Background and beginning*

The EC treatment was implemented to clean wastewater a long time ago. Since its beginning there have been many improvements on energy consumption, treatment time, cost-effectiveness and eventually the design of portable systems. The main reason to choose EC treatment is its capacity to remove both organic and inorganic components present in industrial wastewater.

In a few words, there are many investigations that study different kinds of wastewater from a variety of industries. It

is important to give some examples in which its implementation results promising.

1) *Microplastics*

A very complete study was published in 2023 about the EC treatment on certain kinds of wastewater whose main components were microplastics. The authors designed their own EC system specifically to treat microplastics and analyze as many aspects as possible. In a few words, the results given are extremely promising in terms of future developments of the same technology. Even if their experiment was not large, the samples results speak for themselves because the removal efficiency results were above 80% in almost every of the microplastics degraded [6, p. 9].

2) *Pharmaceutical industry*

Another investigation was about wastewater from the pharmaceutical industry. The water from these industries contains incredible amounts of toxic and even carcinogenic substances. EC treatment for this kind of wastewater is one of the few methods that can be used in this case because regular or conventional methods do not work in this scenario. A study about one of the kinds of this wastewater exposed that the results are highly positive and almost achieve 90% of success in removal efficiency [7, p. 7].

3) *Textile effluents*

Since textile industry wastewater is associated with high salt content, pH, high temperature and often contains extremely toxic components, an effective treatment is needed with urgency. This situation was effectively solved by implementing an Electrocoagulation system which resulted in a highly removal efficiency which allowed the water to be reused in the textile processes.

B. *EC Efficiency: Operating parameters*

Although EC treatment is a promising solution to clean wastewater from different industries, the process needs to be controlled and depends on some initial values of the wastewater. However, all the treatments need to be monitored so considering the advantages it is not a big deal to configure the system to increase its performance.

1) *Initial values of pH*

The pH value present in a body of wastewater is going to change the effectiveness of the process. The interaction of both pH and current density is a determining factor for the Electrocoagulation treatment because different configurations result in better or worse outcomes. Those configurations fluctuate depending on the wastewater origin [8, p. 31].

2) *Treatment time*

Treatment time is a very important aspect of the process mainly because it has an impact on the production times and the effectiveness of the treatment. However, after certain amount of time, the process reaches its limit when the water is no longer cleanable. It is because of this, that the optimal time needs to be stated for each kind of wastewater according to the removal efficiency that is required. In addition, the treatment time mainly depends on the characteristics of the

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electrodes, kind of current (Alternating Current, Direct Current or Alternating Pulse Current) and energy consumption [8, p. 31].

3) *Temperature*

Even if temperature is not a main aspect, it is a well – known fact that higher temperatures enhance molecular mobility, which allows better results in the treatment process. However, there must be a limit value because it can hinder the effectiveness of the EC treatment by re-dissolving the flocs (of undesirable components) formed in the process [8, p. 31].

4) *Current density and energy consumption*

Both current density and energy consumption are crucial parameters of EC wastewater treatment. Current density is fundamental. Specifically, in the treatment time it can make a big difference but, as it was mentioned before, there is a limit where this parameter does not influence the EC’s efficiency. The reason is because if the current density rises, also increases the dissolving rate of the anode which speeds the pollutant sedimentation.

Energy consumption, on the other hand, also plays an important role. The economic aspect is extremely crucial for companies, and it is common sense that companies want to save sources and spend the least amount of money. Fortunately, the EC process does not need much energy to function, and it can even be powered with renewable energies such as solar energy or it can be wind powered [8, p. 31].

5) *Electrode’s material, shape and spacing*

Electrodes are capable of dramatically changing the removal efficiency of the process. The materials tested were Al, Cs, Fe Ag, As, Ba, Cr, Mg, Na, Si, Ca, Cd, Sr, and Zn but the Al and Fe electrodes are the most common materials because they are the most available and cost-effective. They can be combined in different ways for different kinds of wastewater [8, p. 30].

Spacing between electrodes, shown in Fig. 1, is a parameter that depends on the conductivity of the effluent. This means that the electrodes do not need to be very close to each other if there is good conductivity. There is minimum and optimum distance, the more optimum spacing the more pollution removal efficiency [8, p. 30].

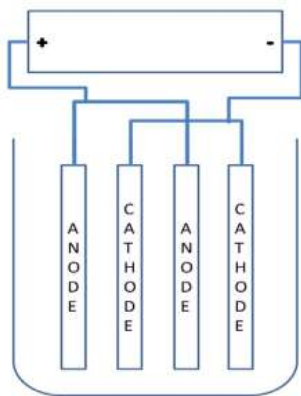


Fig. 1. Anodes and cathodes positioning [8]

C. *Batch Recirculation Electrocoagulation (BRE) as innovative technology*

The electrocoagulation process has been explained with its characteristics, parameters, and advantages in this work. Since an innovation is needed, it has been found that the Batch Recirculation Electrocoagulation (BRE) process is a method to treat industrial wastewater according to the requirements of each industry.

BRE is a treatment specifically for industrial effluents in a continuous manner. The importance of a continuous treatment is the need to not interfere with production processes and to be able to reutilize the same water repeatedly.

Given these needs, an investigation of Continuous Batch Recirculation Electrocoagulation (CBRE) was made [9, p.2]. Even though the research is specifically about distillery effluent, the same principles can be used for other effluents by modifying the parameters of the process.

The system is supplied with direct current to make the electrolysis work. It consists of a big batch filled with wastewater, two water reservoirs (one with wastewater and the other with treated water), control valves, a centrifugal pump to fill in the batch, and the anode and cathode which are made of aluminum or iron as shown in [9, Fig. 2].

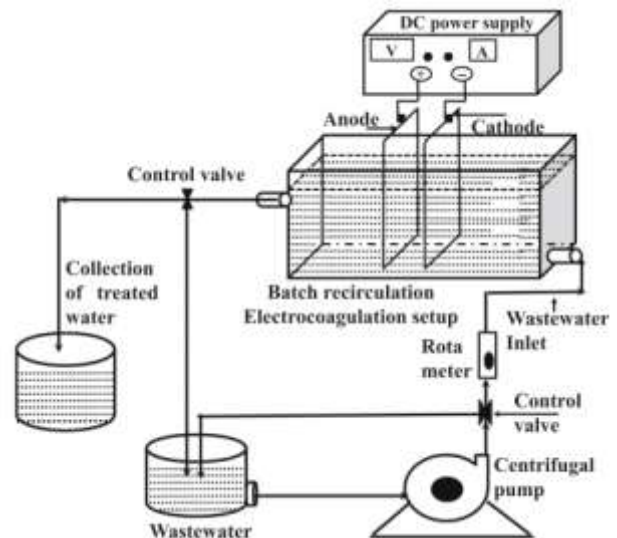


Fig. 2. Batch Recirculation Electrocoagulation [9]

One positive aspect of this system is the possibility of regulating the flow rate depending on the specific need in each case scenario.

Although this system is like a prototype and only distillery wastewater is treated, with changes in the parameters it becomes a very viable way to treat wastewater with low consumption of energy and high rates of pollutant removal efficiency. The researchers concluded their investigations emphasizing the reliability of the process, and the possibility of making it portable and affordable for almost every company on the market [9, p. 3-6].

In addition to this information, it is important to highlight some of the advantages and disadvantages involved in this solution [9, p. 5].

Firstly, there are three main advantages which are as follows:

1) *Cost-effectiveness*

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Electrocoagulation is a cost-effective method for treating industrial effluents. This is because it does not depend on the use of chemicals, which can be expensive.

2) *Efficiency*

Electrocoagulation has the potential to be efficient in removing pollutants from wastewater. This is because it generates coagulants that help separate solid particles from the liquid. Also, it does not use much energy and this energy can be provided by a renewable source.

3) *Green technology*

Electrocoagulation is a green technology that does not require the use of chemicals. This makes it an environmentally friendly option for wastewater treatment.

Secondly, there are main disadvantages as follows:

1) *Long operating time*

Electrocoagulation requires a long operating time. This is because the process involves recirculating a batch of wastewater through an electrocoagulation reactor, which can take time. However, the operating time depends on the level of cleaning required.

2) *Limited applicability*

Electrocoagulation is not capable of removing some toxic elements. This means that it may not be suitable for treating wastewater that contains certain types of pollutants.

3) *Developing method*

BRE needs further research in each case, for each kind of wastewater. The professionals in charge must be willing to carefully study the situation to plan a very competitive solution [9, p. 5-6].

VI. VIABILITY

Although the batch recirculation electrocoagulation process is presented as a promising solution to effectively treat wastewater from all kinds of industries, it needs further research to become one of the best solutions. One aspect to improve is the water flow rate because the removal efficiency depends on it. Moreover, another aspect is the improvement of energy efficiency, which means reducing the amount of electricity needed to make the system works. Given these improvable aspects, by solving them will help to be an appreciated solution between the companies that release wastewater with heavy metals and hazardous chemicals.

VII. CONCLUSION

The importance of water as a crucial resource for social development, stability, and sustainable development cannot be overstated. With the constant publication and discussion of options, solutions, projects, and proposals worldwide, the focus remains on addressing clean water scarcity, particularly magnified by industrial activities. While various methods and treatments are being explored, it is evident that not all are sustainable for cleaning wastewater, necessitating the need for sustainable pathways to achieve the 2030 Sustainable Development Goals (SDGs).

The Batch Recirculation Electrocoagulation (BRE) process has emerged as a promising method for treating industrial effluents. Studies on operating parameters have shown that the BRE process can be effective and cost-efficient for industrial wastewater treatment.

Furthermore, the electrocoagulation technique, in general, is recognized for its ease of operation, eco-friendly nature,

and broad applications in treating drinking water and various industrial wastewater. However, it is important to note that the process has both advantages and disadvantages, as highlighted in a comprehensive review on the green perspectives of electrocoagulation.

Advantages of the BRE process include its cost-effectiveness, efficiency in removing pollutants, and being a green technology that reduces waste production. On the other hand, its long operating time, large surface treatment area requirement, and limited removal of certain toxic elements, limited applicability are notable disadvantages.

In conclusion, while the BRE process holds promise for industrial wastewater treatment, further research and optimization of operating parameters, modeling approaches, and feasibility assessments are crucial to enhance its viability for various applications. Sustainable pathways are imperative to address the challenge of clean water scarcity and achieve the 2030 SDGs. As such, continued efforts to improve the sustainability and effectiveness of wastewater treatment methods, including electrocoagulation processes, are essential for global water resource management and environmental sustainability.

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