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Electroflocculation System Based on Power Electronics that Contributes to the Treatment of Contaminated Water

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Abstract

The article presents the research results of the application of an electroflocculation prototype built from an electronic power system to treat contaminated water. The purpose of the research was to determine the contribution to water purification made by the electrocoagulation prototype. The variables to be evaluated were turbity, pH, electrical conductivity and total dissolved solids. The microbiological variables assessed were aerobic microorganisms, faecal coliforms and total coliforms. The results obtained were for turbidity level less than 5 NTU, TDS 1200 ppm, 8.2 pH, less than 2 mV. Microbiological variables were less than 2 cfu for coliforms and less than 30 for aerobic microorganisms. Finally, it is concluded that the implemented prototype contributes 90% to the water purification process.

Keywords: Electrocoagulation, electrodes, sedimentation, flotation, power electronics, water purification. Turbidity, electronic instrumentation.

INTRODUCTION

There are four types of technologies for the treatment of contaminated water. Physical, biological, chemical and combined treatment technologies. [1][2][3]

Physical treatments are mainly used for the treatment of water with the presence of dyes or pigments, these treatments are made especially by absorption methods, filtration systems or ion exchange resins[4]. The absorbent materials with the highest percentage of color removal are low cost agro-industrial residues such as oil palms, shavings, sawdust, bamboo, algae, pine leaves, canola stems and chitosan. Among the minerals are lignite, magnetite, activated carbon, bentonite, among others. The absorption process can normally be affected by environmental conditions such as pH and temperature, molecular characteristics of dyes and contact time [5][6].

With respect to chemical processes for water treatment, techniques such as ozone, fenton, ultrasound, photocalasis or ultraviolet, conventional oxidants such as hydrogen peroxide, coagulation-flotation and electrocoagulation processes, among others, are used [7]. In chemical treatments there are technologies that can be almost 100% effective in removing color such as photocatalysis technology and the treatment of fenton/UV, and in ozone processes may be that the acidic conditions of the medium help to promote the removal of color but as presented in the technology of absorption of physical treatments the nature of dyes affect the optimal operation of this technology [8]. Another technology is the photocatalytic processes which are analogous to those of fenton/UV, these two technologies use titanium dioxide ($TiO2$) as a catalyst because it is possible to remove color between 90 and 100% in periods of almost 120 minutes [9][10].

Biological treatments are based on the use of substances to accelerate the metabolism of microorganisms which will be responsible for assimilating the substances in the water to be treated. Among the substances that optimize the metabolism, carbon sources or secondary energies can be found [11].

Biological treatments that are applied to water effluents with dyes or pigments can be defined as anaerobic and aerobic treatments. Anaerobic treatments reach 80 to 100% removal in 2 to 58 days. Aerobics are characterized by the use of fungi and activated sludge systems. Combination treatments are no more than the result of the combination of the other 3 technologies (physical, chemical and biological). The main combined technologies are the ozonation -UV/$H2O2$ sequence which gave results between 80% and 100% in dye extraction in 5 to 15 minute times[11].

The coagulation-absorption technology which uses coal and alum removes almost all the color present in the water[12]. Another combined technology is the Ozonation-ultrasound technology that features 98% color removal in less than 1 minute. When choosing a technology, it is important to find out which water treatment system is best suited to the buyer's economic conditions and in which conditions the water to be purified is to be found[13].

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During the electrocoagulation process, 3 chemical processes are presented, which are responsible for clarifying the water. These processes consist of energization of the electrodes, destabilization of the contaminating particles and flocculation [14].

The electrodes are installed in pairs. One is the anode and the other is the cathode. When electricity flows through them, an electrochemical reaction occurs between the metal plates and the compounds in the water.

This generates a reduction process in the cathode which consists of converting the water protons into hydrogen, and the oxidation process in the anode which in turn produces metal ions and oxygen which comes from the hydrolysis of the water. When this occurs, hydrophobic components are formed in the contaminating elements, which cause them to begin to float and thus make it easy to remove. On the other hand, sedimentation also occurs, which consists in the fact that once the union of destabilized particles occurs (due to the difference in potential that exists in the electrodes) they are denser than water, causing an effect of gravity that causes them to descend to the bottom of the electrocoagulation cell.

METHODOLOGY

An electrocoagulation-flotation tank is a thermoplastic vessel which consists of electrodes which are interspersed and covered with the water to be treated, in addition the vessel must have an energy source that must be responsible for inducing the electrical current necessary for the process.[15]

Electrocoagulation cells have more than one pair of plates as electrodes. The most common metals used are iron, aluminum, copper, steel and magnesium. Recent applications have shown that good results can also be achieved from metal alloys. In the work carried out, aluminium electrodes were used.

When designing the electrodes, the distance of the plates, the size of the electrodes, the material of the electrodes, the voltage and the intensity of the electrical current of the source must be taken into account.

The separation between the electrodes is important in the construction of the electrocoagulator system as a separation of less than 10 mm can cause delays in water treatment, in addition to mud clogging on the surfaces of the electrodes. Therefore, the recommended electrode gap is 10mm. Other experiments suggest that water treatment depends on the distance of the electrodes, the increase in current density and the time it takes to keep it running, the first 15 minutes being the most effective[9].

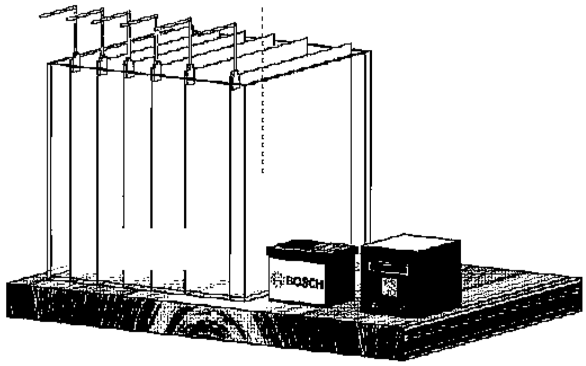

Figure 1. Design of the electroflocculation system

It should be noted that the electrocoagulation cell will be divided into 3 zones. The waterline area, sedimentation area and the area where the electrochemical reactions will occur[15].

Figure 2. Implementation of electrofloculaccion system

In order to obtain concrete results in the investigation, samples of different effluents were taken, so the influence of different variables on electroflocculation was observed. Due to the different characteristics of the effluents, the conductivity of all treated effluents was adjusted at the beginning of each test. A conductivity of 1 mS/cm was established as the standard value. This allowed obtaining the characteristic curves for an electroflocculation process with an effluent of high organic matter content and conductivity adjusted to 1 mS/cm.

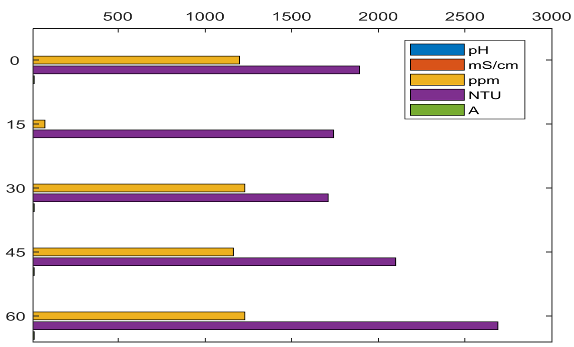

Figure 3. Physical-chemical variable characteristics of the water under study

Different types of tests were carried out, for which two functional reactors were manufactured, one for testing and the other with a higher volumetric capacity. In the test reactor the process behaviour with different plate separations, the influence of conductivity, monopolar and bipolar configurations were observed. Data was captured every 15 minutes. The values of the physicochemical variables, pH, turbidity, conductivity and total dissolved solids in ppm.

Finally, the electronic power system implemented allowed the monitoring of the physical-chemical variables altered by the electrocoagulator by means of virtual instrumentation techniques [16][17][18][19].

RESULTS AND DISCUSSION

The characteristic curves obtained were for an effluent with a conductivity of 1 mS/cm, a volume of 30 litres and a high organic matter content. Figure 5 shows a sample of the inlet water and the treated outlet water.

Figure 4. Inlet water without treatment and outlet water treated by electrostatic flocculation

Turbidity: An effluent with a dark water color is a simple indicator that it is highly contaminated. Not only is it a matter of aesthetics, according to the World Health Organization (WHO) in its manual for the treatment of drinking water, high turbidity can protect microorganisms from the effects of disinfection, generate significant demand in the disinfection process and the proliferation of bacteria.

For a period of 60 minutes, the reactor was able to reduce the turbidity rate from 25NTU to 2 NTU, making it suitable for drinking water, which should be less than 5NTU. Figure x shows the behaviour of turbidity in contaminated water treated by electroflocculation.

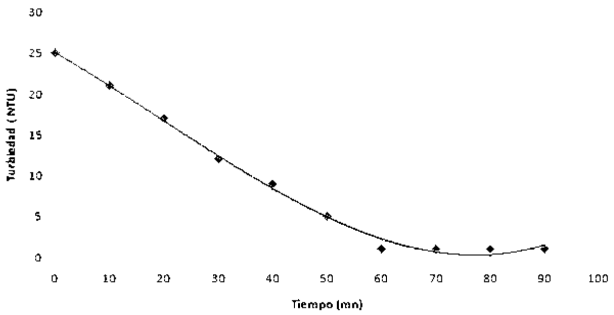

Figure 5. Trubidity of the water under study

Total Dissolved Solids (ppm): is the unit used to measure the amount of particulate matter in a particular solution, in this case the different types of effluents used for testing.

In the case of an effluent without the addition of electrolyte (NaCl), the proportion of ppm decreased throughout the process. When NaCl was added to the effluent it increased the ppm throughout the process and a decrease at the end again. This is due to an incorrect dissolution of the electrolyte at the initial moment and the electrolyte being dissolved during the process. The appearance of floccules also favoured the increase in ppm.

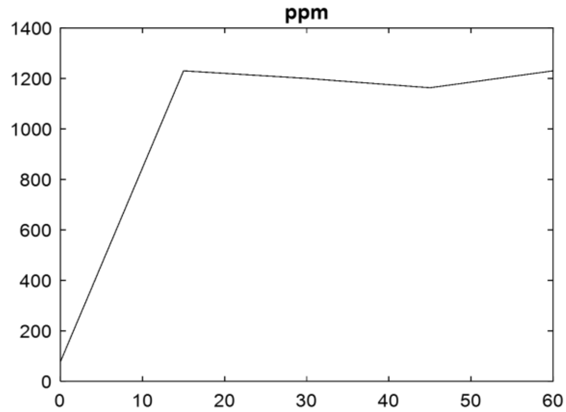

Figure 6. Total solution dissolved in ppm

Figure 10 shows an initial value of 30 ppm, at 15 minutes it rises to 1200 ppm, these changes are due to the addition of NaCl electrolyte, ppm measures the proportion of nutrients and salts in a quantity of water.

pH: Studies do not show the incidence of electrocoagulation on the pH of water because the pH changes as the process progresses. The pH at the end of the process is very different from the pH of the initial effluent, as can be seen in Figure 11, where the pH changed from 8.1 to 8.7 and ended after the 60 minute treatment at 8.2. However, it can be said that pH does not have a significant effect like current density on the efficiency of the electrocoagulation process.

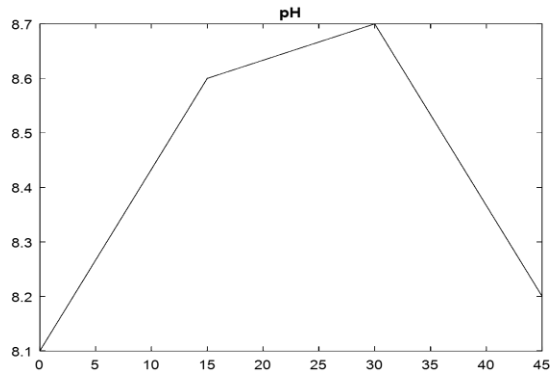

Figure 7. pH behaviour in the treatment process

Conductivity: Electrical conductivity is directly proportional to current density. Therefore the current density increases the efficiency of the electrocoagulation. Thus, the levels of electrical conductivity in the effluent must be controlled. Many effluents have a very low conductivity of less than 0.5 mS/cm, this takes a process up to 5 times longer to be treated than one with a previously adjusted conductivity. The effects of having a low conductivity are not only noticeable in the short term, high stationary periods of the effluents inside the reactors favor the passivation of the electrodes causing the processes to be slower and slower. The conductivity levels of an effluent can be manipulated before the process by adding some substance, the most commonly used being NaCl. An adequate level of conductivity is between 1.0 mS/cm and 1.5 mS/cm.

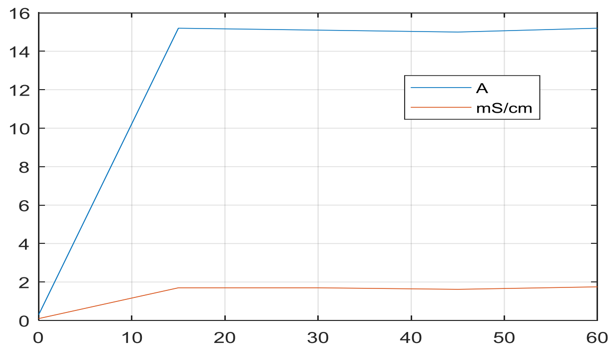

Figure 8. Behaviour of the electrical conductivity in the electroflocculation process

The amount of salts dissolved in the fluid increases the conductivity of the sample, which is why Figure 12 shows a slight increase in conductivity between 10 and 20 minutes.

Separation of the plates: In our research, the separation of the electrodes directly affected the current density applied to the treated effluent. The greater the distance between the electrodes, the smaller the number of plates.

Even if an attempt is made to compensate for the conductivity of the effluent to be treated, with a greater separation of the electrodes the current density is not adequate and current density is one of the most important variables in terms of process efficiency.

Reduction of time and costs: To counteract passivation in the electrodes, the time the effluent remained in the reactor was reduced. This was achieved by increasing the conductivity value, with higher conductivity the current density is increased and the much faster release of oxygen and nitrogen molecules from the electrodes, these molecules are grouped together forming bubbles that seek the surface favouring the mixing of the effluent.

It can then be concluded that an improvement in conductivity not only results in maintenance costs, but also in increased process efficiency.

Removal of total coliforms, faecal coliforms and aerobic microorganisms: The absence of coliforms is taken as an important parameter when talking about drinking water, the appropriate values for water that is totally drinkable and suitable for consumption are 0/100 ml, however, for domestic use, values of less than 2/100 ml are accepted for both total and faecal coliforms and a value of less than 30 cfu/ml for aerobic microorganisms. Table 1 show that the water entering the electrocoagulator was 4800ufc/ml for aerobic microorganisms, 1100ufc for total coliforms and 1100ufc for fecal coliforms.

Table 1. Initial values of aerobic, total coliform and faecal microorganisms.

RTO de microorganismos aeróbicos.	48000 ufc/ml	V/R < 30 ufc/ml
RTO de coliformes totales	1100/100ml	VR < 2/100 ml
RTO de coliformes fecales	1100/100 ml	VR < 2/100 ml

Table 2 shows a decrease to less than 30ufc for aerobic microorganisms, 23ufc for total coliforms and less than 2 for fecal coliforms. This indicates that the electroflocculator implemented contributes to water purification

Table 2. Initial values of aerobic, total coliform and faecal microorganisms.

RTO de microorganismos aeróbicos.	< 30 ufc/ml	V/R < 30 ufc/ml
RTO de coliformes totales	23/100ml	VR < 2/100 ml
RTO de coliformes fecales	< 2/100 ml	VR < 2/100 ml

CONCLUSIONS

The power electronics for the electroflocculation action allowed the level of the physical variable turbidity to be reduced from 25 NTU to 2NTU. This indicates that the implemented reactor contributes to the purification of water analyzed from the turbidity variable, which must be less than 5 NTU for the water to be suitable for human consumption.

For the pH, electrical conductivity and TDS variables, they were not affected by the electroflocculation process. Therefore, with respect to the chemical variables, it is concluded that the electroflocculator does not contribute to the potabilization process.

Regarding the variables of aerobic microorganisms and total and fecal coliforms were positively affected. The changes were from 48000ufc to less than 30ufc for aerobic microorganisms, from 1100ufc to 23ufc for total coliforms and from 1100ufc to less than 2ufc for fecal coliforms. Therefore, the contribution of the electroflocculator implemented to water purification is 90%.

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