



A Study Of Electrocoagulation As An Alternative To Chemical Dosing In Raw Water Treatment

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Abstract: To examine the effectiveness of electrocoagulation treatment of water as a substitute for chemical coagulation in the treatment of fresh water, samples of raw water were collected from Opa dam of Obafemi Awolowo University, Ile-Ife and analyzed. The pH, turbidity, dissolved oxygen, average total solids and total dissolved solids of the samples were determined using standard methods. A batch process electrocoagulation reactor was constructed and used to determine the effects of varying the electrode spacing and current, with the turbidity removal, heavy metal concentration reduction and the current efficiency being a measure of the effectiveness of the electrocoagulation process in treating the water. The effect of varying time and surface area to volume (A: V) ratio on the current efficiency and turbidity removal efficiency was investigated. A jar test was conducted to compare the requirements (in terms of aluminium/alum dosage) and effectiveness of treatment by electrocoagulation with treatment by chemical coagulation. The TSS, pH and turbidity removal efficiency were used in this comparison. A continuous process electrocoagulation reactor was then designed by adding a pre-treatment storage and sedimentation units. The turbidity removal efficiency and the dosage was determined and compared with that obtained from chemical coagulation. The results obtained show that electrocoagulation is a viable alternative to chemical coagulation in the treatment of water at Opa dam. The treatment was most effective at a current of 2.5 A and an electrode spacing of 2.0 cm, and an electrocoagulation-flocculation period of 5 minutes followed by 30 minutes of sedimentation. The turbidity removal efficiency averaged 90%, as compared to the 75% obtained from chemical coagulation. Also, electrocoagulation resulted in a decrease in BOD without change in pH, while chemical coagulation resulted in a discernable increase in the acidity of the water samples.

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Introduction

Water is the most common liquid, without color, taste or smell which falls from the sky as rain into rivers, lakes, and seas, and is drunk by people and animals (Ghalwa, *et al.*, 2015). All sources of natural water have impurities (Goodwin and Douglas, 2012). To make water suitable for consumption, that is, either domestic or industrial use, it is imperative that the water go through some form of treatment so as to remove as much of the undesirable impurities found in the water as required. For domestic uses, treated water must be aesthetically acceptable, free from apparent turbidity, color, odour and objectionable taste (Hammer and Hammer, 2000).

Evidence of man's desire to improve on the quality of water is found in the earliest recordings of knowledge. This is illustrated by a quotation from a body of medical lore in Sanskrit said to date from 2000 B.C: "Impure water should be purified by being boiled over a fire, or being heated in the sun, or by dipping a heated iron into it, or may be purified by

filtration through sand coarse gravel and then allowed to cool" (Garg and Prasad, 2017).

The future of water treatment according to Garg and Prasad (2017) was viewed as relative static undertaking, but few years later, organic chemicals suspected of being carcinogens were found in drinking water. Events such as these have caused water professionals to undertake a thorough re-evaluation of water treatment practices (Holt, 2002; Zhao and Pan, 2013). Over the years coagulation and flocculation have been the traditional methods for the treatment of polluted water.

Water is a very important factor in the development of any community, and the availability and supply of potable water has significant impact on the community. The ideal concept of pure water is but an ideal, and in reality, pure water is rarely, if ever found in nature; rather, water always contains impurities. For water to be declared fit for consumption, it must not contain more than the recommended maximum limits of impurities Lu et al.,

(2015). There are physical, chemical and bacteriological standards which water must adhere to before it can be regarded as potable water. The quality of water is ensured by processing the water through standard water treatment procedures. For municipal water supply, this usually involves the construction and use of a water treatment works. The main source of municipal water supply to the Obafemi Awolowo University community is the Opa Dam, located within the university. The dam was commissioned in 1976 to take care of the fast escalating water demand of the university community due to an increase in the population. Prior to this, the water need of the university was catered for by the Osun State Water Corporation in Ede. The construction of the waterworks at Opa Dam thus served to procure a more reliable and effective source of water supply to the Obafemi Awolowo University community.

The water treatment processes at the Opa waterworks include Aeration; Coagulation and Flocculation; Sedimentation; Filtration; Chlorination; Storage and Distribution. These processes involve the addition of chemicals such as lime and chlorine to the water to effect the proper treatment of the water, rendering it suitable for use and consumption.

Coagulation is a very important physiochemical operation used in water treatment. It is a process used to cause the destabilization and aggregation of smaller particles into larger particles so that they can settle and be removed out of solution, and can be achieved by chemical or electrical means (Zhang *et al.*, 2013). Chemical coagulation is becoming less acceptable today because of the higher costs associated with chemical treatments, that is, the costs of the chemicals required to effect coagulation, the large volumes of sludge generated, and the hazardous waste categorization of metal hydroxides (Yang *et al.*, 2018). Coagulation caused by electrolytically produced ions (electrocoagulation) followed by filtration has been studied as a possible alternative to the conventional coagulation process (Goodwin and Douglas, 2012). Subsequently, it has been discovered that electrocoagulation could be a cheaper and more efficient alternative to chemical coagulation, if the economics of material, labor and maintenance costs incurred are considered on the whole.

Electrocoagulation is a complex process with a multitude of mechanisms operating synergistically to remove pollutants from the water. A wide variety of opinions exist in the literature for key mechanisms and reactor configurations. A systematic, holistic approach is required to understand electrocoagulation and its controlling parameters. This will enable a *priori* prediction of the treatment of various pollutant types (Eryuruk *et al.*, 2019).

Materials And Method

The materials used in carrying out this study were raw water samples, distilled water and alum salt. Raw water samples for this experiment were collected in two distinct batches: During non-peak periods, when there was relatively infrequent rainfall, such that the turbidity of the water was expectedly low, and during peak periods, when the turbidity of the water was expectedly high. Collection of samples was from the inlet point of the aeration chamber in the water treatment plant at Opa dam. Some of the sample was collected into BOD bottles, for determination of the dissolved oxygen content at the point of sample collection.

Distilled water was used as a control to regulate the pH meter, conductivity meter and turbidimeter, as well as serve as a reference point in measuring the turbidity removal efficiency of the treatment process. It was also used as dilution water in preparation of the alum stock solution.

Alum salt was used to prepare a 1% alum stock solution which was used to carry out the Jar test by adding distilled water to 10g of grounded alum salt in a beaker until the one litre mark on the beaker was attained. The mixture was then stirred.

The Electrocoagulation Unit

The electrocoagulation unit was modelled and set up using the bipolar electrode arrangement as shown in Figure 1. The unit also facilitates the coagulation of the particles and it is equipped with a magnetic stirrer. Flocculated water from the flocculation unit settles in the sedimentation unit.

Test running and selection of critical parameters

Initial test runs were done to observe the electrocoagulation phenomenon and determine parameters which seem to affect the process. Emphasis was especially laid on those parameters suggested by literature to have significant impact on the effect of electrocoagulation process. These parameters included the conductivity, current density, electrode spacing, and surface area to volume ratio of the electrolytic system employed.

To investigate these parameters, a 2-litre batch process electrocoagulation reactor, with dimensions 10.5cm x 10.5cm x 22cm was constructed using a parallel plate arrangement of aluminium plates as anode and stainless steel plates as cathodes. The plate had dimensions of 8cm x 22cm, with 19cm of the depth being immersed in water. The steel plates had a thickness of 3mm, while the aluminium plates had a thickness of 15mm. These were connected to the positive and negative terminals of a 20V DC power supply, and various runs were made to determine the effects of different parameters on the electrocoagulation system.

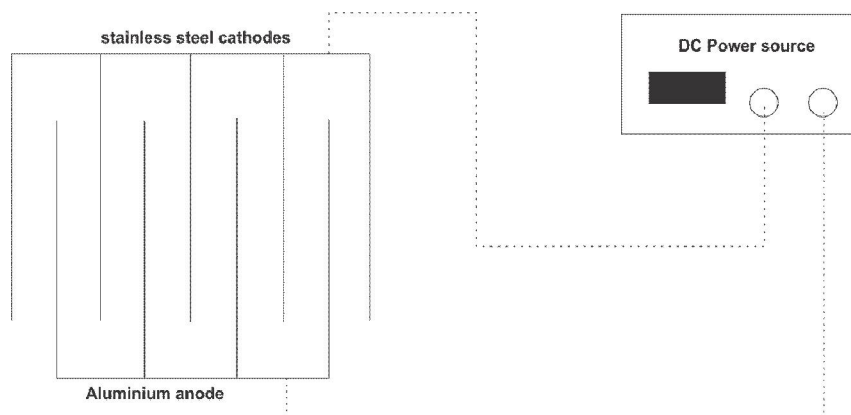


Figure 1: Schematic diagram of electrode arrangement of the electrocoagulation unit

Results And Discussion

Results obtained from the preliminary experiments and test runs were used to carry out further experiments with the batch process reactor to determine the effects of varying current density and electrode spacing. The results obtained from these were then used to design the continuous process electrocoagulation reactor. This was tested for its efficiency in terms of turbidity removal and current efficiency, and the results obtained were compared with those gotten from determining the efficiency of the chemical coagulation process using the jar tests.

Conductivity

The effect of conductivity was explored by comparing the results from raw water as electrolyte with distilled water (with a conductivity of 10 μ mhos) as the electrolyte in batch process reactor. When current was passed through the distilled water, it was observed that at high currents of 5A and above, there was a lot of flotation as bubbles were formed at the cathode. The floc observed was clean and white. However, white powdery settlement was found at the bottom of the reactor. This white residue was found (after filtering) to be of an approximate value to the weight of the aluminium plate dissolved in water, such that it could be inferred that the dissolved aluminium could only settle out of the water, as there were no suspended solids in the distilled water to be coagulated with it. On repeating the procedure with raw water

sample, it was observed that there was little observed at low currents, but at higher currents, flotation was observed with removal of pollutant thereby. However, the current seemed to drop after some time (about 2 mins) so that readjustment had to be made to the system to maintain the current of 2.5 A. This was assumed to be due to electrode passivation. As a result of this, a magnetic stirrer was introduced to stir the water in the reactor. This was effective in keeping the current from dropping as before, and also resulted in more of the pollutant being observed to settle at the bottom of the reactor. This proved the significance of allowing for adequate flocculation to favour pollutant removal by sedimentation. However, as the electrocoagulation process progressed, the current was observed to have a propensity to drop, ostensibly due to the drop in conductivity of the water as more and more of the ions in the water coagulated out of solution as floc on the top of the water, being removed by flotation, or as sludge/sediments at the bottom of the reactor. The experiment was run twice, and the average of the results obtained is shown in Table 1. The results show that the conductivity of the electrolyte plays a significant role in the electrocoagulation process, such that the applied current would have to be high to ensure a fast coagulation, which would invariably favour pollutant removal by flotation.

Table 1: Effect of conductivity on the electrocoagulation process

	pH	Turbidity (NTU)	Conductivity (μ S)	Average dissolved weight of Al plates (g)
Distilled water				
Initial Value	7.0	0.1	10.6	000.135
Final Value	6.9	0.5	9.8	
c.e. = 96.43 %				
Raw Water				
Initial Value	6.4	19.5	226	
Final Value	6.9	1.5	196	000.220
c.e. = 157.14 %				

Time

The effect of time was observed by varying the time of electrocoagulation from 2.5 minutes to 10 minutes at an interval of 2.5 minutes, and it was realised that after a certain time (about 5mins) in the batch process reactor with a 2-litre capacity, the effect of continued electrocoagulation was indiscernible, as most of the pollutant had been removed by flotation. However, to effect adequate pollutant removal, the process was allowed to run for 10 minutes, while stirring with the magnetic stirrer, to ensure that flocculation as well as electrocoagulation took place simultaneously in the batch process reactor.

BOD Analysis

BOD analysis were performed on the raw water samples before and after treatment. The average results of the analysis are given in Table 2. The data show that the electrocoagulation process significantly reduces the BOD in the water, while increasing the dissolved oxygen content of the water after treatment. The increase in dissolved oxygen can be attributed to the air bubble flotation action at the cathode, which causes air bubbles to mix with the water during treatment. The implication of this is that electrocoagulation contributes to the disinfection of water, inferring that less chemicals (e.g. chlorine)

would be required to fully disinfect the water. This is a desirable outcome in the treatment of potable water.

Table 2: Effect of electrocoagulation on BOD of water

	DO ₁	DO ₅	BOD = DO ₁ - DO ₅
Raw water	2.6	1.0	1.6
Treated water	2.8	2.4	0.4

Optimization of parameters with batch process electrocoagulation reactor

The current and electrode spacing were varied to determine the combinations which would give optimal results. The current was varied from 0.5A to 2.5A at an interval of 0.5A, and for each current value, the spacing was varied from 0.5cm to 2.0cm. The active surface area of the electrodes was computed as 912cm or 0.0912m. The current density could therefore be determined for each value of current, and the effects were expressed in terms of both current and current density. The values obtained as the effect of these variations on the aluminium dosage are shown in Table 3. Results show that an increase in aluminium dosage was observed with increasing current density, and decreasing electrode spacing.

Table 3: Variation in aluminium dissolution (in g) against current and spacing. Time of current flow: 10 minutes

Current (A)	0.50	1.00	1.50	2.00	2.50
Spacing (cm)					
0.50	0.028	0.084	0.084	0.143	0.196
1.00	0.031	0.046	0.046	0.130	0.081
1.50	0.025	0.025	0.045	0.122	0.220
2.00	0.011	0.011	0.045	0.069	0.078

The effect of varying current/current density against the pH of the treated samples is shown in Table 4. The results show that the pH is regulated to close to 7.0 by the electrocoagulation treatment process. However, the standard deviation between the pH values obtained does not show a definite correlation between the electrode spacing or current density and the pH. The implication of this is that chemicals (lime) would not be needed to neutralize the water and restore alkalinity after treatment by electrocoagulation as is the case for chemical coagulation.

The effect of varying current/current density against the temperature of the treated samples is

shown in Table 5. The results show that the temperature of the system increases slightly with increasing current/current density, but is not affected by the electrode spacing.

The effect of varying current/current density against the TSS of the treated samples is shown in Table 6. The results show that generally, the total suspended solids in the water increases with increasing current/current density and with increasing electrode spacing. This implies that coagulation is enhanced with increased current and electrode spacing so that the turbidity removal at a high current of 2.5A and at an electrode spacing of 2 cm is more effective than at low currents and lower electrode spacings.

Table 4: Variation of pH against current/current density and electrode spacing, Initial pH of sample: 6.40

Current (A)	0.50	1.00	1.50	2.00	2.50
Current density (Am ⁻²)	5.43	10.86	16.29	21.72	27.14
Spacing (cm)					
0.50	6.70	6.75	6.90	7.00	7.10
1.00	6.80	7.00	7.00	7.00	7.50
1.50	6.80	6.70	7.00	6.95	7.40
2.00	6.90	6.80	7.05	6.90	6.80

Table 5: Variation of final temperature in °C against current/current density and electrode spacing, Initial temperature: 23.5 °C

Current (A)	0.50	1.00	1.50	2.00	2.50
Current density (Am ⁻²)	5.43	10.86	16.29	21.72	27.14
Spacing (cm)					
0.50	24.50	25.50	26.00	26.50	29.00
1.00	24.50	25.50	26.00	26.50	28.00
1.50	24.50	25.50	26.00	27.00	30.00
2.00	24.50	25.50	26.00	26.00	29.00

Table 6: Variation of final TSS in mg/L against current/current density against electrode spacing, Initial TSS: 210 mg/L Time of current flow: 10 minutes

Current (A)	0.50	1.00	1.50	2.00	2.50
Current density (Am ⁻²)	5.43	10.86	16.29	21.72	27.14
Spacing (cm)					
0.50	225	358	311	433	555
1.00	195	136	385	300	442
1.50	60	195	364	248	546
2.00	130	175	235	233	458

The Jar test Analysis

Raw water samples collected at peak periods and at off peak periods were subjected to jar test analysis to determine the optimum alum dosage for treatment of the water by chemical coagulation. The average results of the jar tests are represented in Table 7, Table 8, and Table 9. These results showed that for both classes of water samples, the effective alum dosage was 10ml of a 1% stock solution, which is equivalent

to a dosage of 1mg/L. At dosages above this, the turbidity removal efficiency (t.r.e) decreased.

The turbidity removal efficiency for the water at off-peak periods was found to be higher than that for low peak periods. However, the pH of the water decreased with increasing alum dosage, which led to a decrease in the efficiency of the coagulation process. Thus, the maximum turbidity removal efficiency that could be obtained from the water with higher turbidity was found to be 70%.

Table 7: Jar test 1 for sample A using 1% alum stock solution, Initial turbidity: 16.5 NTU

Alum dosage (ml)	Equivalent alum dosage (ml)	Turbidity	t.r.e (%)	pH	TS (mg/l)	TSS (mg/l)	TDS (mg/l)
10	100	1	94	4.90	890	190	700
20	200	2	89	4.80	830	30	800
30	300	2.5	85	4.80	750	50	700
40	400	3	82	4.76	966	66	900
50	500	3.5	79	4.60	700	200	500
60	600	3.5	79	4.50	710	210	500

Table 8: Jar test 1 for sample B using 1% alum stock solution, Initial turbidity: 50 NTU

Alum dosage (ml)	Equivalent alum dosage (ml)	Turbidity	t.r.e (%)	pH	TS (mg/l)	TSS (mg/l)	TDS (mg/l)
10	100	15	70	5.7	440	200	240
20	200	16.5	67	4.6	680	400	280
30	300	26	48	4.2	270	100	170
40	400	22.5	55	4.0	1300	1000	300
50	500	26.5	47	4.1	1100	800	300
60	600	26.5	47	3.9	1320	1100	220

Table 9: Jar test for sample B using 1% alum stock solution, Initial turbidity: 50 NTU

Alum dosage (ml)	Equivalent alum dosage (ml)	Turbidity	t.r.e (%)	pH
5	50	20.0	60	6.2
10	100	16.5	67	5.5
15	150	19.5	61	4.8
20	200	20.0	60	4.5
25	250	24.5	51	4.2
30	300	25.5	49	4.0

For the same water, when subjected to electrocoagulation, the turbidity removal efficiency was found to be much higher than in chemical coagulation, with turbidity removal efficiencies ranging from 80% for the water with lower turbidity to 96% for the high turbidity water. This implies that the turbidity removal efficiency improves with increasing turbidity during electrocoagulation, the reverse of which is the case for chemical coagulation.

For the continuous process electrocoagulation treatment experiments, the aluminium dissolved and

the equivalent aluminium dosage are shown in Table 10. The data shows that the average aluminium dosage is 23mg/l. For the batch process electrocoagulation process, the average aluminium dosage as computed from the data in Table 3 is 46.4 mg/l. From the results, it was observed that electrocoagulation offers better turbidity removal efficiency and a lower optimum aluminium dosage without altering the pH of the water significantly enough to alter its alkalinity. In fact electrocoagulation restores the neutrality of the raw water.

Table 10: Results from investigations to surface area to volume ratio

Volume of reactor (m ³)	Active surface area (m ²)	Surface area to volume ratio (m ² /m ³)	Dissolved aluminium (g)
0.002	0.0912	45.60	0.048
0.004	0.0864	21.60	0.090
0.005	0.0816	16.32	0.114

The effect of the surface area to volume ratio on the electrocoagulation process was investigated by running the batch process for five minutes using different capacity containers, ranging from two litres to five litres. The average results obtained are given in Table 9. The results show that regardless of the surface area to volume ratio, the aluminium dosage remained the same. However, the dosage did not affect the pH which remained neutral after treatment by electrocoagulation, regardless of the initial pH of the raw water sample. The results suggests that large volumes of the water samples can be treated with electrocoagulation without necessarily having correspondingly large electrodes, although the rate of

aluminium dissolution will be commensurate with the surface area to volume ratio.

Conclusion

The results revealed that electrocoagulation is a very viable alternative to the present traditional treatment method of chemical coagulation being used in the Opa waterworks treatment plant. Apart from being more effective in terms of turbidity removal and optimum dosage values, it is also more effective at reducing the total dissolved solids present in the water. The dissolved oxygen content of raw water increases when treated by electrocoagulation, with an appreciable decrease in the biological oxygen demand,

which suggests that electrocoagulation would provide a cheaper alternative to chemical coagulation in terms of chemical usage. It is also apparent that turbidity removal is enhanced at higher currents, although this has to be balanced with optimum aluminium dosage to prevent wastage of the anodes. One way of doing this is to maximize the surface area to volume ratio (A:V) effect, so that a maximum volume can be treated with the least possible dosage.

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