Treatment of Wastewater in The Fruit and Vegetable Process Industries (FVPI) Through Electrocoagulation Process- Analysis Using RSM

Nokubonga Sinalo Mjoli[1], Nhlanganiso Ivan Madondo[2], Emmanuel Kweinor Tetteh[3] and Sudesh Rathilal[4]

***Abstract*—** The purpose of this study is to investigate and validate the use of zinc-copper (Zn-Cu) electrodes in electrocoagulation technology for the efficient treatment of wastewater produced by the fruit and vegetable processing industries (FVPI). The wastewater was characterized both before and after treatment to confirm the effectiveness of this treatment method. Using a laboratory electrocoagulation system, the effects of various parameters, such as charged voltage (1-30 V), agitation speed (90-150 rpm), and settling time (20-60 min), on conductivity, COD removal, and turbidity removal in FVPI wastewater were investigated. The Box-Behnken Design (BBD) and Response Surface Methodology (RSM) were used to optimize the electrocoagulation procedure. A model was developed to depict the treatment procedure. The optimal parameters were 45 minutes for settling, 150 rpm for running, and 29.6 A for voltage, which removed 75% of the turbidity, 93% of COD and reduced conductivity to 971 µS/cm from the effluent. The regression model's predictions are accurate, as evidenced by the correlation between the predicted value for conductivity, turbidity and COD removal percentage are 0.8659, 0.8665 and 0.7245 and the measured values are 0.9390, 0.9862 and 0.8361 respectively. A prediction model describing the contaminant removal in terms of process factors was produced via multiple regression analysis. The model equation appears to be valid based on the coefficient of regression (R^2) value of 0.9651, 0.9961 and 0.8712 for conductivity, turbidity and COD respectively. To enhance and increase FVPI wastewater electrocoagulation treatment, the RSM via BBD can be used.

***Keywords*—** BBD, Electrocoagulation, FVPI wastewater, RSM, BBD, zinc-copper electrodes

I. INTRODUCTION

Water Shortage is an issue that has been considerably exacerbated by human activity, particularly industrial activity, domestic use and agricultural purposes. In order to guarantee the renewability of this resource for a growing global population, it is imperative that certain treatment techniques be taken into consideration. Water is essential to the Fruit and Vegetable Process Industry (FVPI), and drinking water is used most of the time [1]. Projects in South Africa are presently being implemented with the goal of examining the viability of recycling and reusing wastewater in the agro-food industry by creating an integrated strategy that combines mass pinch analysis and water footprint evaluation [2], [3]. Water from the eThekwini Bulk Market in Clairwood, Durban, South Africa is produced by the market itself from a number of sources, including home wastewater, process water, ablution systems, washing fruit and vegetables, and facility cleaning.

The FVPI in South Africa mostly treats wastewater using traditional methods [4]. Although the industry does not frequently utilise advanced wastewater treatment (WWT), the majority at least perform primary treatment [1]. According to [4], less than 20% of the facilities under investigation offer advanced or tertiary care. Common wastewater treatment techniques utilised for the FVPI include processes like aerobic lagoons, biological aeration, trickling filters, and anaerobic lagoons [4]; [1]. These methods' drawbacks include the production of sludge, potential odour emission, land requirements, potential ground water pollution, and potential direct system operating effects from environmental factors [5], [6].

In the past decade, research has focused on wastewater treatment techniques including electrocoagulation (EC) for the treatment of industrial wastewater streams [7]. The removal of fats, oil, and grease (FOG) [8], [9], the dye industry, household waste, and wastewater from chicken slaughterhouses [10], [8]. These topics make up the majority of the examined EC research. Research on the use of electrocoagulation in the management of FVPI is receiving more attention [11].

An excellent substitute for FVPI treatment is electrocoagulation (EC), an electrochemical process that can handle variations in pollutant quality and quantity and remove

Nokubonga Sinalo Mjoli[1] is with Green Engineering Research Group; Department of Chemical Engineering, Faculty of Engineering and the Built Environment, Durban University of Technology, Durban, 4001, South Africa corresponding author’s phone:083 981 3195; Nhlanganiso Ivan Madondo[2] Green Engineering Research Group; Department of Chemical Engineering, Faculty of Engineering and the Built Environment, Durban University of Technology, Durban, 4001, South Africa Emmanuel Kweinor Tetteh[3] Green Engineering Research Group; Department of Chemical Engineering, Faculty of Engineering and the Built Environment, Durban University of Technology, Durban, 4001, South Africa

Sudesh Rathilal[4] Green Engineering Research Group; Department of Chemical Engineering, Faculty of Engineering and the Built Environment, Durban University of Technology, Durban, 4001, South Africa

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persistent pollutants like dye and FOG from wastewater [8], [9]. According to [10], the primary benefits of the EC process are (i) the quick breakdown of organic compounds, (ii) the absence of the need to add extra compounds, (iii) environmental compatibility, (iv) high efficiency in pollutant degradation, and (v) cost-effectiveness. EC uses redox processes to break down organic pollutants by applying electric current.

The procedure of electrocoagulation involves dissolving copper or zinc ions from electrodes composed of copper or zinc electrically in order to produce coagulants in situ [12], [13]. At the cathode, hydrogen gas is discharged, while metal ions are produced at the anode [14], [13]. Additionally, the hydrogen gas would help the water's particle flocculation. This method is sometimes referred to as Electroflocculation.

Therefore, utilising a batch reactor to treat wastewater from the bulk market, this study looked at optimising electrocoagulation. A settling period of 20 to 60 minutes, a mixing speed of 90 to 150 rpm, and a voltage of 1 to 30 V were the parameters that were examined. Response surface approach was used to optimise the removal of pollutants using a Box-Behnken Design (BBD) model.

II. MATERIALS AND METHODS

A. *Wastewater sample source*

The Clairwood fresh produce bulk market in the eThekwini municipality of KwaZulu Natal, South Africa, provided the wastewater effluent samples. An equalization tank was used to collect and store the wastewater, which came from a variety of processes including washing fruit and vegetables, bathing and ablution systems, process water, and bund area washing. In order to preserve the physicochemical properties of the samples, they were stored in polypropylene airtight storage containers at 4°C in the lab prior to use. The samples utilized in this investigation were obtained by grab sampling 40 L weekly from the equalization tank using plastic scoops.

B. *Characterization of municipal wastewater*

The APHA procedures for water characterization were used to quantify the wastewater properties prior to the research (see table 1). The samples' color and chemical oxygen demand (COD) were assessed using a spectrophotometer (HACH DR3900, USA), and their pH and conductivity were measured with a pH and conductivity meter (Thermo Scientific Eutech Elite PTCS, USA). A turbidity meter (Hanna HI 98703-02, USA) was used to determine the sample's turbidity.

TABLE I
RAW WASTEWATER PROPERTIES.

Parameter	Value	Std Dev.
pH	6.91	0.1216
Color (Pt.Co)	968	7.2576
Turbidity (NTU)	123	2.3547
Conductivity (µS/cm)	1210	5.6988
COD (mg/L)	1528	6.4785

C. *Experimental Setup and Wastewater treatment Procedure*

In the electrocoagulation process experiment, a batch reactor was utilized, as Figure 1 illustrates. An electrocoagulation cell or a glass beaker reactor that can accommodate two liters was used as the experimental apparatus for each run of the experiment. For every experiment ran, electrodes made of copper and zinc were linked as Zn–Cu (anode–cathode).

To attain a satisfactory contaminant removal %, each electrode's surface area was around 50 cm^2, and the interelectrode distance between each linked electrode was set at 5 cm. Several experiments on electrocoagulation have been conducted with varying distances between electrodes [15], [16] at 1 cm and [15], [17] at 2 cm. However, [18] states that there should be a maximum of 1 to 5 cm between each electrode.

Using a blade stirrer, the experiment was conducted in a batch reactor setting. Two liters of effluent were added to the glass beaker containing the blade stirrers and electrodes. The electrodes were connected to a direct-current electrical power supply. The electrodes were completely submerged in the wastewater in the glass beaker and operated at a constant room temperature of 25 ± 0.5°C throughout all tests. The EC setup was stirred using a jar test flocculator JLT6 bench equipped with blade stirrers. After mechanically polishing the electrodes with abrasive paper, they were carefully rinsed with hydrochloric acid (0.1 M HCl) for five minutes, and then they were rinsed with deionized water to remove any attached solid residue particles that might lead to the electrodes to rust or corrode because of the oxidation process.

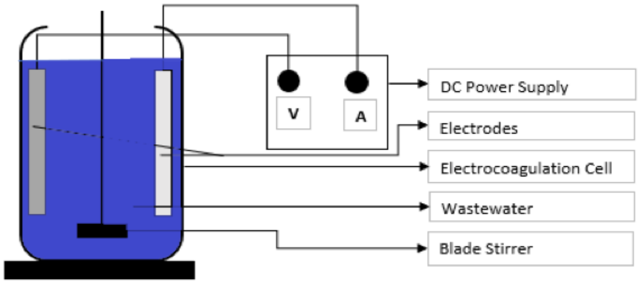

Fig. 1 Batch electrocoagulation set up with blade stirrer.

D. *Design of Experiment with Response Surface Methodology (RSM)*

The expert (version 13) response surface approach design was utilized to ascertain the statistical and mathematical data derived from an experimental investigation. Utilizing response surface methods, Box-Behnken Design (BBD) was employed, with the reaction time held constant at 30 minutes while adjusting the voltage (1-30 V), settling time (20-60 min), and mixing speed (90-150 rpm). The elimination % of turbidity, COD, and conductivity content were assessed by taking these factors into consideration. Based on the amount of variables employed in an experiment, BBD was utilized to limit the number of trials conducted in addition to statistical data analysis [19], [20]. In a similar vein, Table 2 displayed both the coded and actual values for the chosen variables. Real variables are those that are really utilized in an experiment, while coded variables are those that are randomly assigned by RSM or that may be changed in accordance with the specifications.

A three-level fractional factorial design called a Box Behnken design (BBD) is used to identify the type of response surface in an experimental zone. The design is a cross between an incomplete block design and a two-level factorial design, with certain parts staying at the center levels and a set number of variables flowing through all possible design combinations in each block [20].

The lack of an embedded factorial design, extreme points, and a rotatability value in the experimental design is the experiment's drawback when it comes to the BBD. This is because it requires fewer investigations to provide outcomes that are equivalent.

TABLE II
CODED AND ACTUAL VALUES OF THE VARIABLES OF THE DESIGN OF EXPERIMENTS

Variables	Units	Factors	Levels		
			-1	0	+1
Mixing Speed	Revs Per Minute (Rpm)	A	90	120	150
Induced Voltage	Volts (V)	B	1	15.5	30
Settling Time	Minutes (Min)	C	20	40	60

III. RESULTS AND DISCUSSION

A. Effects of Operating Parameters on Contaminant Removal

The primary purpose of agitating speed is to facilitate the efficient transmission of coagulant matter, which is generated by the electrode solution, to the reactor. The inability of coagulant matter to disperse effectively within the reactor results in an inhomogeneous composition and the manifestation of regional variations. Additionally, the homogenization of system variables like temperature and pH can be induced by stirring speed [21]. However, flocs created in the reactor may be destroyed by high speeds, resulting in the formation of small flocs that are difficult to remove from water. Upon investigating the impact of stirring speed on the system's performance, it was determined that increasing the speed for all input variables resulted in the most effective removal of contaminants (refer to Table 3). The most effective reductions in conductivity and COD were observed at approximately 120 rpm.

One of the operational parameters that has a direct impact on the efficacy of electrocoagulation is the applied voltage. Experiments involving EC at voltages ranging from 1 to 30 V revealed that an increase in voltage decreases the level of contaminant removal, which is also according to [22]. At the maximal induced voltage (30 V), the conductivity was determined to be 940 µS/cm, which was the lowest recorded. Despite variations in the other input variables, the turbidity and COD removal percentages were 74% and 92%, respectively at 30 V.

The rate of contaminant removal increases in parallel with the settling time. This is because suspended and other flocculent particles accumulate in the bulk of the solution during their movement, resulting in the formation of settled particles [23]. However, the conductivity increases until it reaches its maximum in approximately forty minutes, after which it decreases; consequently, the optimal operating time is approximately forty-six minutes.

TABLE III
RSM DESIGN FOR ACTUAL TESTED VALUES FOR CONTAMINANT REMOVAL

Run	Voltage	Mixing Speed	Settling Time	Conductivity	Turbidity	COD
1	30	120	20	945	43	79
2	30	90	40	1002	46	47
3	15,5	150	60	952	59	90
4	15,5	150	20	962	42	58
5	1	120	20	971	18	23
6	30	120	60	940	56	92
7	15,5	120	40	989	36	53
8	30	150	40	976	74	81
9	15,5	120	40	983	37	54
10	1	90	40	1010	26	20
11	15,5	90	20	967	33	34
12	15,5	120	40	981	38	54
13	15,5	90	60	989	50	50
14	1	120	60	969	31	26
15	1	150	40	997	22	32

B. Fit Statistics

The fit statistics table, shown in **Error! Reference source not found.**, is one of the most important tables in statistics. The fit statistics table contains the relevant accuracy, standard deviation, coefficient of determination (R^2), predicted R^2, adjusted R^2, coefficient of variation, and mean, among other key statistical coefficients [24]. The coefficient of determination (R^2) provides a statistical measure of how well the projected regression model fits the actual/real experimental data [25], [20]. The R^2 term, which is expressed in percentage form, essentially establishes the change in the response (y) that is described by the suggested model. The value of R^2 ranges from 0 to 1. The best-fit regression model is indicated by an R^2 score that is almost equal to 1. The turbidity model yielded more gratifying findings, with a substantially superior R^2 of 0.9961 when compared to the regression models for electrical conductivity and COD.

One drawback of the traditional coefficient of determination (R^2) is that it usually yields a larger R^2 score when more input variables are added to the model, even if the original variable is crucial. Because of this, rather of using the conventional coefficient of determination (R^2), many researchers now choose to use the adjusted R^2 [25]. The main benefit of using adjusted R^2 is that it does not increase in value with the addition of an input variable. Similar to R^2, turbidity had the strongest adjusted R^2 of 0.9862, indicating the greater robustness of the turbidity model.

Another crucial fit statistics measure is predicted R^2, which is useful in indicating the expected R2 value for the predicted regression model. The adjusted R^2 values were 0.9390, 0.9862, and 0.8361, whereas the predicted R^2 values for conductivity, turbidity, and COD were 0.8659, 0.8665 and

0.7245, respectively. For electrical conductivity, turbidity, and COD, the differences between the adjusted and predicted R^2 values were 0.0731, 0.1197 and 0.1116, respectively. As to [26], there should be less than 0.2 discrepancy between the adjusted R^2 and predicted R^2. A reasonable degree of agreement is shown by the fact that all of the study's outcomes had values that were less than 0.2. As a result, there was no problem with the regression model equations or the experimental data points.

TABLE IV
FIT STATISTICS FOR CONDUCTIVITY, TURBIDITY REMOVAL AND COD REMOVAL.

Statistical parameter	Conductivity	Turbidity Removal	COD Removal
Standard deviation	5.04	1,76	9,63
Mean	975.51	40,85	53,04
Coefficient of Variation (COV %)	0,52	4,30	18,15
R^2	0,9651	0,9961	0,8712
Adjusted R^2	0,9390	0,9862	0,8361
Predicted R^2	0,8659	0,8665	0,7245
Adequate Precision	20,7142	37,8501	15,4214

A. Model Validation

One of the essential graphs for validating a model is the one that compares predicted values to actual values. **Error! Reference source not found.** displays the expected vs. actual graph for each response, including conductivity, turbidity, and COD. The percentage of the total variability in the dependent variable that the regression equation in the independent variable accounts for is the regression coefficient (R^2) or coefficient of determination. Predictive versus actual response values ought to be randomly distributed at a 45-degree angle along a line [26]. For each input variable, the regression coefficient (R^2) was computed, and the results are displayed in **Error! Reference source not found.**. The regression coefficient (R^2) for the modified input variables was more than 0.7. This suggested that the model had considerable validity [26]. As seen in the Fit Statistics section, the turbidity model was more dependable than the other models, and the turbidity data points were more closely separated from the 45-degree line than the points from the other responses.

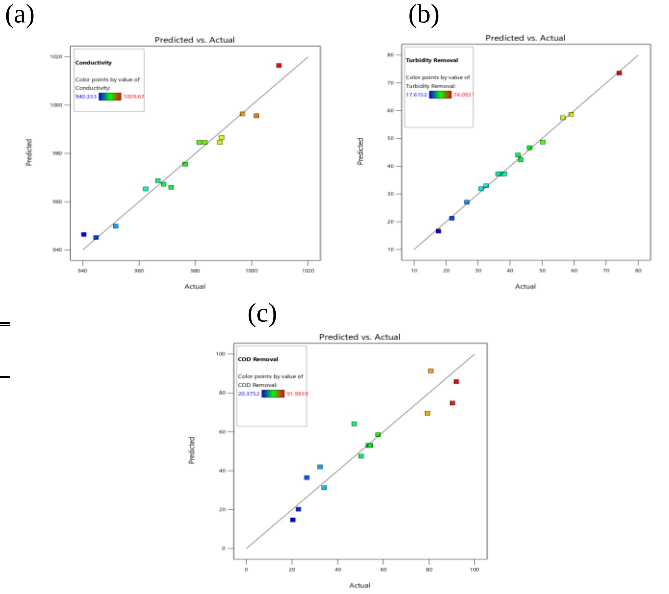

Fig. 2 Model validation of-Predicted vs Actual: (a) conductivity; (b) turbidity removal; (c) COD removal.

B. Numerical optimization

The primary benefit of response surface approach with Box-Behnken design (BBD) is figuring out the best value for the removal degree of pollutants under various conditions. The findings were optimized using the RSM regression equation based on the BBD (design expert 13). During the optimization process, the response on the observed conductivity, turbidity removal efficiency, and COD removal efficiency were maximized by selecting the induced voltage (A), mixing speed (B), and settling time (C) within the range. With an induced voltage of 29.65 V, mixing speed of 150 rpm, and a settling time of 45.74 min, the optimal values of conductivity, turbidity removal, and COD removal were 971.23 µS/cm, 75.25%, and 93.11%, respectively, with a 95% confidence level with a desirability of 0.764.

IV. CONCLUSIONS

The everyday activities of humans produce wastewater, which is then released into the environment untreated. Electrocoagulation, on the other hand, is a straightforward technique used to treat wastewater because of its simplicity and efficiency in lowering contaminants including turbidity, conductivity, and COD. The conductivity and percentage of turbidity and COD removal were determined while taking into account the induced voltage, mixing speed, and settling time of the Zn-Cu (anode-cathode) electrode combination. At various operating parameters, the electrode combination was effective in reducing conductivity and the removal percentage of turbidity and COD. The results of the study demonstrated that the more gradually the supplied voltage, mixing speed, and settling time are increased, the more successful the electrochemical cell is in reducing conductivity and increasing the percentage of turbidity and COD removed. Statistical data analysis was employed to assess the model's validity, and optimization played a significant role in achieving these objectives by utilizing BBD to consider operating parameters in intervals and maximize the removal efficiencies of turbidity and COD while minimizing conductivity. In summary, the findings of this research demonstrated that, given particular operational conditions, electrocoagulation could serve as an effective and desirable method to eliminate turbidity, COD, and conductivity from FVPI wastewater.

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