Environmental Health Engineering and Management Journal 2022, 9(2), 177-188
http://ehemj.com
doi 10.34172/EHEM.2022.19
Environmental Health Engineering and Management Journal

Original Article

Comparison of sono-direct and sono-alternate current electro-coagulation processes for removal of color and turbidity from domestic wastewater

Lelisa Regea Mengistu[1], Zerihun Asmelash Samue[1], Chali Dereje Kitila[1], Abreham Bekele Bayu[2*]

[1]Jimma Institute of Technology, Faculty of Civil and Environmental Engineering, Jimma University, Jimma, Ethiopia
[2]Jimma Institute of Technology, School of Chemical Engineering, Jimma University, Jimma, Ethiopia

Abstract

Background: Nowadays there is a problem related to wastewater handling which is released from different activities. Electrocoagulation has been a dominant treatment method for wastewater treatment. There are different forms of electrocoagulation methods for wastewater treatment. Nevertheless, there was no comparison made for the removal efficiency of the sono-alternate current (SAC), alternate current (AC), sono-direct current (SDC), and direct current (DC) electrocoagulation process.

Methods: The efficiency of electrocoagulation method was compared for removal of color and turbidity from Jimma University domestic wastewater. Batch reactor DC/AC electrocoagulation cell was used to determine the removal efficiency. During the comparison, the response surface methodology (RSM) was used to analyze and optimize the data taken from the laboratory. In addition, ANOVA was used to analyze the interaction effects of different parameters.

Results: The removal of color and turbidity from domestic wastewater was about 97.53% and 95.28% respectively, using direct current electrocoagulation (DCE). For alternate current electrocoagulation (ACE), the removal of color and turbidity was 98.35% and 96.12%, respectively. The removal of color and turbidity for sono-DCE (SDCE) was obtained to be 98.55% and 98.27%, respectively and for sono-ACE (SACE), the removal of color and turbidity was 99.95% and 99.76%, respectively at the optimum experimental conditions of chemical oxygen demand (COD) 960 g/L, initial wastewater pH of 6.8, the current density of 0.4 A/dm^2, inter-terminal spacing of 1 cm, and the association of electrode of Al-Al.

Conclusion: According to the findings of this study, it can be concluded that, the SAC electrocoagulation method is the best and promising technique compared with all other electrocoagulation methods.

Keywords: Alternating current, Direct current, Wastewater, Sono-alternate, Sono-direct, Turbidity, Color removal

Citation: Regea Mengistu L, Asmelash Samue Z, Dereje Kitila C, Bekele Bayu A. Comparison of sono-direct and sono-alternate current electro- coagulation processes for removal of color and turbidity from domestic wastewater. Environmental Health Engineering and Management Journal 2022; 9(2): 177-188. doi: 10.34172/EHEM.2022.19.

Article History:
Received: 6 December 2021
Accepted: 10 January 2022
ePublished: 21 May 2022

***Correspondence to:**
Abreham Bekele Bayu,
Email: abreham.bekele@ju.edu.et

Introduction

Domestic wastewater outlets are considered as one of the sources of pollution (1). Domestic wastewater is a dark burnished color liquid with high concern with chemical oxygen demand (COD) and biochemical oxygen demand (BOD) due to a large number of natural substances like proteins, polyphenols, organic acids, and polysaccharides (2). Untreated wastewater from domestic wastewater can bring about high soil and water pollution (3, 4). However, the discharge of domestic wastewater can lead to pollution for both surface and groundwater (5). The increased concentrations of these contaminants pose a serious threat to vegetable life, fauna, the atmosphere, and human beings (6, 7). There has been an increasing interest in the current time in the treatment of toxins from water, soil, and air (8, 9). Electrocoagulation is a promising wastewater treatment method based on the cathode and anode separation technique (10, 11). Chemical methodical study of parts of material world methodologies happens inefficiently, requires heavy use of chemicals, and produces large amounts of mud (12). The drawback of biological processing method is, it requires a large dilution which favors a slow and long process for the treatment (13). Therefore, powerful and efficient wastewater treatment is a primary approach to increase the biodegradability of contaminants, or as a more complex type of treatment to defeat COD or to minimize COD (14). It is influential to use technology and to bring successful conclusions with high performance and low supply drawn upon consumption (15, 16). Unending mechanical cleaning results and formation of sound cavitation bubbles near the conductor surface, makes quick waves which are the second stage in combination with electrocoagulation to clean the conductors (17).

Electrocoagulation offers great potential for removing ionic species capable of disintegration, a very influential metal, from wastewater (18-21). Electrocoagulation is an electrochemical process in which soluble iron (Fe) and/or container (Al) is secondhand as the anode and/or cathode, and metal ions (Fe^{2+} or Fe^{3+}, Al^{3+}) are free due to anodic decay. In the overall response, the M(OH)n formed is used as a coagulant for the system. This may be the minimum hydroxide or iron hydroxide, contingent upon the electrodes used. Ultrasound is transmitted to the material by waves that compress and decompress the smallest part. Cavitation bubbles are developing in the mind or physically when the negative pressure is big enough to disturb the distance between liquid smallest part (22). The collapse of these bubbles can produce very high coldness of some degree and pressures, and these conditions can demolish the water molecules in the cavitation bubbles. Therefore, the gap by ultrasonic rot of water molecules produces sensitive percent radicals of OH^-. It exists as a non-selective oxidizer for the organic contaminants in wastewater (23). The unification of the sono-alternate current (SAC) and sono-direct current (SDC) electrocoagulation processes helps to optimize the removal efficiency of dependent limit by combining electrocoagulation and ultrasound utilizing the alternate current (AC)/direct current (DC) method. The effects of SAC/SDC, current mass, pulse event, electrode organization, and electrolysis duration on COD the act of moving efficiency exist investigated utilizing Al-Al electrodes and simulated wastewater. This study reported the findings in relation with other similar studies of direct and alternative electrocoagulation, integrated electrocoagulation, and quick methods. The discharging of liquid waste product to the water body made high concentration of material body and toxic COD shock. Thus the cytotoxic chemicals found in waste water need appropriate treatment before discharging to the water body. A correct treatment technology that is well tested and applied is needed to discharge this waste product to water bodies. Otherwise, it will affect the setting and human life (24). Sono-electrocoagulation is becoming a promising wastewater treatment technology- appearing with a substantial reduction of chemical cost and a significant reduction of sludge production. Sono-electrocoagulation has a high application potential, principally derived from the high reactivity and low property of the hydroxyl group radicals. DC and AC electrocoagulation treatment technology have been distinctly studied and their corresponding treatment efficiency and limitations are well-identified under different settings.

The following equations show the mechanism of the electrocoagulation process by the aluminum electrode:

Anodic reaction: $Al_{(s)} \rightarrow Al^{+3}(aq) + 3e^-$ (1)

Cathodic reaction: $3e^- + 3H_2O \rightarrow H_{2(g)} + 2OH^-_{(aq)}$ (2)

Chemical reaction that takes place in the aqueous medium:

$Al^{+3}(aq) + OH^-(aq) \rightarrow Al(OH)_{3(s)}$ (3)

Overall reaction: $Al^{+3}_{(aq)} + 3H_2O \rightarrow Al(OH)_{3(s)} + 3H^+(aq)$ (4)

Based on the literature review, most of the previous studies focused on the efficiency of the electrocoagulation process for removal of pollutants from the contaminated water and wastewater separately. This study aimed to compare and find the best highly effective and less power usage electrocoagulation process in removing turbidity and color from the domestic wastewater to reduce the risks of these pollutants on human and environmental health.

Materials and Methods

Materials and chemicals used

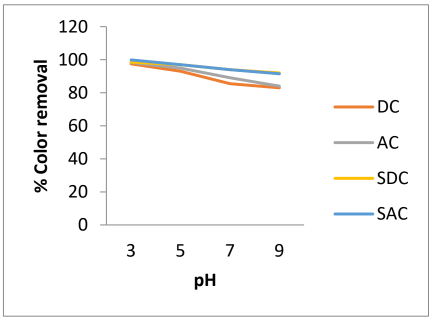
The materials used in this study were batch reactor (DC/AC electrocoagulation cell), DC/AC power supply, ultrasonic, parallel electrode (Iron and Aluminum), magnetic stirrer, copper wires, magnetic bar stirrer, electrical clips, locally available chip woods (holding electrodes), turbidometry, kits, spectrophotometry, and wash bottle. The chemicals used were potassium dichromate, sulfuric acid, ferrous ammonium sulfate, silver sulfate, mercury sulfate, ferroin indicator, and organic free distilled water.

Sample collection and preservation method

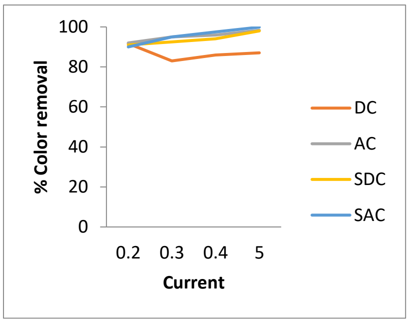
Samples were taken from the Jimma University cafeteria at the University's shared wastewater treatment plant in southwestern Ethiopia. Samples were collected in polyethylene containers, transported to the laboratory in 1 hour, and protected at 4°C during the experiment.

Experimental set-up

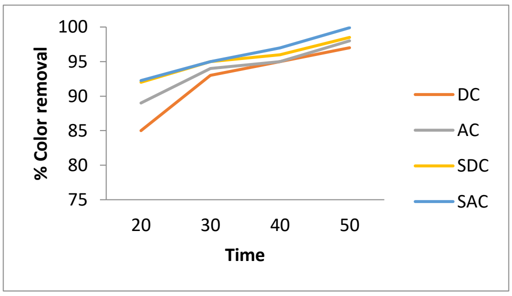
Figures 1 and 2 show the process layout of Sono direct electro coagulation (SDCE) and Sono alternative electro coagulation (SACE) used for the color and turbidity removal efficiency from domestic wastewater, respectively. The electrochemical reactor capacity of 2.25 L of an acrylic object that reflects an image capacity was used for the effective active capacity of wastewater established at capacity of 1.0 L. The required color and turbidity concentration of wastewater established by the accumulation of distilled water to the raw make pure effluent utilizing a dilution factor. The beginning pH value of the wastewater was measured with a pH beat (Elico: model LI120) and changed to the equivalent value in the range 1-11 accompanying 0.1 NH_2SO_4 and 0.1 N NaOH solutions before the start of the test. The electrode association Al/Al) plates were used as anodes and/or cathodes with dimensions of 13 cm × 6 cm × 1 cm, respectively, acceptable length, breadth, and thickness.



(a)

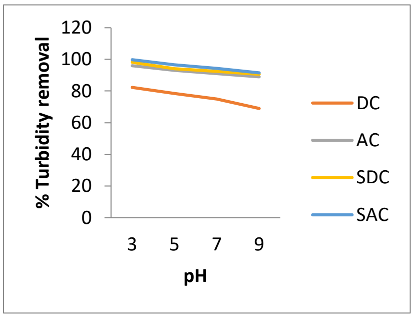


(b)

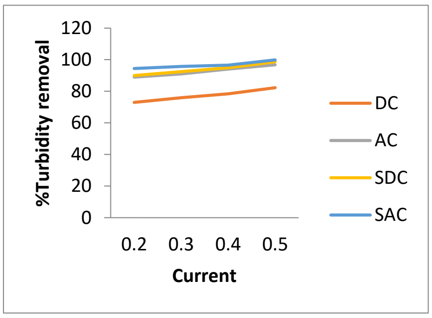


(c)

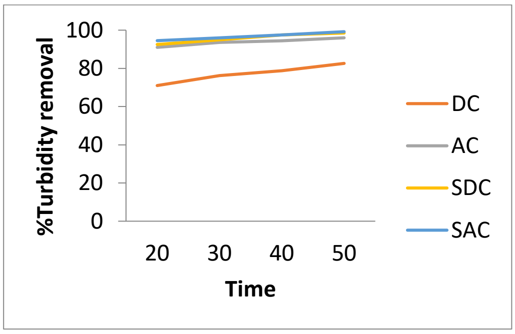
Figure 1. Color removal efficiency versus different factors (pH), (current), and (time), using Al-Al electrode.



(a)



(b)



(C)

Figure 2. Turbidity removal efficiency versus different factors (pH), (Current), and (time), using Al-Al electrode.

The effective terminal surface area was 10 cm × 10 cm × 0.1 cm. There was a 2-cm gap between the below of the electrode and below of the electrochemical cell reactor to admit proper agitation (Figure 3). The terminal distance between the anode and cathode was transformed by 2 cm. Before starting each experiment, the electrodes were laundered with 15% HCl and water purified by distillation or demineralization. The anode and cathode were connected to the sono direct and AC capacity packs (0-5 A, 0-270 V) in a unipolar parallel boundary. Samples were removed from the electrical device at regular opportunity intervals and centrifuged at 15 000 rpm for 15 minutes (REMI, model: R24) for the removal of color and turbidity. The results were obtained from samples taken and run in the laboratory-based on various parameters. Eighty experiments were conducted and each experiment contains twenty running.

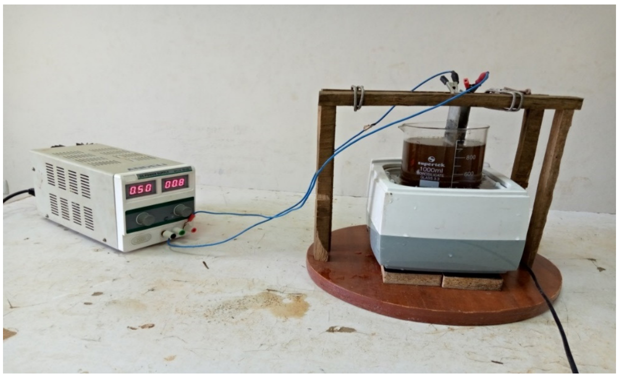


Figure 3. Real setup of sono-electrocoagulation process.

Response surface methodology (Design Expert11)

Response surface methodology (RSM) established as a mathematical-mathematical method is useful for optimizing concerned with atom and molecule change reactions and related to manufacturing processes and is often secondhand in the design of experiments (25, 26). RSM is a special set of mathematical and mathematical methods, containing the design of experiments, model fitting and validation, and state optimization. The purpose of the RSM (Design Expert11) searches is to optimize the reaction of objects affected by a large number of variables. RSM (Design Expert11) is a beneficial statistical system for optimizing chemical reactions and related to manufacturing processes and is frequently used in the design of experiments. RSM is the ultimate common addition method and is secondhand in many areas, including the study of chemical and biochemical processes (27-29). This method is used to fit practical models to experimental data (30-33). The RSM process applied in a group of statistical data concerning manipulation of numbers according to its methodology. It is used to expand and optimize processes in which affected by several variables (34-37). RSM is an effective technique accompanying important use in experimental design, new results or goods created development, and design, and addition of existing product and process design (38, 39). Besides RSM define the impact of key determinants alone or together with related processes.

Analysis

Removal efficiency of color and turbidity

The removal efficiency (%) was measured based on the color and turbidity of domestic effluent before and after the integrated SDCE and SACE process.

Equations (5) and (6) were used to determine the percentage of color and percentage of turbidity removal efficiency.

$$\text{Color reoval}(\%) = \frac{Ai - At}{Ai} * 100 \quad (5)$$

Where:

A_i – *is initial absorbance and,*

A_t –*is absorbance after treatment.*

$$\text{Turbidity removal }(\%) = \frac{Ti - Tf}{Ti} * 100 \quad (6)$$

Where:

T_i – *is initial turbidity and,*

T_f- *is turbidity after treatment (in NTU)*

Results

Wastewater characterization

The effluent was obtained from the institutional domestic wastewater located in Oromia, Jimma University. The water quality parameters such as color – (dark brown), odor – (burnt sugar), COD – (960 mg/L), and wastewater pH – (6.8) were analyzed for the institutional effluent as shown in Table 1.

Removal efficiency of color and turbidity

The removal efficiency (%) was measured based on the color and turbidity of domestic effluent before and after the integrated SDCE and SACE process. In Table 2, factors like pH, electric current, and reaction time were considered with different ranges. Similarly, the removal efficiency for color and turbidity was determined. Hence, using Al-Al electrode consumption by DC electro coagulation the removal efficiency of color and turbidity was up to 97.53% and 95.28%, respectively.

In Table 3, factors like pH, electric current, and reaction time were considered with different ranges just like that of Table 2. Similarly, the removal efficiency of color and turbidity was determined by considering all those factors. Hence, using AC electrocoagulation, the removal efficiency of color and turbidity was up to 98.35% and 96.12%, respectively.

In Table 4, factors like pH, electric current, and reaction time were considered with different ranges just like that of Table 3. Similarly, the removal efficiency of color and turbidity was determined by considering all those factors. Hence, using SDC electrocoagulation the removal efficiency of color and turbidity was up to 98.55% and 98.27%, respectively.

In Table 5, factors like pH, electric current, and reaction time were considered with different ranges. Similarly, the removal efficiency of color and turbidity was determined by considering all those factors. Hence, using SAC electrocoagulation the removal efficiency of color and turbidity was up to 99.95% and 99.76%, respectively. Furthermore, the removal efficiency of color and turbidity

Table 1. Characteristics of domestic wastewater before treatment

Parameters	Quantity	Unit
pH	6.8	-
Color	3	-
Turbidity	116	NTU
COD	960	mg/L
BOD	384	mg/L

Table 2. Input data and removal percentage by DC electrocoagulation

Run	Factor1	Factor 2	Factor 3	Response 1	Response 2
	A: pH	B: Current (A)	C: Time (min)	Color removal efficiency (%)	Turbidity removal efficiency (%)
1	7	0.4	60	92.56	91.23
2	5	0.4	40	94.93	92.72
3	9	0.5	50	91.03	89.59
4	3	0.5	50	97.53	95.28
5	9	0.4	40	88.93	88.84
6	5	0.4	40	95.25	92.56
7	7	0.4	40	91.34	90.12
8	9	0.5	30	86.32	88.73
9	3	0.5	30	96.83	95.32
10	5	0.4	40	95.15	92.50
11	3	0.3	30	94.66	94.23
12	7	0.4	20	85.43	89.73
13	5	0.2	40	91.69	90.57
14	7	0.4	40	91.36	90.23
15	9	0.3	30	83.45	87.53
16	7	0.4	40	91.55	90.53
17	3	0.3	50	95.26	94.56
18	9	0.4	40	88.16	88.96
19	5	0.5	50	95.78	92.81
20	3	0.3	40	94.83	94.29

Table 3. Input data and removal percentage by AC electrocoagulation

Run	Factor 1	Factor 2	Factor 3	Response 1	Response 2
	A: pH	B: Current (A)	C: Time (min)	Color removal efficiency (%)	Turbidity removal efficiency (%)
1	7	0.4	60	93.96	92.51
2	5	0.4	40	95.93	93.72
3	9	0.5	50	92.54	90.15
4	3	0.5	50	98.35	96.12
5	9	0.4	40	89.65	89.84
6	5	0.3	30	94.65	93.56
7	7	0.4	40	92.55	91.13
8	9	0.5	30	90.58	89.75
9	3	0.5	30	96.25	96.17
10	5	0.4	40	95.94	93.50
11	3	0.3	30	95.68	95.25
12	7	0.4	20	89.35	91.28
13	5	0.2	40	92.58	89.19
14	7	0.4	40	92.68	91.82
15	9	0.3	30	87.54	89.32
16	7	0.4	40	92.38	91.54
17	3	0.3	50	96.23	94.95
18	9	0.4	40	90.56	89.90
19	5	0.5	50	96.95	93.81
20	3	0.3	40	95.68	94.18

Table 4. Input data and removal percentage by SDC electrocoagulation

Run	Factor 1	Factor 2	Factor 3	Response 1	Response 2
	A: pH	B: Current (A)	C: Time (min)	Color removal efficiency (%)	Turbidity removal efficiency (%)
1	7	0.4	60	94.83	93.6
2	5	0.4	40	97.19	95.23
3	9	0.5	50	92.59	91.59
4	*3*	*0.5*	*50*	*98.55*	*98.27*
5	9	0.4	40	93.25	90.59
6	5	0.4	40	96.94	92.55
7	7	0.4	40	94.96	92.17
8	9	0.5	30	91.57	90.53
9	3	0.5	30	97.39	96.83
10	5	0.4	40	96.82	92.62
11	3	0.3	30	95.85	95.63
12	7	0.4	20	92.45	91.73
13	5	0.2	40	91.45	91.93
14	7	0.4	40	94.93	92.18
15	9	0.3	30	90.78	89.87
16	7	0.4	40	94.88	92.16
17	3	0.3	50	97.46	95.29
18	9	0.4	40	92.87	91.22
19	5	0.5	50	96.89	94.56
20	3	0.3	40	96.91	95.26

Table 5. Input data and removal percentage by SAC electrocoagulation

Run	Factor 1	Factor 2	Factor 3	Response 1	Response 2
	A: pH	B: Current (A)	C: Time (min)	Color removal efficiency (%)	Turbidity removal efficiency (%)
1	7	0.4	60	94.40	94.26
2	5	0.4	40	97.17	96.55
3	9	0.5	50	93.35	91.83
4	3	0.5	50	99.95	99.76
5	9	0.4	40	92.25	91.02
6	5	0.4	40	97.17	96.53
7	7	0.4	40	93.22	93.76
8	9	0.5	30	92.09	91.35
9	3	0.5	30	97.91	97.94
10	5	0.4	40	97.16	96.46
11	3	0.3	30	96.59	95.83
12	7	0.4	20	92.90	91.94
13	5	0.2	40	96.33	94.45
14	7	0.4	40	94.57	93.65
15	9	0.3	30	90.81	90.14
16	7	0.4	40	93.83	93.75
17	3	0.3	50	97.88	97.52
18	9	0.4	40	91.92	91.81
19	5	0.5	50	98.65	96.73
20	3	0.3	40	97.76	96.31

is clearly explained in Figures 1 and 2 concerning different factors.

As shown in Figures 1 and 2, SACE showed higher color and turbidity removal among the three factors of pH, current, and time. Hence, using SAC electrocoagulation, the removal efficiency of color and turbidity was up to 99.95% and 99.76%, respectively. Figure 1 shows color removal efficiency versus three factors using Al-Al electrode. Figure 2 shows turbidity removal efficiency versus three factors using Al-Al electrode.

Laboratory results of SACE/SDCE by aluminum electrode

During the electrocoagulation system, several processes take place whatever types of electrodes are used up. Especially, the formation of flocs on the upper part of the electrocoagulation cell due to the formation of hydrogen gas and the formation of a small quantity of sludge at the bottom of the electrocoagulation cell. The treatment with SAC and AC shows clear water compared with before treatment and DC treatment as shown in Figure S1.

Discussion

All tests were performed in the laboratory at range temperature. A batch electrical device was also tested and a 1-liter wastewater sample was filled in a beaker for electrode consolidation. This Electrocoagulation process uses aluminum electrodes weighing 30.70 g and with dimensions of 13 cm × 6 cm × 1 cm thickness. The policeman wire is affiliated to a DC/AC power source and at one end is connected to the electrode by an energetic clip. The current was therefore supplied and the results were acted under various influence limits.

Al-Al electrode combination

In this experiment, two aluminum electrodes were combined parallel by considering different determinants according to the study of Sanchez et al (40), to evaluate the removal efficiency of color and turbidity individually.

Effect of SAC/SDC electrocoagulation

Usually DC happens using an electrocoagulation process. In this case, an impermeable group of chemical elements layer makes possibility of formation on the cathode as well as disintegration formation in contact with the anode due to burning. These process prevents the active current transport between the anode and cathode, so the effectiveness of electrocoagulation processes declines (41). These disadvantages of DC have been overcome by adopting change AC in the electrocoagulation processes (42).

In Table 2, determinants like pH, electric current, and reaction opportunity were measured with different ranges. Similarly, the removal efficiency of color and turbidity was determined. Hence, using Al-Al terminal consumption by DC electrocoagulation the removal efficiency of color and turbidity was up to 97.5% and 95.281%, respectively. In Table 3, determinants like pH, electric current, and backlash time are shown with various ranges just like those of Table 2. Similarly, the removal efficiency of color and turbidity was determined by considering all these determinants. Hence, using AC electrocoagulation, the removal efficiency of color and turbidity was up to 98.352% and 96.12%, respectively. In Table 4, factors like pH, electric current, and reaction time were considered with different ranges just like those of Table 3. Similarly, the removal efficiency of color and turbidity was determined by considering all those factors. Hence, using SDC electrocoagulation the removal efficiency of color and turbidity was up to 98.55% and 98.27%, respectively.

In Table 5, factors like pH, electric current, and reaction time were considered with different ranges. Similarly, the removal efficiency of color and turbidity was determined by considering all those factors. Hence, using SAC electrocoagulation, the removal efficiency of color and turbidity was up to 99.952% and 99.76%,respectively. Furthermore, the removal efficiency of color and turbidity is clearly explained in Figures 1 and 2 concerning different factors.

Factors affecting Sono-Electro coagulation

Electrocoagulation is the process of applying energetic current for the treatment of wastewater using some coagulant. However, the treatment of wastewater by electrocoagulation process may be done by considering various factors. In this paper, pH, current density, and reaction time were considered as factors affecting the treatment of wastewater from Jimma University.

pH

Initial pH (pH_0) exhibits a significant impact on the (SDC and SAC) electrocoagulation process. There are different allowable concentrations of hydroxyl radicals and different forms of aluminum hydroxide complexes under the condition of various solution pH values. Under the acidic conditions (pH<5), the most favorable species are $Al(OH)_3^{2+}$, $Al(OH)^{2+}$, and $Al(OH)^{2-}$, which easily react with H_2O_2 to produce OH (43). The maximum concentration of Al^{2+} is observed at solution pH 3 and more OH is generated through the reaction of H_2O_2. In this experiment, the sample regulated solution pH using sulfuric acid solution and sodium hydroxide to pH 3-9. This range will give the data about how acidic pH, neutral pH, and bases pH will affect the electrocoagulation efficiency in the removal of COD, color, and turbidity by DC, AC, SDC, and SAC, respectively (44, 45). For all pH, color and turbidity are decreased; but the maxim removal was recorded at pH 3 (97.53%) and (95.28%), respectively, by DC electrocoagulation. For AC, the maximum removal efficiency of color and turbidity was obtained to be (98.35%) and (96.12%), respectively at pH 3. At pH 3, the maximum removal efficiency of color and turbidity by SDC was obtained to be (98.55%) and (98.27%), respectively by SDC and the maximum removal efficiency of color and turbidity by SAC was obtained to be (99.95%) and (99.76%), respectively.

Current

It refers to the amount of electric current in Ampere that is used to wastewater employed or rented during the electrocoagulation process. By changing the value of energetic current applied to the sample with various parameters, the removal efficiency also changes. By increasing the current in Ampere, the removal efficiency of pollutants also increases. Higher removal efficiency of pollutants is obtained while gradual decrement of the electric current was used. By increasing current density from 0.2 A to 0.5A, the removal efficiency also increases (46). This is due to the large number of ions produced on the electrode's which is advanced destabilization of the pollutant.

Reaction time

The reaction period is also another determinant that affects the electrocoagulation process. It is the time necessary to complete the reaction process of a sample taken by electrocoagulation. According to this activity, the response time is an individual hour in which the removal efficiency is checked at various time intervals utilizing the initial value as a baseline. In this study, the testing room result shows that one hour of backlash time is somewhat enough to remove the contaminant. Increasing the reaction time increases the removal efficiency of contaminants from wastewater (21, 47-49).

Optimization with RSM (Design Expert 11)

RSM is a concerning manipulation of numbers-mathematical procedure useful for optimizing concerned with atom and molecule change response and related to manufacturing processes and is used frequently as a second-hand fashionable method in the design of experiments (49, 50). One of the main advantages of RSM by central composite design is to obtain the optimum conditions for removal of pollutants based on the laboratory experiments. The results were optimized using the regression equation of RSM (Design Expert 11) based on the central composite design. In the optimization, factors like pH (A), current (B), and time (C) were selected and the responses such as color, and turbidity removal efficiency were optimized. For DCE, the optimum value was obtained at pH 3, current of 0.5A, and time 50minute, so that the optimum value of color and turbidity was 97.53% and 95.28%, respectively. Similarly for alternative current electrocoagulation, the optimum value was obtained at pH 3, current 0.5A, time 50 such that the optimum value of color and turbidity was 98.35% and 96.12% respectively. For SDCE, the optimum value was obtained at pH 3, current 0.5A, and time 50 minutes such that the optimum value of color and turbidity was 98.55% and 98.27% respectively. Similarly, for SACE, the optimum value was obtained at pH 3, current of 0.5A, time of 50 minutes so that the optimum value of color and turbidity was 99.95% and 99.76%, respectively. The ANOVA analysis is presented for all electrocoagulation methods from Table S1 to Table S8.

According to Table S1, the model is significant. It means that all P-values less than 0.0500 indicate the model terms are significant. In this case, A, B, C, AC, A^2, and C^2 are significant model terms. The quadratic model regression equation for color removal is obtained by RSM (Design Expert 11) according to Eq.7.

$$\text{Color Removal (\%)} = 91.7706 - 3.1747A + 1.24384B + 1.76354C + 0.0161826AB + 0.762029AC - 0.0574674BC - 0.328139A^2 - 0.168592B^2 - 0.701383C^2 \quad (7)$$

According to Table S2, the model is significant. It means that all P-values less than 0.0500 indicate the model terms are significant. In this case, A, B, C, AC, A^2, and B^2 are significant model terms. The quadratic model regression equation for turbidity removal is obtained by RSM (Design Expert 11) according to Eq. 8.

$$\text{Turbidity Removal (\%)} = 90.4002 - 1.82076A + 0.495112B + 0.367234C + 0.0588338AB + 0.10836AC - 0.035158BC + 0.244952A^2 - 0.265446B^2 + 0.0140078C^2 \quad (8)$$

The comparison between the experimental and predicted value from the model is expressed in Table S3. It was observed that the model predictions matched the experimental values and the data points lay close to the diagonal line indicated above. This indicates that the analysis of variance of the regression model was highly significant ($P<0.0001$). According to Table S3, the model is significant. It means that all P values less than 0.0500 indicate the model terms are significant. In this case, A, B, and C are significant model terms. The quadratic model regression equation for turbidity removal is obtained by RSM (Design Expert 11) according to Eq. 9.

$$\text{Color Removal (\%)} = 93.0331 - 2.63278A + 1.35219B + 0.879572C + 0.335682AB + 0.121849AC + 0.424108BC - 0.306784A^2 - 0.131826B^2 - 0.298931C^2 \quad (9)$$

According to Table S4, the model is significant. It means that all P-values less than 0.0500 indicate the model terms are significant. In this case, A, B, A^2, and B^2 are significant model terms. The quadratic model regression equation for turbidity removal is obtained by RSM (Design Expert 11) according to Eq. 10.

$$\text{Turbidity Removal (\%)} = 91.5619 - 1.77523A + 0.457193B + 0.111264C - 0.0889244AB + 0.1061AC + 0.235679BC + 0.261887A^2 - 0.765569B^2 + 0.143006C^2 \quad (10)$$

According to Table S5, the model is significant. It means that all P values less than 0.0500 indicate model terms are significant. In this case, A, B, C, AB, B^2, and C^2 are significant model terms. The quadratic model regression equation for COD removal is obtained by RSM (Design Expert 11) according to Eq. 11.

$$\text{Color Removal (\%)} = 95.026 - 1.92375A + 0.502824B + 0.59484C - 0.100644AB - 0.0612501\,AC - 0.0430777BC - 0.0373135\,A^2 - 1.05326B^2 - 0.338604\,C^2 \quad (11)$$

According to Table S6, the model is significant. It means that all P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, AB, and A^2 are significant model terms. The quadratic model regression equation for COD removal is obtained by RSM (Design Expert 11) according to Eq. 12.

$$\text{Turbidity Removal (\%)} = 91.8009 - 1.12714\,A + 0.650306B + 0.748792C - 0.454289\,AB - 0.0993755\,AC - 0.225915BC + 0.573586\,A^2 - 0.318724\,B^2 - 0.135157C^2 \quad (12)$$

The comparison between the experimental and predicted values from the model is expressed in Table S7. It was observed that the model predictions matched the experimental values and the data points lay close to the diagonal line indicated above. This indicates that the analysis of variance of the regression model was highly significant (P<0.000). According to Table S7, the model is significant. P values less than 0.0500 indicate that the model terms are significant. In this case A, B, C, and A^2 are significant model terms. The quadratic model regression equation for color removal is obtained by RSM (Design Expert 11) according to Eq. 13.

$$\text{Color Removal (\%)} = 94.526 - 2.46924A + 0.892367B + 0.44072\,C + 0.0420437\,AB - 0.187845\,AC + 0.265598\,BC - 0.319395\,A^2 + 0.306116\,B^2 + -0.237268\,C^2 \quad (13)$$

According to Table S8, the model is significant P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, and C^2 are significant model terms. The quadratic model regression equation for Turbidity removal is obtained by RSM (Design Expert 11) according to Eq. 14.

$$\text{Turbidity Removal (\%)} = 93.9293 - 2.37556A + 0.609093B + 0.534959C - 0.238754AB - 0.137921AC - 0.133093BC - 0.186216A^2 - 0.0320387B^2 + -0.21838\,C^2 \quad (14)$$

Interactions of different parameters and responses by DC, AC, SDC, and SAC

The interactions of different parameters and the responses by electrocoagulation method is shown in Figures 4 and 5.

Comparison of SDCE and SACE process

An experiment was conducted to analyze the color and turbidity removal rate by comparing DCE, ACE, SDCE, and SACE methods using domestic wastewater. The results are shown using operating conditions such as COD- of

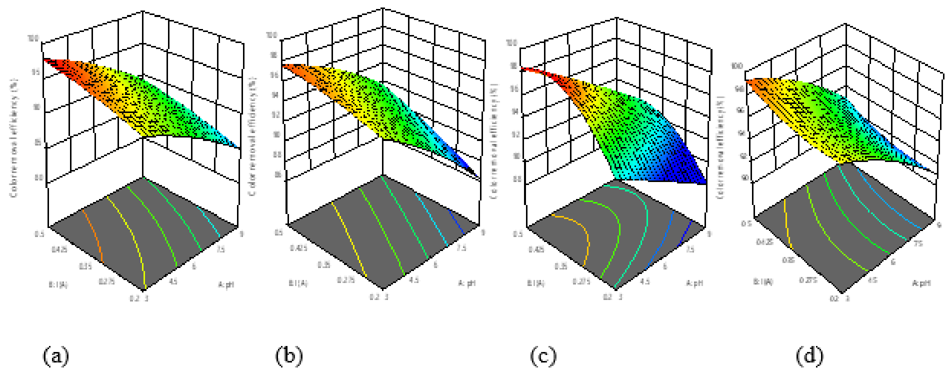


Figure 4. Three-dimensional color removal response surface graphs for DC (a), AC (b), (c) SDC, and (d) SAC versus pH, time, and current.

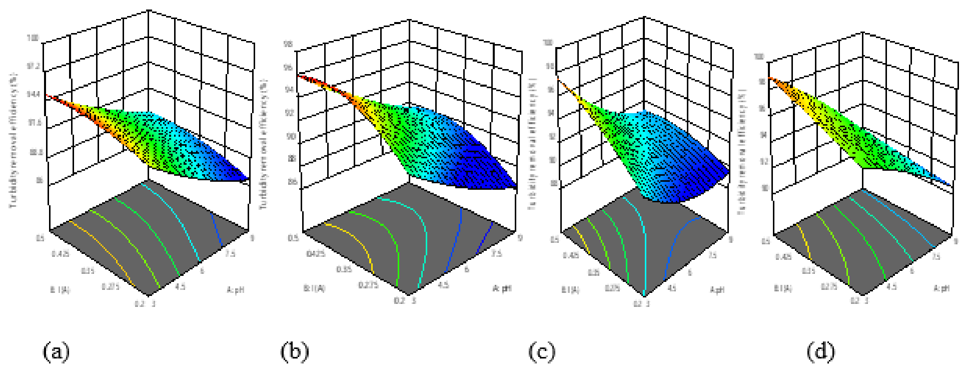


Figure 5. Three-dimensional turbidity removal response surface graphs for DC (a), AC (b), (c) SDC, and (d) SAC versus pH, time, and current.

960 mg/L, wastewater pH-of 6.8, current density –of 0.50 A, electrode spacing-of 1 cm, electrode combination-of Al/Al, and reaction time-of 1 hour. According to Figures 1 and 2, it can be seen that the percentage of color and turbidity removal is higher in the ACE process than that in the DCE process and higher in the SACE than in the SDCE process. This is because ACE and SACE having lower sludge formation and impermeable layer formation than DCE and SDCE processes according to the study of Souza and Ruotolo (50). Therefore, when comparing DCE and ACE and SDCE and SACE methods to remove the percentage of color and turbidity from domestic wastewater, the ACE method is more appropriate than using the DCE method, and the SACE method is better than using the integrated SDCE procedure.

Conclusion

In this study, the application of DC, SDC, AC, and SAC electrocoagulation processes in the treatment of domestic wastewater was compared. Under optimal experimental conditions, SAC and AC electrocoagulation had a higher color and turbidity removal rate and less sludge formation than the SDC and DC electrocoagulation. In the SAC and AC electrocoagulation methods, current density, initial sewage pH, and pollutant concentration are the main factors that affect the color and turbidity removal rate from domestic wastewater. With SAC and AC electrocoagulation, the maximum removal efficiency was obtained at pH-3 and obtained as 99.95% of color, and 99.76% of turbidity for SAC, and 98.35% of color, and 96.12% of turbidity for AC. However, the SDC and DC electrocoagulation method had the maximum removal efficiency of color, and turbidity at pH-3, so that the removal efficiency of color and turbidity by SDC was obtained as 98.55% and 98.27%, respectively, and the removal efficiency of color and turbidity by DC electrocoagulation method was 97.53% and 95.28%, respectively. Thus, the SAC and AC electrocoagulation methods produced less sludge and had a much higher water recovery rate than the SDC and DC electrocoagulation methods. Therefore, it can be concluded that the SAC electrocoagulation method is the best and a novel technique compared to all electrocoagulation methods.

Acknowledgments

The authors would like to express their gratitude to Jimma Institute of Technology, Jimma University for supporting this experimental study.

Ethical Issues

The authors hereby certify that all data collected in the field of study were described in the manuscript and no data from the study have been or will be published separately elsewhere.

Competing Interests

The authors declare that there are no conflicts of interests.

Authors' contributions

All authors have contributed to the data collection, analysis, and interpretation. All authors have reviewed, improved, and approved the manuscript.

Supplementary files

Supplementary file 1 contains Figure S1 and Tables S1-S8.

Reference

1. Winiwarter V, Schmid M, Dressel G. Looking at half a millennium of co-existence: The Danube in Vienna as a socio-natural site. Water Hist 2013; 5: 101-19. doi: 10.1007/s12685-013-0079-x.
2. Zhang J. Recent trends and research strategies for wastewater treatment in China. Water Cons and Wastewater Treat in BRICS Nations 2020; 169-86. doi: 10.1016/B978-0-12-818339-7.00008-4.
3. Lu Y, Song S, Wang R, Liu Z, Meng J, Sweetman AJ, et al. Impacts of soil and water pollution on food safety and health risks in China. Environment International 2015; 77: 5-15. doi: 10.1016/j.envint.2014.12.010.
4. Abreham Bekele Bayu. Conversion of degradable municipal solid waste into fuel briquette: Case of jimma city municipal solid waste. Iranian Journal of Energy and Environment 2020; 11(2): 122-9. doi: 10.5829/ijee.2020.11.02.05.
5. Alka S, Shahir S, Ibrahim N, Ndejiko MJ, Vo D-VN, Manan FA. Arsenic removal technologies and future trends: A mini review. J Clean Prod 2021; 278: 123805. doi: 10.1016/j.jclepro.2020.123805.
6. Falguera V, Aliguer N, Falguera M. An integrated approach to current trends in food consumption: Moving toward functional and organic products?. Food Control 2012; 26(2): 274-81. doi: 10.1016/j.foodcont.2012.01.051.
7. Amibo TA, Bayu AB, Akuma DA. Polyethylene terephthalate wastes as a partial replacement for fine aggregates in concrete mix, case of Jimma town, south west ethiopia. Sriwijaya Journal of Environment 2021; 6(1): 20-35. doi: 10.22135/sje.2021.6.1.20-35.
8. Bekele Bayu A, Beyecha Hundie K. Conversion of Degradable Solid Waste into alternative energy using local wastes as a binder, case of southwestern ethiopia. Sriwijaya Journal of Environment 2021; 5(3): 134-41. doi: 10.22135/sje.2020.5.3.134-141.
9. Woldegebriel A, Amibo TA, Bayu A. Evaluation of groundwater potential zone using remote sensing and geographical information system: In Kaffa Zone, South Western Ethiopia. Sriwijaya Journal of Environment 2021; 6(2): 36-52. doi: 10.22135/sje.2021.6.2.36-52.
10. Chakraborty SK. River pollution and perturbation: Perspectives and processes. Riverine ecology volume 2, biodiversity conservation, conflicts and resolution. Springer Nature 2021. P. 443-530. doi: 10.1007/978-3-030-53941-2_5.
11. Zorpas AA, Lasaridi K, Voukkali I, Loizia P, Chroni C. Household waste compositional analysis variation from insular communities in the framework of waste prevention strategy plans. Waste Manag 2015; 38: 3-11.doi: 10.1016/j.wasman.2015.01.030.
12. Undabeytia T, Shuali U, Nir S, Rubin B. Applications of chemically modified clay minerals and clays to water purification and slow release formulations of herbicides.

Minerals 2020; 11: 9. doi: 10.3390/min11010009.
13. Bhat AP, Gogate PR. Cavitation-based pre-treatment of wastewater and waste sludge for improvement in the performance of biological processes: A review. J Environ Chem Eng 2021; 9(2): 104743. doi: 10.1016/j.jece.2020.104743.
14. Li J, Li C, Zhao L, Pan X, Cai G, Zhu G. The application status, development and future trend of nano-iron materials in anaerobic digestion system. Chemosphere 2021; 269: 129389. doi: 10.1016/j.chemosphere.2020.129389.
15. Young W, Hwang K, McDonald S, Oates CJ. Sustainable consumption: Green consumer behaviour when purchasing products. Sustainable Development 2010; 18(1): 20-31. doi: 10.1002/sd.394.
16. Banerjee O, Cicowiez M, Horridge M, Vargas R. Evaluating synergies and trade-offs in achieving the SDGs of zero hunger and clean water and sanitation: An application of the IEEM platform to guatemala. Ecological Economics 2019; 161: 280-91. doi: 10.1016/j.ecolecon.2019.04.003.
17. Thakur S, Chaudhary J, Kumar V, Thakur VK. Progress in pectin based hydrogels for water purification: Trends and challenges. J Environ Manage 2019; 238: 210-23. doi: 10.1016/j.jenvman.2019.03.002.
18. Hashim KS. The innovative use of electrocoagulation-microwave techniques for the removal of pollutants from water. [Disertation]. Liverpool John Moores University: Liverpool John Moores University; 2017.
19. Robles-Gonzalez V, Galindez-Mayer J, Rinderknecht-Seijas N, Poggi-Varaldo HM. Treatment of mezcal vinasses: A review. J Biotechnol 2012; 157(4): 524-46. doi: 10.1016/j.jbiotec.2011.09.006.
20. Hashim KS, Al Khaddar R, Jasim N, Shaw A, Phipps D, Kot P, et al. Electrocoagulation as a green technology for phosphate removal from river water. Sep Purif Technol 2019; 210: 135-44. doi: 10.1016/j.seppur.2018.07.056.
21. Mohammadi L, Rahdar A, Bazrafshan E, Dahmardeh H, Susan MABH, Kyzas GZ. Petroleum hydrocarbon removal from wastewaters: A review. Processes 2020; 8: 447. doi: 10.3390/pr8040447.
22. Shan M, Zhu C, Zhou X, Yin C, Han Q. Investigation of cavitation bubble collapse near rigid boundary by lattice Boltzmann method. J Hydrodyn 2016; 28: 442-50. doi: 10.1016/S1001-6058(16)60647-9.
23. Zong Y, Mao Y, Xu L, Wu D. Non-selective degradation of organic pollutants via dioxygen activation induced by Fe(II)-tetrapolyphosphate complexes: Identification of reactive oxidant and kinetic modeling. Chemical Engineering Journal 2020; 398: 125603. doi: 10.1016/j.cej.2020.125603.
24. Naidoo S, Olaniran AO. Treated wastewater effluent as a source of microbial pollution of surface water resources. Int J Environ Res Public Health 2013; 11(1): 249-70. doi: 10.3390/ijerph110100249.
25. Venkatesa Prabhu S, Ramesh G, Adugna AT, Beyan SM, Gizachew Assefa K. Kinetics of iron bioleaching using isolated leptospirillum ferriphilum: Effect of temperature. International Journal of Innovative Technology and Exploring Engineering 2019; 8(12): 2278-3075. doi: 10.35940/ijitee.L3210.1081219.
26. Latebo S, Bekele A, Abeto T, Kasule J. Optimization of Trans-esterification process and characterization of biodiesel from soapstock using silica sulfuric acid as a heterogeneous solid acid catalyst. J Eng Res 2021; 10(1): 78-100. do: 10.36909/jer.12003.
27. Amibo TA, Beyan SM, Damite TM. Production and optimization of bio-based silica nanoparticle from teff straw (eragrostis tef) using rsm-based modeling , characterization aspects , and adsorption efficacy of methyl orange dye. Journal of Chemistry 2022; 2022: 1-15. doi: 10.1155/2022/9770520.
28. Venkatesa PS, Girma G, Gizachew AK, Surafel BM, Ramesh G. Biosolubilization of Cr (VI) from tannery sludge: Process modeling, optimization, rate kinetics and thermodynamics aspects. Int J Recent Technol Eng 2019; 8(4): 4808-16. doi: 10.35940/ijrte.D7771.118419.
29. Mustefa Beyan S, Venkatesa Prabhu S, Mumecha TK, Gemeda MT. Production of alkaline proteases using aspergillus sp. isolated from Injera: RSM-GA based process optimization and enzyme kinetics aspect. Curr Microbiol 2021; 78: 1823-34. doi: 10.1007/s00284-021-02446-4.
30. Beyan SM, Prabhu SV, Ambio TA, Gomadurai C. A statistical modeling and optimization for cr (vi) adsorption from aqueous media via teff straw-based activated carbon: Isotherm, kinetics, and thermodynamic studies. Adsorption Science & Technology 2022; 2022: 1-16. doi: 10.1155/2022/7998069.
31. Amibo TA, Beyan SM, Damite TM. Novel lanthanum doped magnetic teff straw biochar nanocomposite and optimization its efficacy of defluoridation of groundwater using RSM: A case study of Hawassa City, Ethiopia. Materials Science and Engineering 2021; 2021: 1-15. doi: 10.1155/2021/9444577.
32. Beyan SM, Amibo TA, Prabhu SV, Ayalew AG. Production of nanocellulose crystal derived from enset fiber using acid hydrolysis coupled with ultrasonication, isolation, statistical modeling, optimization, and characterizations. J Nanomater 2021; 2021: 1-12. doi: 10.1155/2021/7492532.
33. Mumecha TK, Surafel Mustefa B, Venkatesa Prabhu S, Zewde FT. Alkaline protease production using eggshells and membrane-based substrates: Process modeling, optimization, and evaluation of detergent potency. Eng Appl Sci Res 2021; 48(2): 171–80.
34. Beyan SM, Prabhu SV, Sissay TT, Getahun AA. Sugarcane bagasse based activated carbon preparation and its adsorption efficacy on removal of BOD and COD from textile effluents: RSM based modeling, optimization and kinetic aspects. Bioresour Technol Rep 2021; 14: 100664. doi: 10.1016/j.biteb.2021.100664.
35. Asrat Y, Adugna AT, Kamaraj M, Beyan SM. Adsorption phenomenon of arundinaria alpina stem-based activated carbon for the removal of lead from aqueous solution. J Chem 2021; 1-9. doi: 10.1155/2021/5554353.
36. Kidus Tekleab W, Beyan SM, Balakrishnan S, Admassu H. Chicken feathers based Keratin extraction process data analysis using response surface-box-Behnken design method and characterization of keratin product. Curr Appl Sci Technol 2020; 20(2): 163-77. doi: 10.14456/cast.2020.6.
37. Amibo TA. Modeling and pulping variables optimization of ethanol-alkali pulping and delignification of grevillea robusta in ethiopia by response surface methodology. European Journal of Materials Science and Engineering 2021; 6(1): 34-51. doi: 10.36868/ejmse.2021.06.01.034.
38. Beyecha Hundie K, Bekele Bayu A. Optimization of hydrolysis conditions using central composite design to convert corn stover to bioethanol. European Journal of Materials Science and Engineering 2020; 5(4): 234-45. doi:

10.36868/ejmse.2020.05.04.234.
39. Amibo TA, Bayu AB. Calcium carbonate synthesis, optimization and characterization from egg shell. Int J Mod Sci Technol 2020; 5(7): 182-90.
40. Sanchez B, Rojas CR, Vandersteen G, Bragos R, Schoukens J. On the calculation of the D -optimal multisine excitation power spectrum for broadband impedance spectroscopy measurements. Meas Sci Technol 2012; 23(8): 085702. doi: 10.1088/0957-0233/23/8/085702
41. Naje AS, Chelliapan S, Zakaria Z, Ajeel MA, Alaba PA. A review of electrocoagulation technology for the treatment of textile wastewater. Rev Chem Eng 2017; 33(3): 263-92. doi: 10.1515/revce-2016-0019.
42. Dhanabalan SC, Dhanabalan B, Chen X, Ponraj JS, Zhang H. Hybrid carbon nanostructured fibers: Stepping stone for intelligent textile-based electronics. Nanoscale 2019; 11(7): 3046-101. doi: 10.1039/C8NR07554A.
43. Amibo TA, Beyan SM, Mustefa M, Sundramurthy VP, Bayu AB. Development of nanocomposite based antimicrobial cotton fabrics impregnated by nano SiO_2 loaded AgNPs derived from *Eragrostis Teff straw* . Materials Research Innovations 2021; 2021: 1-15. doi: 10.1080/14328917.2021.2022372.
44. Rani M, Shanker U. 2-Green synthesis of TiO_2 and its photocatalytic activity. In: Andbook of smart photocatalytic materials fundamentals, fabrications, and water resources applications. Elsevier; 2020; P. 11-61. doi: 10.1016/B978-0-12-819051-7.00002-6.
45. Vasudevan S, Lakshmi J. Electrochemical removal of boron from water: Adsorption and thermodynamic studies. Can J Chem Eng 2012; 90(4): 1017-26. doi: 10.1002/cjce.20585.
46. Shahamat YD, Farzadkia M, Nasseri S, Mahvi AH, Gholami M, Esrafili A. Magnetic heterogeneous catalytic ozonation: A new removal method for phenol in industrial wastewater. J Environ Health Sci Eng 2014; 12(1): 50. doi: 10.1186/2052-336X-12-50.
47. Sayara T, Khayat S, Saleh J, Van Der Steen P. Evaluation of the effect of reaction time on nutrients removal from secondary effluent of wastewater: Field demonstrations using algal-bacterial photobioreactors. Saudi J Biol Sci 2021; 28(1): 504-11. doi: 10.1016/j.sjbs.2020.10.035.
48. Atamaleki A, Miranzadeh M, Mostafaii GR, Akbari H, Iranshahi L, Ghanbari F, et al. Effect of coagulation and sonication on the Dissolved Air Flotation (DAF) process for thickening of biological sludge in wastewater treatment. Environ Health Eng Manag 2020; 7(1): 59-65. doi: 10.34172/EHEM.2020.08.
49. Soubh A, Abdoli M, Ahmad LA. Optimizing the removal of methylene blue from aqueous solutions using persulfate activated with nanoscale zero valent iron (nZVI) supported by reduced expanded graphene oxide (rEGO). Environ Health Eng Manag 2021; 8(1): 15-24. doi: 10.34172/EHEM.2021.03.
50. Souza RBA, Ruotolo LAM. Electrochemical treatment of oil refinery effluent using boron-doped diamond anodes. Engineering 2013; 1(3): 544-51. doi: 10.1016/j.jece.2013.06.020.