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Evaluation of operational parameters for the removal of turbidity and total coliform from wastewater using fabricated electrocoagulation treatment unit

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ABSTRACT

The purpose of this study was to design and fabricate a prototype electrocoagulation wastewater treatment unit. The treatment system consist of wastewater storage tank, reactor tank with electrodes, treated water collection tank, filtration unit, filtered water storage tank, DC power supply. The study focuses on the effect of electrocoagulation treatment unit on treatment of wastewater containing physical and biological impurities using aluminium and iron electrodes. The aluminium electrodes used as anode and iron electrodes used as cathode. This study was based on treatment of synthetic wastewater containing turbidity and total coliform colonies. The unit was optimized at various operating conditions including pH, current density, and contact time. Impurities removal efficiency of designed Electrocoagulation (EC) unit was investigated at various conditions. Batch flow system was used for operation of reactor. From the experiments, the best turbidity removal efficiency was 94% at 6.5 pH, 18 mins and 3 A and for total coliform the removal efficiency was 98.95 % at 6.5 pH, 18mins and 3A. Results showed that aluminium and iron electrode are very effective electrode material for removal of physical and biological impurities cost effectively.

1. Introduction

Nowadays the main tasks for human beings is to make available fresh water to a huge number of people throughout the earth. Necessity of fresh water is mainly acute in Third-World Nation states [1]. Watercourses, channels, creeks and additional water containing areas are being continuously contaminated because of unselective release of industrialized discharges as well as additional human actions and natural practices because of demands of industries and domestic wastewater treatment in order to avoid environmental pollution and especially contamination of pure water resources are becoming national and international issues [2-3]. The discharge of feces from the body and urination mostly occur near water origins; like abstraction wells and other water bodies [4]. Such drinking water sources become contaminated with pathogenic organisms due to the waste of human and animal excreta. Individuals in underdeveloped nations might not have other choice for drinking water, due to the scarcity of water, lack of water treatment plants and the environmental conditions of the area [5]. More than one billion individuals every year are getting into contact to unprotected portable water because of bad source impure water quality and lack of satisfactory water treatment [6]. The presence of particulate materials such as algae, clays, silts, organic particles and soluble substances in water often causes it to get turbid or coloured [7]. Small particles, especially those with density close or less than to water such as bacteria and colloidal particles may never settle and remain suspended in the water. Therefore, agglomeration of particles into a larger floc is a necessary step for their removal by sedimentation [8] .Extremely established nations, such as the US, are also facing a serious necessity for wastewater treatment due to continuously growth in population, city expansion and climatic changes. The recycle of wastewater has turn out to be a completely essential [9]. Hence there is a crucial necessity to flourish advanced, efficient and low-cost systems for treating of wastewater. An extensive variety of wastewater cleaning methods are recognized which consist of biological process as well as a choice of physical and chemical methods which require chemical additions [10]. Frequent usage of physical and chemical cleaning procedures is filtration, air stripping, ion-exchange, chemical precipitation, chemical oxidation, carbon adsorption, ultrafiltration, RO, electro dialysis, volatilization, gas stripping and solar disinfection [11-12]. By cloud of identical favourable procedures built on EC technique are getting established, additionally present methods are upgraded which ensure no any addition of chemical [13]. These include electrocoagulation, electro flotation, electro decantation, and others [14]. From all the above, one of the best is electrocoagulation that is proofed to be cost-effective but till now it is less considered during technical consideration [15].

Electrocoagulation is currently a recognized water cleaning technique. This one is established on in situ electrolytic disbanding of the anode terminal besides might be freely automatic. At the same time by the anodic response, gas soap suds are produced at the cathode physique, supporting electro flotation. Typically, aluminium, iron, or stainless steel be there utilized by way of the conductor tools [16-17]. The popularity of these substance such as aluminium, Iron is in line for to their accessibility, low-cost , harmless in sense of toxicity, and demonstrated as efficient [18]. EC can be used for treatment of different types of water such as tannery and dyeing wastewater, organic wastewater, sewage, drinking water and heavy metal wastewater [19]. The removal mechanism for every pollutant varies much more it also changes as per factors being considered during the treatment of wastewater containing different compounds. This treatment is complex process having various interactive operation and removal mechanism as per type of pollutants. Even the design configuration of reactor also varies as per desired need of treatment [20]. The mass of aluminium and iron electrodes decreased as the time of electrolysis increased and there is more consumption of electrode mass in acidic media. Electrodes life or consumption is depended of type of current applied. Electrodes consume at high quantity when AC current is applied moreover when DC current is applied electrodes consume at negligible amount [21].

The ultimate goal of wastewater treatment through EC as disinfection unit is to produce an effluent of such quality (dependent upon final use) that minimal additional controls are needed to manage any human health, agricultural or environmental risks. When reuse involves high-level risks of exposure for humans or livestock, that water will require disinfection processes to achieve the treatment levels set in the Guidelines of WHO [22]. The key intentions of this study is the way to conclude the best functioning factors accompanying using a worktable measure electrocoagulation component utilized for the treatment of synthetic wastewater. This study focus mainly on the development of prototype electrocoagulation water treatment unit. The quality of synthetic wastewater containing turbidity and total coliform were assessed at various pH, time and current density by treating the synthetic wastewater through this unit.

2. Materials and Methodology

2.1 Materials

Materials used in the study include Kaolin for increasing the turbidity, EMB Agar to use it as medium for growth of colonies, filter papers for filtering the water and aluminium and iron electrode for treating the water in electrocoagulation unit. This study focuses on the removal of turbidity and bacteria from synthetic wastewater prepared at laboratory.

2.2 Design of Electrocoagulation Unit

The electrocoagulation unit was designed and operated for the removal of physicochemical and biological impurities of water. Electrocoagulation treatment unit design include a storage tank with a capacity of 15 L, installed before the reactor so as to use it as wastewater storage tank. The inlet valve is installed to flow out wastewater to reactor. The wastewater supplied through inlet valve is treated in electrocoagulation reaction tank which consist of the aluminium electrodes as anode with a size of 6 x 6 in^2 and 3 mm thick whereas iron electrodes as cathode with a size of 6 x 6 in^2 and 1.5 mm thick and quantity of electrode was varied according to the requirement. The electrodes were square in shape which were arranged with a space of 1inch between them with submerged area of 30 in^2 each. The electrode arrangement is monopolar. In monopolar arrangements, the performance improvement is achieved by using EC cells with monopolar electrodes in parallel combinations. The reactor tank also consist of mixing pump which help in stabilizes the quality of water. The electrodes are connected to DC transformer comprising of range of 0-50 V and 0-10 A as shown in Figs. 1 and 2. The treated water is flowed out of the reaction chamber secondary tank for self-settling process and the self-settled water is further released from secondary tank with help outlet valve and transferred to the filtration unit and filtered water will be tested for microbial and physicochemical parameter analysis.

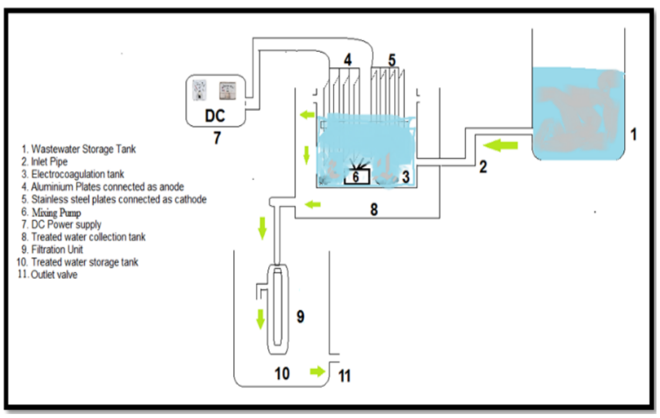

Fig. 1. Design structure of electrocoagulation treatment unit

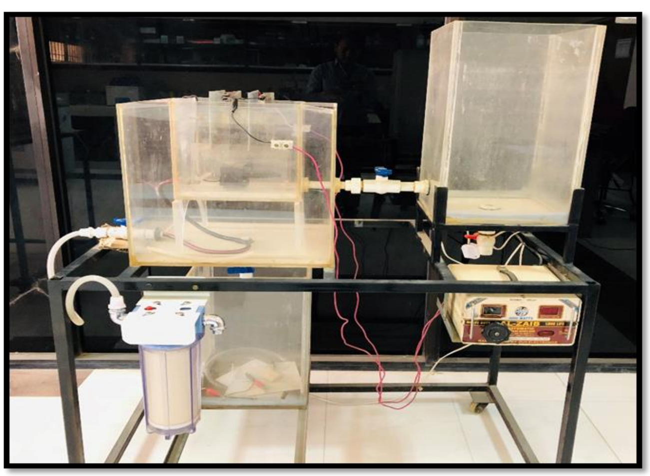

Fig. 2. Setup for electrocoagulation treatment unit

2.3 Sample Preparation and Analysis

2.3.1 Preparation of synthetic wastewater containing turbidity

An artificial turbid wastewater was prepared by addition of kaolin solution to tap water. Kaolin solution was prepared, by adding five grams of laboratory grade kaolin (Anachemia AC-5302) into a litre of water. About 1000 mL of kaolin solution was added to 20 L and to obtain 250 NTU [23]. The samples were analysed by turbidity meter which determine the turbidity of water.

2.3.2 Preparation of synthetic wastewater containing bacterial contamination

An artificial bacterial contaminated wastewater was be prepared by addition of wastewater in surface water. Before treatment the numbers of colonies of total coliform were identified in the wastewater. To test wastewater containing bacterial contamination were analysed by membrane filtration technique using Millipore Membrane Filtration Assembly, a 100 mL sample is tested for Coliform Forming Unit [24]. Overall bacteria from water sample will be filtered by filter paper. The filter paper was placed in EMB agar medium that are further incubated at a temperature of 35 + 0.5°C for 24 h. Bacteria generate lactose in the agar medium and yield an acid-aldehyde compound combines with Schiff's layer over the colonies which are viewed under 10-15 X magnification using colony counter.

2.4 Operation of Electrocoagulation Reactor

This includes the removal of multiple physical and biological parameters. The parameters removed from wastewater include turbidity and total coliform. All the parameters removal involves variable conditions till best efficiency achieved. The overall reactions involved in this system include seeding which is the reduction of metallic ions from anode electrode in order to form new larger particles with high stability, the next is emulsion breaking in which oxygen and hydrogen ions are broken down from water available in the reactor [25]. Another is bleaching process in which oxygen ions available in the reactor helps in oxidizing the bacteria, biohazards, cyanides, dyes, virus, etc. Afterwards oxidation reduction process takes place, in this process the reaction is finally moved towards its natural end point inside the reactor and rapidly the natural process occurs like it occurs in the wet chemistry [26].

The removal of the turbidity involves the preparation of synthetic turbid wastewater by adding kaolin solution to portable water. For performance evaluation of EC unit for turbidity removal, total 24 samples were treated of varying turbidity levels. The variable operational parameter for the turbidity removal were pH within the range of 5.5 to 8.5, contact time i.e. 06 to 18 min, and current density of 1.5A and 3 A. Turbidity was analysed by turbidity meter (Lovibond).

In order to remove biological impurities from synthetic wastewater, firstly an artificial bacterial contaminated wastewater was prepared by addition of sewerage wastewater in surface water. The evaluation of total coliform using EC treatment method involve 24 number of sample containing variable total coliform colonies under various operational parameter for the total coliform removal include pH within the range of 5.5 to 8.5, contact time i.e. 06 to 18 min, and current density of 1.5 A and 3 A. Total coliform colonies were analysed using membrane filtration technique.

3. Result and Discussion

The result for the treatment of wastewater containing Turbidity and Total Coliforms using electrocoagulation at various operating parameters are given below.

3.1 Removal of Turbidity

During the operation of the electrocoagulation treatment unit for the removal of turbidity from synthetic wastewater, the removal efficiency was observed at variable parameters. These parameters include pH, current density, contact time and electrode material. To find the effect of each parameter, the remaining parameters were kept unvaried. Water turbidity removal efficiency was observed at fixed 1.5 A current density with variable pH as 5.5, 6.5, 8.5 and reaction time as 6, 12, 18 min. Higher removal efficiency i.e. 90% was observed at 18 minutes having pH as 6.5 and current density 1.5 A as shown in Table 1.

During second experiment water turbidity removal efficiency was observed at fixed 3 A current density with variable pH as 5.5, 6.5, 8.5 and reaction time as 6, 12, 18 min. Higher removal efficiency i.e. 94% was observed at 12 min having pH as 6.5 and current density 3 A as shown in Table 2. This is due to the electrolytic addition of coagulating metal ions directly from sacrificial electrodes. These ions coagulate with turbidity agents in the water, in a similar manner to the addition of coagulating chemicals such as alum and ferric chloride, and allow the easier removal of the pollutants [27].

Table 1

Turbidity removal efficiency at 1.5 A

S. No.	pH	Current Density (A)	Time of Contact (min)	Initial Turbidity (NTU)	Final Turbidity (NTU)	Removal Efficiency (%)
1	5.5	1.5 A	6	165	80	51.52
2			12	205	61	70.24
3			16	210	39	81.43
4			18	220	37	83.18
5	6.5	1.5 A	6	202	73	63.86
6			12	198	49	75.25
7			16	201	27	86.57
8			18	222	22	90.09
9	8.5	1.5 A	6	206	107	48.06
10			12	216	71	67.13
11			16	199	40	79.90
12			18	209	41	80.38

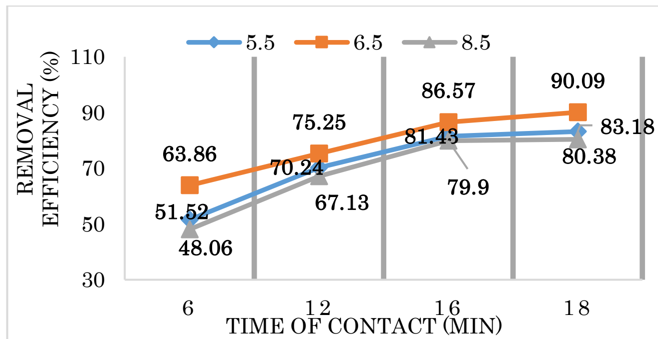

Fig. 3. Time optimization for turbidity removal for 1.5 A

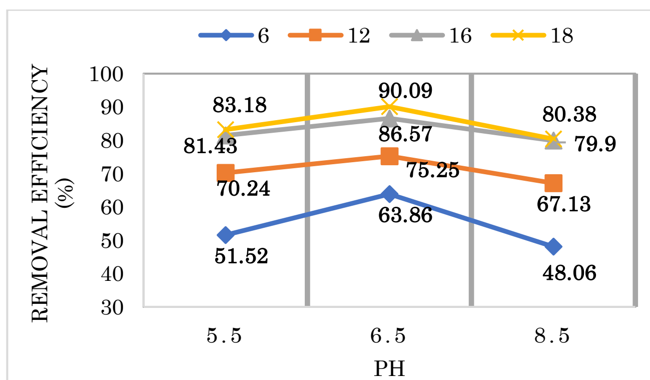

Fig. 4. pH optimization for turbidity removal for 1.5 A

Another factor affecting the turbidity removal is pH. When pH slightly acidic more H^+ ions are produced and there is greater conductivity due to which more ions are released that forms flocs and settlement process is increased The turbidity removal efficiency using aluminium and iron electrodes increased as the initial pH increased from 5.5 to reach its maximum value at pH 6.5 and then declined with further increase of pH as 8.5. This change of turbidity removal with the initial pH is mainly attributed to the predominant species of aluminium where in neutral pH the majority of aluminium coagulants were formed and there are oxidants such as oxygen, present in sufficient concentration, Fe^{2+} is oxidized in bulk solution to Fe^{3+} which is good coagulant hence increases the removal efficiency [28].

Table 2

Turbidity removal efficiency at 3 A

S. No.	pH	Current Density (A)	Time of Contact (min)	Initial Turbidity (NTU)	Final Turbidity (NTU)	Removal Efficiency (%)
1	5.5	3 A	6	206	107	48.06
2			12	216	71	67.13
3			16	199	40	79.90
4			18	209	41	80.38
5	6.5	3 A	6	201	80	60.20
6			12	205	53	74.15
7			16	210	27	87.14
8			18	220	13	94.09
9	8.5	3 A	6	165	39	76.36
10			12	205	37	81.95
11			16	204	33	83.82
12			18	198	27	86.36

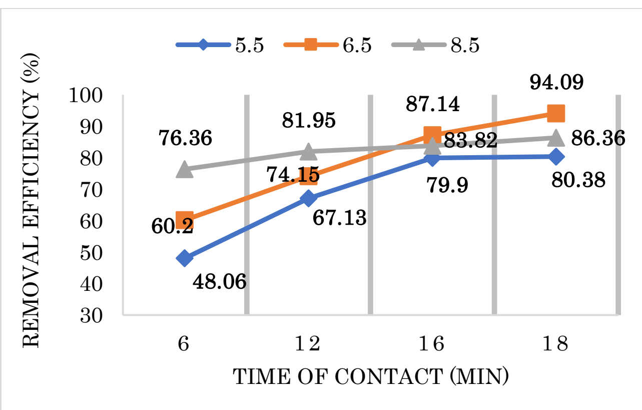

Fig. 5. Time optimization for turbidity removal for 3 A

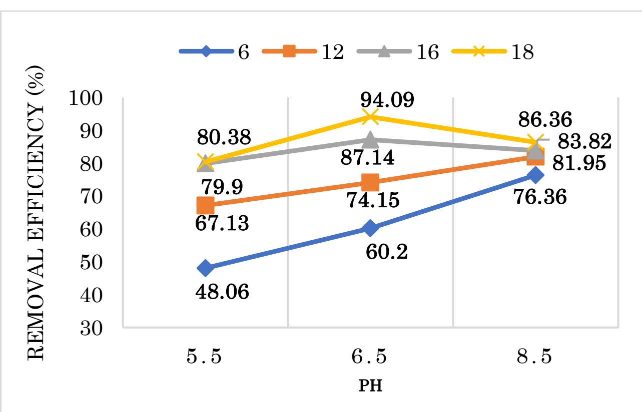

Fig. 6. pH optimization for turbidity removal for 3 A

3.1.1 Effect of operational parameters on turbidity removal

The Figs. 3 and 5 above represent the influence of contact time on turbidity removal efficiency. The removal efficiency was determined at variable time interval i.e. 6, 12, 16, 18 min. The removal efficiency increases promptly and reaches to approximate 94% at 18 minutes and heading towards the constant removal efficiency. The pH of wastewater is highly important in treatment using electrocoagulation method. This study is carried by keeping the pH in the range from 5.5 to 8.5. The best turbidity reduction percentage was obtained at neutral pH using electrocoagulation treatment method. The above Figs. 4 and 6 show that highest turbidity removal efficiency was obtained at 6.5 pH at variable current density and time of contact. The applied current at electrodes is most important constraint which affects the removal efficiency. In order to find the effect of current density, the turbid water was treated with variable current density i.e. 1.5 A and 3 A. All the current density produced variable turbidity removal efficiency. The turbidity removal increased with change in current density. The best removal was found at 3 A with efficiency of 94%. The electrode material also plays an important role in removal of turbidity from water. The combined effect of aluminium and iron electrode showed best removal efficiency of turbidity as 94% at 6.5 pH, 3 A and 18 min.

$$\text{Energy Consumption (kWh)} = \frac{EIt_{EC}}{(C_o - C_t)V} \quad (1)$$

Using Eq. 1, when E = 28 V, I = 3 A, $t_{EC} = 18\,min = \frac{18}{60}\,h$, C_o = 220 NTU, C_t = 13 NTU, V = 10 L, then

$$\text{Energy Consumption} = \frac{28\times3\times0.3}{(220-13)10} = 0.012\,kWh.$$

3.2 Removal of Total Coliform

During the operation of the electrocoagulation treatment unit for the removal of total coliform from synthetic wastewater, the removal efficiency was observed at variable parameters. These parameters include pH, current density, contact time and electrode material. To find the effect of each parameter, the remaining parameter was kept unvaried. Bacterial (total coliform) removal efficiency was detected at 1.5 A current density with the variability in pH as 5.5, 6.5, 8.5 and reaction time as 6, 12, 18 min. The higher removal efficiency was witnessed at 18 min having pH as 6.5 and current density 1.5 A as shown in Table 3.

During the second attempt for removal of total coliform at 3 A current density at variable pH as 5.5, 6.5, 8.5 and reaction time as 6, 12, 18 min. The total coliform removal efficiency was 98%, was observed at 12 min having pH as 6.5 and current density 3 A as shown in Table 4.

Table 3

Total Coliform removal efficiency at 1.5 A

S. No.	pH	Current Density (A)	Time of Contact (min)	Before Disinfection (CFU/100mL)	After Disinfection (CFU/100mL)	Removal Efficiency %
1	5.5	1.5 A	6	243	113	53.50
2			12	189	67	64.55
3			16	167	43	74.25
4			18	207	39	81.16
5	6.5	1.5 A	6	156	51	67.31
6			12	223	35	84.30
7			16	255	13	94.90
8			18	221	04	98.19
9	8.5	1.5 A	6	227	86	62.11
10			12	218	69	68.35
11			16	177	52	70.62
12			18	161	31	80.75

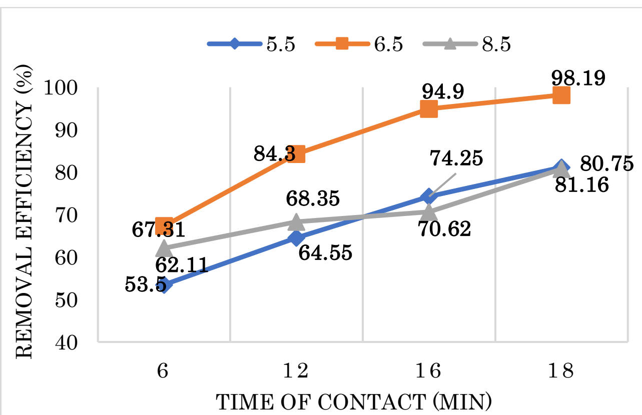

Fig. 7. Time optimization for total coliform removal for 1.5 A

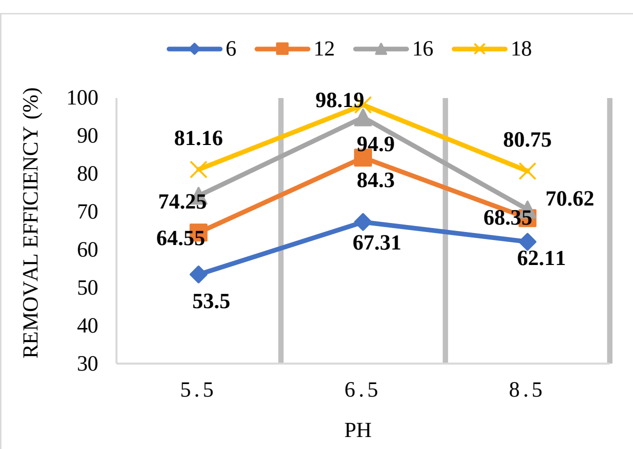

Fig. 8. pH optimization for total coliform removal for 1.5 A

Table 4

Total Coliform removal efficiency at 3 A

S. No.	pH	Current Density (A)	Time of Contact (min)	Before Disinfection (CFU/100mL)	After Disinfection (CFU/100mL)	Removal Efficiency (%)
1	5.5	3 A	6	197	88	55.33
2			12	226	53	76.55
3			16	211	45	78.67
4			18	187	27	85.56
5	6.5	3 A	6	176	39	77.84
6			12	205	4	98.05
7			16	211	3	98.58
8			18	191	2	98.95
9	8.5	3 A	6	143	54	62.24
10			12	191	69	63.87
11			16	215	52	75.81
12			18	183	31	83.06

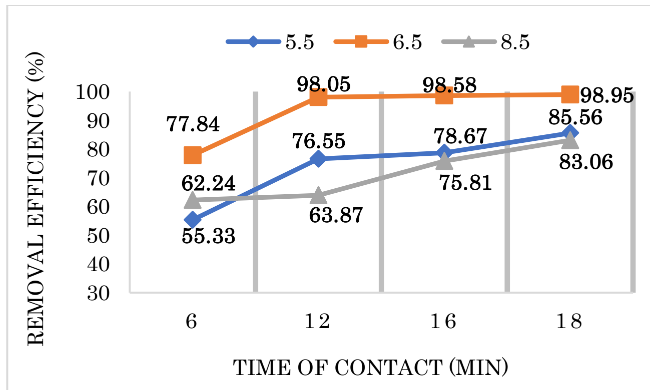

Fig. 9. Time optimization for total coliform removal for 3 A

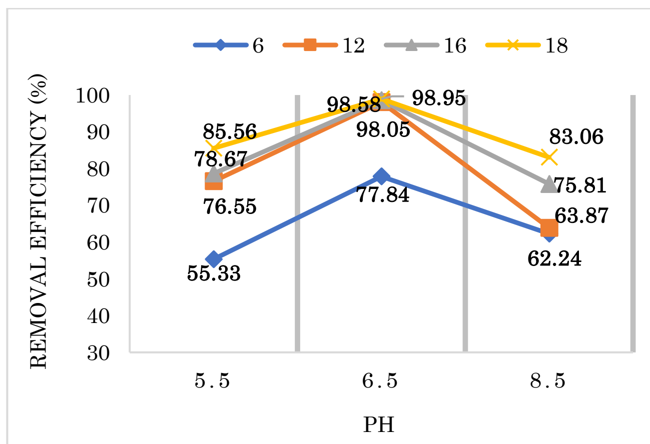

Fig. 10. pH optimization for total coliform removal for 3 A

3.2.1 Effect of operational parameters on total coliform removal

Figs. 7 and 9 present the impact of contact time on total coliform removal efficiency. The experiments were carried out to determine the removal percentage at various time lapse i.e. 6, 12, 16, 18 min. The removal efficiency increases quickly and reaches to 98% at 12 min and provides the constant removal efficiency.

The pH of wastewater is highly important in removal of total coliform using electrocoagulation treatment method. The experiment study was carried at pH between 5.5 and 8.5. The higher reduction percentage of total coliform was obtained at slightly acidic pH and neutral pH using electrocoagulation treatment method. Figs. 8 and 10 show high total coliform removal efficiency at 6.5 pH with variability in current density and time of contact. The current supplied to electrodes is vital in effecting the removal efficiency of total coliforms. In order to find the best removal efficiency by varying the applied current, the synthetic wastewater having bacterial contamination was treated at current density of 1.5 A, 3 A. During the experiment it was observed that current applied provide some removal efficiency and the best removal was achieved at 3 A with efficiency 98%. The electrode material plays vital role in removal of total coliform from wastewater. The combined effect of the electrodes used in the research i.e. aluminium and iron are much more effect in removal of total coliform and best percentage removal efficiency with respect to pH, current density, contact time and electrode material was 98% at 6.5 pH, 3 A and 12 min.

Using Eq. 1, when E = 28 V, I = 3 A, $t_{EC} = 12\,min = \frac{12}{60}\,h$, C_o = 205 CFU, C_t = 04 CFU, V = 10 L, then

Energy Consumption = $\frac{28 \times 3 \times 0.2}{(205 - 04)10} = 0.0083\,kWh.$

4. Conclusion

This study focuses on the removal of turbidity and total coliform by using electrocoagulation treatment unit and purpose of fabricating the pilot scale project is to use this project for treating of impurities in future at one platform. This treatment unit can be operated by varying some of the parameter such as pH, contact time, current density and electrodes materials (iron and aluminium). It is a user friendly interface experiment setup. Specifically, following conclusions are made.

1. Electrocoagulation is an investigational method where optimum conditions are determined. The values we obtain over the experiments are correlated and adjusted in order to account for adjusting the parameter required for removal of turbidity and total coliform.

2. It was concluded that turbidity removal efficiency was dependent on contact time, pH and current density. From the batch reactor experiment it was observed that turbidity removal was 90.1% at 1.5 A, 18 min and 6.5 pH, and 94% at 3 A, 18 min and 6.5 pH.

3. Similarly total coliform removal using electrocoagulation was found to be 98.2 % at 1.5 A, 18 min and 6.5 pH, and 98.95 % at 3 A, 18 min and 6.5 pH.

4. From the experimental results using acidic, neutral and alkaline pH condition of synthetic wastewater it was finally concluded neutral pH condition, maximum contact time and maximum current density proved highly effective in the removal of turbidity and total coliform.

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