



## Electrochemical treatment of skim serum effluent from natural rubber latex centrifuging units

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### ABSTRACT

Electrochemical treatment of raw and anaerobically treated skim serum effluent from natural rubber latex centrifuging units was investigated using different electrodes like aluminium, stainless steel, mild steel, and cast iron in the presence of chloride ions. Experimental results were assessed in terms of the removal of COD, biochemical oxygen demand (BOD), TKN, ammoniacal nitrogen, turbidity, sulphides and phosphates. The effect of operating factors such as supporting electrolyte, duration of electrolysis, pH, concentration of effluent and the presence of Fenton's reagent as chemical oxidant were studied. The influence of these factors on the biochemical constituents and population of total bacteria were also investigated. Aluminium anode was found to be more effective to remove pollutants and maximum removal of BOD took place within 30 min of electrolysis. After electrochemical treatment phosphate removal efficiency was 99.5% and complete removal of sulphide was observed from the anaerobically treated effluent. Electrochemical treatment is effective in removing biochemical constituents and total bacteria in the presence of Fenton's reagent.

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### 1. Introduction

Natural rubber (NR) latex is milky white or slightly yellowish opaque fluid of the rubber tree (*Hevea brasiliensis*). NR latex harvested from plantations needs to be processed soon after harvesting to maintain its quality. One of the major types of processed rubber is the preserved latex concentrate. Ammoniated field latex containing 30–33% rubber is concentrated by centrifuging to 60% rubber and skim latex (containing 4–6% rubber) using high speed centrifuges. The skim latex (contains about 0.8% ammonia) is coagulated with 98% sulphuric acid to recover rubber. The skim serum produced after coagulation of rubber is stored in a separate trap. The physico-chemical characteristics of skim serum effluent revealed that the effluent contains many hazardous constituents. Since concentrated sulphuric acid was used to coagulate skim latex and the pH of the serum effluent is around 3.6 it shows that it is highly acidic and therefore it is hazardous to environment if discharged without treatment. Also it contains high amount of ammoniacal nitrogen (AN) (5000 mg/L since ammonia is added to the fresh latex as a preservative), total Kjeldahl nitrogen (TKN) (7000 mg/L), phe-

nol, phosphate and heavy metals like Fe, Cu and Zn. In addition to this organic constituents present in the effluent may become hazardous to aquatic life if they are discharged to water bodies without any treatment. It also contains significant amount of non-rubbers which include proteins, sugars, carotenoids and organic and inorganic salts which originate from the latex and very little amount of uncoagulated latex [1]. These constituents are excellent substrates for the proliferation of microorganisms generating high biochemical oxygen demand (BOD) and objectionable odour and cause serious impact on the environment especially on water bodies since there is a wide network of streams near to the rubber processing units in Kerala. It needs proper treatment to minimise the threat to the environment. Biological treatment methods alone are unable to degrade it completely and further treatment is needed for the purification of this wastewater.

Electrochemical treatment is a non-biological and chemical free process which ensures a better quality of treated water. Electrochemical treatment method is widely accepted and applied because of its versatility, energy efficiency, amenability to automation and environmental compatibility [2]. The main reagent in the electrochemical treatment is the electron which is a "clean reagent" [3]. Electrolysis has been used for the treatment of various wastes and wastewaters from a number of industries, such as textile [4], food processing [5], tannery [6], dairy products [7], domestic wastewater [8], pharmaceutical wastewaters [9], cigarette industry wastewaters [10] and colour removal of distillery effluent [11]. Fenton's

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**Table 1**  
Characteristics of effluent used for electrochemical treatment.

| No. | Parameters      | RE     | ATE (1) | ATE (2) |
|-----|-----------------|--------|---------|---------|
| 1   | pH              | 3.6    | 8.2     | 8.5     |
| 2   | COD             | 38,800 | 10,900  | 4508    |
| 3   | BOD             | 27,650 | 7,890   | 1015    |
| 4   | TKN             | 7,000  | 2,380   | 4480    |
| 5   | AN              | 5,000  | 1,680   | 3500    |
| 6   | Phosphate       | 2,583  | 680     | 525     |
| 7   | Sulphide        | 14     | 45      | 235     |
| 8   | Turbidity (NTU) | 350    | 110     | 107     |

All values are in mg/L except pH and turbidity; RE, raw effluent; ATE, anaerobically treated effluent.

reagent was used for the treatment of olive oil mill and textile dyeing wastewater [12,13].

Investigation of the effect of anodic oxidation of raw and anaerobically treated skim serum effluent using different electrodes like aluminium, stainless steel (SS), mild steel (MS), and cast iron in the presence of chloride ions is the objective of the study. Fenton's reagent has been used as the chemical oxidant. Also studied the effect of several operating factors such as supporting electrolyte, duration of electrolysis, pH, concentration of effluent and the presence of chemical oxidant on the removal of chemical oxygen demand (COD), BOD, TKN, AN, turbidity, sulphides and phosphates. Also investigated the influence of these factors on the biochemical constituents and population of total bacteria.

## 2. Experimental

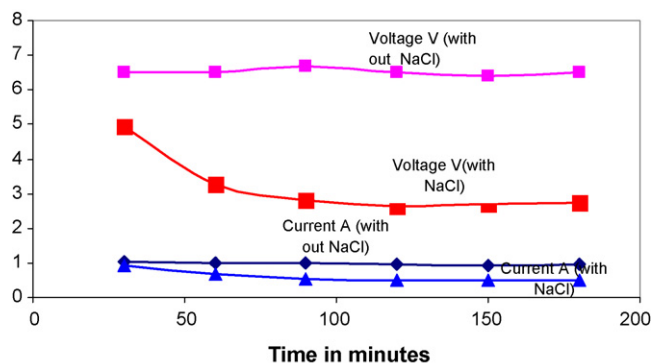
The skim serum effluent samples were collected from a centrifuge latex concentration unit in Kottayam district of central Kerala, India. To obtain anaerobically treated sample for the study, the effluent was subjected to anaerobic treatment in a bench scale an up-flow anaerobic sludge blanket (UASB) reactor. Raw and treated samples were analysed for various parameters as per standard methods [14] and the results of analysis are given in Table 1.

A glass reactor with a capacity of 500 cm<sup>3</sup> was used for all the electrocoagulation experiments. Plates made of cast iron, aluminium, mild steel and stainless steel (7 cm × 5 cm) were used as anodes. Graphite of similar geometric dimensions was used as the cathode. The area of the electrode exposed to electrolysis was fixed at 25 cm<sup>2</sup> and the remaining area was prevented from exposure. The cathode and anode were placed vertically and parallel to each other at a fixed distance of 2 cm apart using a non-conducting material in the electrolytic cell.

To compare the efficiency of different electrodes in removing pollutants, galvanostatic conditions were maintained using DC power supply (Systronics dual channel power supply 615D) and a current of 1.3 A was applied. 10 g/L of NaCl solution was added to the effluent prior to electrolysis as the supporting electrolyte. The cell was equipped with a magnetic stirrer in order to keep the electrolyte well mixed during electrolysis and voltage and current were recorded at every 5 min intervals. Fenton's reagent was prepared from 35% hydrogen peroxide and FeSO<sub>4</sub> (obtained from Merck). 200 mg/L of Fe and 2 mL/L of H<sub>2</sub>O<sub>2</sub> were added during electrolysis.

Raw and anaerobically treated samples were subjected to electrochemical treatment for different intervals. During electrochemical treatment, samples were drawn at regular intervals and parameters like pH, turbidity, COD, BOD, TKN, AN, sulphides and phosphates were determined.

Biochemical analysis of the different types of effluent was done using a UV-vis recording spectrophotometer, UV-240. Concentration of total sugars [15], reducing sugars [16], soluble proteins [17], phenols [18] and free amino acids [19] were estimated as per standard analytical techniques. The standard serial dilution plate



**Fig. 1.** Variations of current and voltage with time (with and without NaCl) using steel as anode and graphite as cathode.

technique of Pramer and Schmidt [20] was employed for the enumeration of microbiological population.

## 3. Results and discussion

### 3.1. Effect of supporting electrolyte

The effect of NaCl (supporting electrolyte) in electrochemical treatment was ascertained by electrolysis of the raw effluent with steel as anode and graphite as cathode for 3 h in the presence as well as in the absence of NaCl (Fig. 1). Current and cell voltage remained almost constant when electrolysed without NaCl. When electrolysis was repeated in the presence of (10 g/L) NaCl, current and voltage dropped in the beginning and then maintained a steady value. Presence of supporting electrolyte decreased the cell voltage, which led to a decrease in power consumption. Only slight variation in pH was observed during electrolysis in the absence of supporting electrolyte but pH was found to increase from 3.8 to 5.65 in the presence of NaCl. Better performance was observed when electrolysis was carried out in the presence of sodium chloride. Higher percentage removal of COD, BOD, TKN and AN was observed when electrolysed in the presence of supporting electrolyte (Table 2). This can be attributed to the different oxidation mechanisms prevailing in the presence of NaCl [11] and absence of it. At higher concentration of NaCl, the destruction of organics might be due to the presence of chlorine and hypochlorites. When the off-gases from the cell were collected and tested, it showed the presence of carbon dioxide, chlorine and hypochlorite. The removal of organics through electro-generated oxidising agents like chlorine/hypochlorite has already been established [21,22].

In the undivided cell, chlorine formed at the anode and hydroxides formed at the cathode reacted to form chlorine and hypochlorites. Both the hypochlorites and free chlorine were chemically reactive and oxidised organics in the effluent to carbon dioxide and water.

### 3.2. Comparison of different electrodes

Electrolysis of raw effluent (RE) was carried out for 20 min using electrodes made of aluminium, cast iron, MS, and SS in the

**Table 2**  
Effect of supporting electrolyte on effluent parameters during electrolysis using steel as anode and graphite as cathode.

| Supporting electrolyte | pH before | pH after | Percentage removal |     |     |    |
|------------------------|-----------|----------|--------------------|-----|-----|----|
|                        |           |          | COD                | BOD | TKN | AN |
| Without NaCl           | 3.45      | 3.5      | 17.3               | 40  | 13  | 23 |
| With NaCl              | 3.8       | 5.65     | 31.5               | 58  | 16  | 30 |

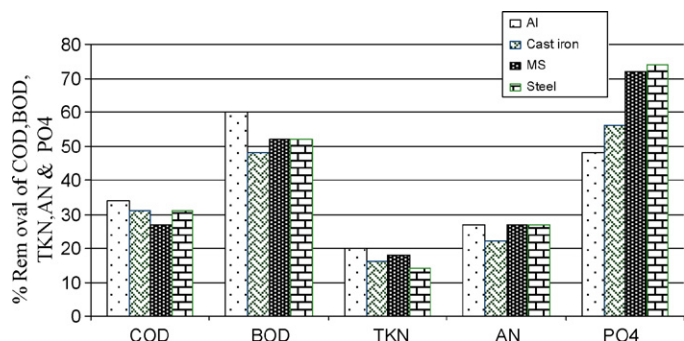
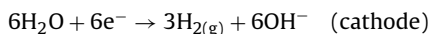
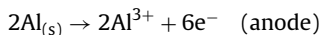


Fig. 2. Comparative plots of COD, BOD, TKN, AN and PO<sub>4</sub> reduction using different electrodes.

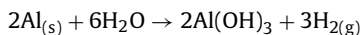
presence of 10 g/L of NaCl as supporting electrolyte. After electrolysis samples were analysed and the results proved that aluminium electrode has greater efficiency in removing COD, BOD, TKN and AN as shown in Fig. 2. But a reverse order was observed in the efficiency to remove phosphate (PO<sub>4</sub>). Steel electrode showed the maximum phosphate removal of 74% followed by MS, cast iron and aluminium. Aluminium electrode produced a very clear solution after settling the coagulated particles. This might be due to the greater charge neutralization of colloidal particles by positively charged metal ions generated *in situ* by electrolysis.

Aluminium is the best anode material. Also it is the most affordable material that provides trivalent cations and can be used in almost all kinds of wastewater treatment applications. The trivalent metal ions have a higher charge density, which allows for the superior adsorption capabilities [23].

The dominant reactions at the anode and cathode with aluminium electrodes are:



The dissolution of anode can be represented by the equation as:



The aluminium ions released from the sacrificial electrodes neutralize the electrostatic charges on the colloidal/suspended solids, enabling the formation of flocs. It has been reported that electrolytically added aluminium ions are much more active than chemically added aluminium ions and cause higher degree of destabilisation and flocculation in relatively small dosages [23]. The electrocoagulated floc differs significantly from the floc formed during chemical coagulation process. The former contain less bound water and has more resistance to shear. Hence, they exhibit better dewatering characteristics [23]. Aluminium electrode has proven to be very effective when compared to iron and combination of iron/aluminium electrodes and aluminium electrode has the ability to handle a wide variety of wastewater compositions and flow rates [4,24].

### 3.3. Pollutant removal as a function of time

Raw effluent was subjected to electrolysis at pH 3 for 150 min to study the effect of duration of electrolysis on pollutant removal using aluminium anode and graphite cathode. 10 g/L of NaCl was added as supporting electrolyte. After every 15 min a minimum quantity of effluent was drawn from the cell for analysis.

Current and voltage were noted at every 5 min interval. Current was in the range of 1.29–1.36 A and cell voltage was in the range of 5.7–7.3 V. Current remained almost constant during electrolysis. Though voltage dropped as electrolysis proceeds, it remained

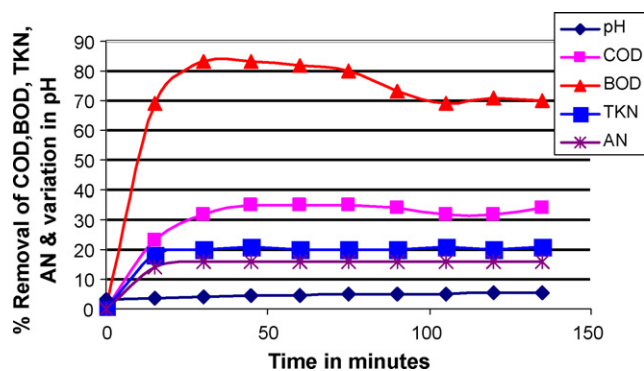


Fig. 3. Pollutant removal as a function of time using aluminium anode and graphite cathode.

constant at the end of the electrolysis, indicating the absence of adsorption or passivation of the electrode [11]. Maximum removal of BOD within 30 min and COD took place within 45 min (Fig. 3). After this, electrolysis did not show much effect on the pollutant removal. Therefore 45 min could be taken as the optimum time for electrolysis. The long duration of electrolysis leads to the dissolution of electrode which makes the effluent more viscous. The pH of the solution was found to be increasing from 3 to 5.65 at the end of the electrolysis.

### 3.4. Determination of instantaneous current efficiency (ICE)

Current efficiency decreases during the electrochemical treatment of wastewater containing organic pollutants due to the side reaction of oxygen evolution [26]. ICE is the current efficiency measured at a particular time or constant time intervals during the electrochemical treatment of wastewater. Calculation of ICE gives information about the formation of polymeric products at the anode during treatment. Two methods have been used for the determination of the ICE during electrochemical treatment: the oxygen flow rate (OFR) method and the chemical oxygen demand method [25]. The choice of the method depends on the solubility of the electrolysis product. The COD method is used only if the electrolytic products are soluble in the electrolyte. The OFR method is used where electrolysis products are soluble or insoluble. In the OFR method, the ICE is calculated by the oxygen production measured during the electrolysis of organic pollutants.

In the present study, ICE values were calculated by the COD method using the following relation:

$$\text{ICE} = \frac{[(\text{COD})_t - (\text{COD})_{t+\Delta t}]FV}{8I \Delta t}$$

where  $(\text{COD})_t$  and  $(\text{COD})_{t+\Delta t}$  are the chemical oxygen demands at times  $t$  and  $t + \Delta t$  (in mg O<sub>2</sub>/dm<sup>3</sup>) respectively, 'I' is the current

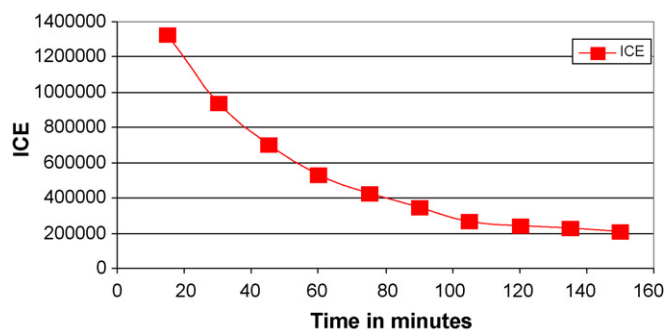


Fig. 4. Plots of ICE values with respect to time using aluminium anode and graphite cathode.

**Table 3**  
Pollutant removal in the presence of Fenton's reagent using cast iron electrode.

| pH  | Reagent | Percentage removal |      |      |      |
|-----|---------|--------------------|------|------|------|
|     |         | COD                | BOD  | TKN  | AN   |
| 3   | Nil     | 24.9               | 41.5 | 17.5 | 15.1 |
| 6.5 | Nil     | 26.1               | 42.8 | 21.6 | 21.2 |
| 3   | FR      | 32.5               | 75.8 | 18.3 | 6    |
| 6.5 | FR      | 32.5               | 76.1 | 18.3 | 6    |

FR, Fenton's reagent.

(A), 'F' the Faraday constant (96,487 C/mol) and 'V' the volume of the electrolyte (dm<sup>3</sup>). The calculated ICE values were plotted with respect to time when aluminium was used as anode (Fig. 4). The ICE was found to decrease with time during electrolysis and gradually reached a constant value after 120 min. The initial decrease might be due to partial coverage of the active electrode surface by bulky molecules in the medium. Because of continuous oxidation, surface coverage was not increased further. At longer duration, not much change in ICE was observed. This indicated that the electrode surface reactions were not affected much during electrolysis and the constancy in ICE values was due to the steady state obtained between the mass and charge transfers. This was in agreement with the results of earlier observations [11].

### 3.5. Effect of Fenton's reagent

To study the effect of Fenton's reagent in the presence of cast iron electrode at different pH, raw effluent was subjected to electrolysis at pH 3 and 6.5 using cast iron as anode and graphite as cathode and 10 g/L of NaCl as supporting electrolyte. Current (1.32–1.29 A) remained almost constant for the variation of cell voltage range of 11–6.9 V. Another set of effluents under the same conditions but with 20 mg/L Fe and 2 mL/L H<sub>2</sub>O<sub>2</sub> (Fenton's reagent) was also electrolysed for a current of 1.32–1.26 A having a potential of 8.5–9 V.

The results are given in Table 3 which showed that the change of pH from 3 to 6.5 increased the percentage removal efficiency of COD from 24.9 to 26.1, BOD from 41.5 to 42.8, TKN from 17.5 to 21.6 and AN from 15.1 to 21.2. Addition of Fenton's reagent increased the COD removal efficiency to 32.5% and BOD removal efficiency to 76.1%. But TKN and AN removal efficiency dropped to 18.3 and 6% respectively. The results show that presence of Fenton's reagent is effective to remove high percentage of BOD from raw serum effluent.

### 3.6. Effect of pollutant concentration on electrochemical treatment

Raw effluent and two different forms of anaerobically treated effluents viz: ATE (1) and ATE (2) were electrolysed using aluminium anode and graphite cathode for 45 min by adding Fenton's reagent and 10 g/L of NaCl as supporting electrolyte. It was found

**Table 4**  
Effect of concentration of Fe in Fenton's reagent on ATE using aluminium anode and graphite cathode.

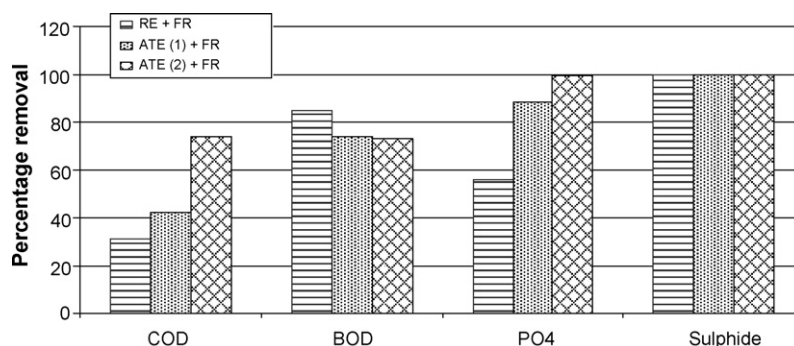
| Reagent     | pH  | Percentage removal |     |     |     |    |          |                 |
|-------------|-----|--------------------|-----|-----|-----|----|----------|-----------------|
|             |     | Turbidity          | COD | BOD | TKN | AN | Sulphide | PO <sub>4</sub> |
| Nil         | 8.5 | 75                 | 57  | 20  | 22  | 17 | 57       | 52              |
| 20 mg/L Fe  | 8.5 | 100                | 57  | 20  | 28  | 15 | 65       | 60              |
| 100 mg/L Fe | 8.5 | 100                | 60  | 22  | 21  | 15 | 72       | 68              |
| 200 mg/L Fe | 8.5 | 100                | 67  | 54  | 30  | 20 | 78       | 83              |
| 300 mg/L Fe | 8.5 | 100                | 66  | 53  | 28  | 16 | 81       | 86              |

**Table 5**  
Effect of pH on pollutant removal during electrolysis using aluminium anode and graphite cathode.

| pH | Percentage removal  |                    |           |     |     |     |    |          |                 |
|----|---------------------|--------------------|-----------|-----|-----|-----|----|----------|-----------------|
|    | Before electrolysis | After electrolysis | Turbidity | COD | BOD | TKN | AN | Sulphide | PO <sub>4</sub> |
| 3  |                     | 4.9                | 100       | 65  | 50  | 31  | 20 | 100      | 89              |
| 5  |                     | 6.8                | 100       | 70  | 79  | 30  | 20 | 85       | 81              |
| 7  |                     | 7.6                | 100       | 62  | 59  | 28  | 20 | 40       | 96              |
| 9  |                     | 8.7                | 100       | 55  | 48  | 29  | 20 | 29       | 85              |

that for the RE, current varied from 1.37 to 1.29 A for a cell voltage of 5.7–9.4 V, for ATE (1) the current was 1.38–1.34 A for a constant potential of 5.8 V and for ATE (2) the current was in the range of 1.32–1.29 A having a constant potential of 6.7 V.

Fig. 5 shows that the percentage COD removal efficiencies were 31, 42 and 74 corresponding to the initial COD concentrations of 38,800 mg/L (RE), 10,900 mg/L [ATE (1)] and 4508 mg/L [ATE (2)] respectively. In absolute terms the COD values changed from 38,800 to 26,772 mg/L, 10,900 to 6322 mg/L, and 4508 to 1172 mg/L for RE and ATE (1) and (2) respectively. The lower the COD of the effluent used for electrolysis, the higher the rate of removal. But in the case of BOD, the removal efficiency was 83% for RE and it decreased to 74% and finally to 73% for anaerobically treated effluents. In other words the BOD changed from 27,650 to 4147 mg/L, 7890 to 2051 mg/L and 1015 to 274 mg/L for RE and ATE (1) and (2) respectively. This may be due to the removal of biodegradable substrates during anaerobic treatment. After electrolysis phosphate removal efficiency was 56% for raw effluent and it increased to 99.5% for anaerobically treated effluent which showed that as the concentration of phosphate dropped from 2583 to 525 mg/L by anaerobic treatment, its removal efficiency increased. This might be due to the ability of metal ions (Al<sup>3+</sup>) to combine with phosphates to form AlPO<sub>4</sub>. Metal ions formed from the anode become new centres for large, stable and insoluble complexes [23]. Complete removal of sulphide was observed in all the treatment trials. From this it is clear that electrochemical method is more effective for the treatment of anaerobically treated effluent having lower organic load.



**Fig. 5.** Effect of pollutant concentration of effluent on electrolysis using aluminium anode and graphite cathode.

**Table 6**  
Effect of electrolysis on the biochemical constituents of raw and treated effluent.

| No. | Sample details         | Soluble protein | Phenol | Total sugar | Reducing sugar | Non-reducing sugar | Free amino acid |
|-----|------------------------|-----------------|--------|-------------|----------------|--------------------|-----------------|
| 1   | RE                     | 870             | 586    | 1250        | 1095           | 155                | 16,120          |
| 2   | RE + DC                | 285             | 182    | 390         | 295            | 95                 | 14,724          |
| 3   | RE + FR                | 351             | 335    | 639         | 450            | 189                | 20,082          |
| 4   | RE + FR + DC           | 65              | 165    | 270         | 156            | 114                | 16,611          |
| 5   | ATE(1,COD 10900)       | 425             | 434    | 107         | 83             | 24                 | 7,932           |
| 6   | ATE + DC               | Nil             | 59     | Null        | Null           | Null               | 6,831           |
| 7   | ATE + FR               | 114             | 224    | 42          | 25             | 17                 | 6,417           |
| 8   | ATE + FR + DC          | Nil             | 25     | Null        | Null           | Null               | 6,157           |
| 9   | ATE(2,COD 4508)        | 289             | 45     | 65          | 56             | 9                  | 5,779           |
| 10  | ATE + FR + DC (30 min) | 17              | 17     | Null        | Null           | Null               | 4,322           |
| 11  | ATE + FR + DC (45 min) | Nil             | 7      | Null        | Null           | Null               | 4,290           |

Abbreviations used: RE, raw effluent; ATE, anaerobically treated effluent; DC, direct current; FR, Fenton's reagent. All values are expressed in mg/L.

### 3.7. Influence of concentration of iron in Fenton's reagent

To study the effect of concentration of iron in Fenton's reagent, anaerobically treated effluent was subjected to electrolysis using aluminium anode and graphite cathode for 30 min after adding 20, 100, 200 and 300 mg/L of Fe (as  $\text{Fe}^{2+}$ ) respectively in four different sets of effluent (250 mL each) along with 2 mL/L of  $\text{H}_2\text{O}_2$  in each. A control cell without any Fenton's reagent was also subjected to electrolysis. A current in the range of 1.26–1.32 A and cell voltage in the range of 5.9–7.4 V was used in all set of experiments. Current and voltage were recorded at every 5 min intervals. 10 g/L of NaCl was added as supporting electrolyte in each set. The results are given in Table 4. Turbidity was completely removed after electrolysis using Fenton's reagent. Percentage removal of COD, BOD, TKN and AN were maximum for 200 mg/L of iron concentration in Fenton's reagent. But maximum removal of sulphide and phosphate were for 300 mg/L of iron. As the concentration of iron increased, more sulphides and phosphates combined to form corresponding iron salts. The increase in the removal of pollutants with the increase in the concentration of iron might be due to the formation of hydroxyl radical in the presence of  $\text{Fe}^{2+}$  and  $\text{H}_2\text{O}_2$ . A constant ratio of Fe:substrate above the minimal threshold level produced the desired end product [26].

### 3.8. Effect of pH

One of the parameters that possibly affect the extent of treatment is the pH of the wastewater. To study the influence of pH on pollutant removal, pH of the anaerobically treated effluent was adjusted from 8.5 to 3, 5, 7 and 9 using sulphuric acid and sodium hydroxide. 200 mg/L of Fe (as  $\text{Fe}^{2+}$ ) and 2 mL/L of 30%  $\text{H}_2\text{O}_2$  were added to each set. It was then subjected to electrolysis for 20 min using aluminium anode and graphite cathode. 10 g/L of NaCl was added as supporting electrolyte.

When  $\text{FeSO}_4$  was added to the anaerobically treated effluent the colour of the solution changed to black, due to the formation of iron sulphide, since anaerobically treated effluent contains sulphide. When pH changed from 3 to 9 the colour of the effluent changed from colourless to brown after electrolysis; the brown colour was due to the formation of ferric hydroxide in alkaline pH. Current and cell voltage remained almost constant throughout the experiment. This demonstrates that the electrochemical cell constituents are unaffected during the entire period of electrolysis. Froth formation was observed as electrolysis progressed and more froth was on the cathode (graphite) side and the quantity of froth decreased as pH increased. Maximum percentage removal of COD and BOD were observed at pH 5, TKN and sulphide at pH 3 and phosphate at pH 7 (Table 5). Removal of ammoniacal nitrogen was not affected by pH change. Complete removal of sulphide was possible at pH 3. As pH increases, the removal of sulphide decreases. Therefore pH around 5

can be taken as optimum pH for electrolysis in the presence of Fenton's reagent. In alkaline pH hydrated ferrous ion is transformed into colloidal ferric species which decompose  $\text{H}_2\text{O}_2$  to oxygen and water [26].

### 3.9. Biochemical and microbiological analysis of the electrolysed effluent

Electrolysis was good in removing soluble protein, phenol and total sugar from raw effluent. It was more effective in treating anaerobically treated effluent. Soluble protein and total sugar were completely removed from the anaerobically treated effluent when electrolysed even in the absence of Fenton's reagent. Results of biochemical analysis of raw and treated effluent are given in Table 6. Electrocoagulation can be successfully employed for the removal of protein and fat present in wastewater [23].

Comparison of biochemical constituents of anaerobically treated effluents having 10,900 and 4508 mg/L COD (No. 5 and 9 in Table 6) showed that as COD decreases, biochemical constituents also decreases. As time of electrolysis of ATE increases from 30 to 45 min (No. 10 and 11 in Table 6), a reduction in the biochemical parameters were observed. Complete removal of free amino acids by electrolysis was not possible. This may be due to the generation of individual amino acids by the degradation of proteins.

The population of total bacteria present in raw, anaerobically treated and electrolysed effluent was enumerated using appropriate media and found that RE and ATE contains  $25 \times 10^4$  and  $30 \times 10^5$  colony forming units per unit volume (cfu/mL) respectively. After electrolysis using Fenton's reagent for 20 min no such colony forming units were observed which shows that electrolysis in the presence of Fenton's reagent could remove total bacterial population completely (Table 7). The same type of observation was reported by Mohanasundaram that electrocoagulation process

**Table 7**  
Results of microbiological analysis.

| No. | Sample                 | cfu/mL           |
|-----|------------------------|------------------|
| 1   | RE                     | $25 \times 10^4$ |
| 2   | RE + EL                | $5 \times 10$    |
| 3   | RE + FR                | $8 \times 10^3$  |
| 4   | RE + FR + EL           | Null             |
| 5   | ATE                    | $30 \times 10^5$ |
| 6   | ATE + FR               | $4 \times 10^2$  |
| 7   | ATE + EL (15 min)      | $3 \times 10^2$  |
| 8   | ATE + EL (20 min)      | $1 \times 10^2$  |
| 9   | ATE + EL (25 min)      | 23               |
| 10  | ATE + EL (30 min)      | 3                |
| 11  | ATE + EL (45 min)      | Null             |
| 12  | ATE + FR + EL (20 min) | Null             |
| 13  | ATE + FR + EL (45 min) | Null             |

RE, raw effluent; ATE, anaerobically treated effluent; EL, electrolysis; FR, Fenton's reagent.

destroys fecal coliform by 99.999% [23]. Without Fenton's reagent a little more time for electrolysis (45 min) was needed to remove total bacterial count. The increase of electrons creates an osmotic pressure that ruptures bacteria, cysts and viruses and thus electrocute microorganism in the water [27].

#### 4. Conclusion

Application of electrochemical coagulation to treat raw and anaerobically treated serum effluent was the focus of the study.

Various metal electrodes like aluminium, cast iron, steel, and mild steel were compared for their efficiency in removing COD, BOD, TKN, AN and phosphate and found that aluminium anode was more effective to remove pollutants compared to others. Addition of Fenton's reagent during electrolysis was very effective in removing pollutants.

Presence of supporting electrolyte increased the percentage removal of COD, BOD, TKN and AN. Maximum removal of COD took place within 45 min and BOD within 30 min of electrolysis. The ICE decreases with time during electrolysis and gradually reaches a constant value. Lower the COD of the effluent used for electrolysis, higher is the rate of pollutant removal. After electrochemical treatment phosphate removal efficiency was 56% for raw effluent and it increased to 99.5% for the anaerobically treated effluent. Complete removal of sulphide was observed in all trials. It is concluded that electrochemical treatment is very effective for anaerobically treated effluent having low organic load.

Percentage removal of COD, BOD, TKN and AN were maximum for 200 mg/L of iron concentrations in Fenton's reagent. But sulphide and phosphate removal increased as iron concentration increased. pH around 5 could be taken as optimum pH for electrolysis in the presence of Fenton's reagent.

Biochemical analysis revealed that electrolysis in the presence of Fenton's reagent is effective in removing soluble protein, phenol and sugars especially from anaerobically treated effluent. Microbiological analysis showed the complete removal of total bacteria by 20 min electrolysis in the presence of Fenton's reagent.

Electrochemical treatment is a simple method and at the same time ensures rapid processing since it takes only 30–45 min for treatment compared to conventional biological treatment like activated sludge process and other aerobic oxidation methods. It removes very fine colloidal particles through coagulation and the quantity of the sludge generated and water bound to the sludge is less and therefore easy for dewatering. Another advantage of EC is emulsion breaking and bleaching by oxygen ions produced in the reaction chamber oxidises bacteria, viruses, sulphides and other biohazards. One of the main attractions of electrochemical treatment is the use of solar energy for electrolysis with the help of photovoltaic cells and therefore this method can be applied in rural areas too. Since electricity is expensive, use of solar energy reduces the running cost of the treatment processes. Thus it is concluded that electrochemical treatment could be effectively used for the post-treatment of anaerobically treated effluents from latex centrifuging unit.

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