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Removal of Arsenic from Water by Electrocoagulation and Electrodialysis Techniques

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Electrochemical methods have been described for the removal of arsenic from contaminated water due to their advantages in comparison to other removal methods. Only electrocoagulation and electrodialysis were used for this purpose. The present review article describes state-of-art of arsenic removal by using these techniques. Attempts have been made to explain the optimization for maximum removal of arsenic by controlling metal electrodes, pH of water, current densities, processing time and ionic concentration. The maximum arsenic removal achieved was brought down to the ppb level (10 ppb being permissible limit of World Health Organization in drinkable water). Efforts have also been made to explain the mechanism of arsenic removal by these techniques. Besides, the future perspectives of electrochemical techniques for the removal of arsenic have also been highlighted.

KEYWORDS Arsenic, removal, electrocoagulation, electrodialysis, optimization, mechanism of arsenic removal

INTRODUCTION

Arsenic is a quite abundant element in the earth crust and sea water, respectively (1). It occurs in the form of metalloid, inorganic and organic forms (2). Arsenic species in groundwater occur in two oxidation states *viz.* As(III) [H_3AsO_3 , H_2AsO_3^- , HAsO_3^{2-}] and As(V) [H_3AsO_4 , H_2AsO_4^- , HAsO_4^{2-} and

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AsO_4^{3-}]. Mainly the concentrations of arsenic species depend on redox potential and pH (3–4) of water. As(III) is predominant species under reducing condition while As(V) found in oxidizing situation (5). Inorganic arsenic compounds include hydrides, halides, oxides, acids and sulfides (6,7).

On the other hand, organic forms of arsenic are methylated species i.e., mono-methyl arsenic acid [MMA(III)], mono-methyl arsenate acid [MMA(V)], dimethyl arsenic acid [DMA(III)], dimethyl arsenate acid [DMA(V)] (8–10). Inorganic arsenic species are more toxic than organic ones (11). Besides, arsenite As(III) is about 60 times more toxic than arsenate As(V). The order of toxicities of arsenic species are arsenite > arsenate > MMA > DMA (12). Arsenic is a deadly poison responsible of various types of cancer, if present in water (13,14). Besides, other harmful effects include thickening and discoloration of skin, stomach pain, nausea, vomiting, diarrhea, numbness in hands and feet, partial paralysis and blindness (15).

The spreading of arsenic in the ground water is a worldwide problem as about 100 million people are at risk globally. It is known that more than 20 countries are suffering from arsenic havoc (7). Figure 1 indicates the arsenic distribution worldwide. In view of these facts, the development of fast, efficient and economic methods for arsenic removal from water is the urgent need of today. A thorough search of literature was carried out and many methods reported include precipitation, sorption, ion exchange, coagulation, flocculation, nano-filtration, electrochemical and reverse osmosis (16–21).



FIGURE 1 Worldwide arsenic distribution in groundwater.

We compared and analyzed these methods (22) and found that up till now, no economic method is available; especially at large scale for arsenic free water supply to the communities. Our experience of about 10 years on water treatment and literature dictate that electrochemistry may be a viable and inexpensive technique of arsenic removal in near future due to some advantages such as economic, no waste management problem, no use of chemicals during purification process, etc. In spite of this, there are only a few papers on the removal of arsenic by electrochemical methods.

ELECTROCHEMICAL TECHNIQUES

Electricity was used to treat water as early as 1887 in the United Kingdom (5). Electrochemical methods for wastewater treatment are inexpensive and eco-friendly in nature. The most important electrochemical methods used for metal removal are electrocoagulation, electrodeposition, electroflootation, electrodialysis and electrooxidation (23–30). All these methods have been used to treat effluents of various industries such as tannery, electroplating, and textile processing. Some important electrochemical methods used for the treatment of arsenic from water are discussed in previous reviews (4, 7, 11, 16, 21, 28).

Electrocoagulation

The electrocoagulation (EC) method was first patented in 1906 by A.E. Dietrich for treating bilge water from ships. The process involves electrochemical phenomenon that simultaneously removes heavy metals, suspended solids, emulsified solids and other contaminants from water using electricity with metal plates/electrodes instead of chemicals (31). EC is a simple and efficient technique in which no coagulant is added, thus, reducing the amount of sludge (32). Electrocoagulation for arsenic has been achieved by iron and aluminum electrodes. However, some authors also reported the use of titanium, copper and zinc electrodes (33, 34). The whole process of electrocoagulation can be described in three parts: (i) electrolytic oxidation of the sacrificial anode and, thus, formation of coagulants, (ii) destabilization of the contaminants, particulate suspension and breaking of emulsion and (iii) aggregation of the destabilized particles to form flocs.

MECHANISM OF REMOVAL

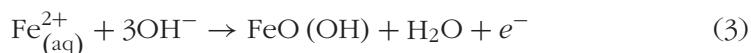
EC involves a simple electrochemical cell unit made of an anode and a cathode. The anode material is oxidized when the proper potential is applied from an external source (equation 1):



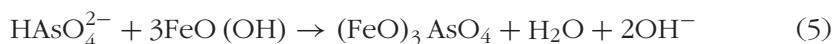
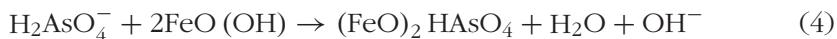
Considering arsenic removal by using Fe-Fe electrodes in basic medium, there are two possible ways as described by Maldonado-Reyes et al. (34) and Gomes et al. (35). Maldonado-Reyes et al. (34) described As(V) removal as per the following equations:



Iron is dissolved from the anode, generating ferrous cations (eq. 2), which readily oxidize to their ferric form and hydrolyze to polymeric iron oxy-hydroxide i.e., goethite ($FeO(OH)$), (eq. 3). The goethite has been identified by X-ray diffusion.



As(V) is mainly in the arsenate acid H_3AsO_4 state with its three pK_{a3} s: 2.19, 6.84 and 11.5. At pH 7, arsenate acid is in the basic form $HAsO_4^{2-}$ (60%) and acid form $H_2AsO_4^-$ (40%). Both forms produce insoluble complexes with fresh goethite $FeO(OH)$:



Generally, As(V) forms bi-dentate binuclear bridging complexes with an elevated iron to arsenic weight ratio, which allows the reduction of arsenic to minimum levels (34).

Gomes et al. (35) described the removal phenomenon of both As(V) and As(III) species. According to them, in EC ferric ions were generated from iron electrodes and formed various hydrated species such as $Fe(H_2O)_6^{3+}$, $Fe(H_2O)_5(OH)_2^+$, $Fe(H_2O)_4(OH)_2^+$, $Fe_2(H_2O)_8(OH)_2^{4+}$ and $Fe_2(H_2O)_6(OH)_4^{4+}$ and goethite ($FeO(OH)$); depending on pH of the aqueous medium. All these ferric compounds have a strong affinity for arsenic species. Among these the maximum coagulation power for As(III) and As(V) are with the hydrous ferric oxide ($Fe_2O_3 \cdot xH_2O$) and goethite [$FeO(OH)$] (36,37). Arsenate anions form naturally occurring arsenate minerals, i.e., $FeAsO_4 \cdot 2H_2O$ (scorodite) and $Fe_3(AsO_4)_2 \cdot 8H_2O$ (symplesite) as the dominant solid phases (38).

APPLICATIONS

Many metal electrodes have been used to remove arsenic from water using electrocoagulation technique. The most important metals used for electrodes are iron, aluminum, copper and titanium. The applications of these electrodes for the removal of arsenic are summarized next.

Iron-iron electrodes. Iron electrodes showed the best arsenic removal efficiency i.e., up to 93–99% (33,34). Kumar et al. (33) removed As(III) from water with iron electrodes and reported that arsenic concentrations were brought down to 10.0 $\mu\text{g/L}$ by applying 100 coulombs per liter. As(V) concentration initially increased due to As(III) oxidation and then decreased as the total arsenic concentration became low. The rate of oxidation of As(III) to As(V) seems faster than the rate of adsorption onto hydrous ferric oxide. However, as time goes, sufficient hydrous ferric oxide ($\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$) is generated and all arsenic forms got adsorbed on it. Iron oxidation resulted into ferrous ions, which underwent further alkalization by water reduction. Similarly, Dolo et al. (39) studied arsenic removal on Fe-Fe electrodes and found a maximum efficiency of 99.6% at pH 7.0.

Aluminum-aluminum electrodes. As mentioned above, aluminum electrodes have been used for removal of arsenic species. Furthermore, Kumar et al. also (33) removed As(III) by using aluminum electrodes and reported that only 37% of arsenic was reduced, which is quite low, as compared to the iron electrode. The reason for this may be poor adsorption capacity of hydrous aluminum oxide for As(III) (40).

Copper-copper electrodes. The efficiency of copper electrodes is very promising with 99% Arsenic removal at pH 6.0 (41). X-ray diffraction (XRD) analysis of Cu–Cu electrode by-product showed the presence of tenorite [syn-CuO] and cuprite [syn-Cu₂O]. XRD also showed a small peak that might be of copper arsenic oxide [Cu₄(AsO₄)₂O] (40). Maldonado-Reyes et al. (34) described the production of cupric ions during oxidation of copper electrode. The interfacial pH of the cupric solution increased due to alkalization and consequently copper hydroxide precipitated. It is important to mention that the significant precipitation of Cu(OH)₂ occurred at pH 7.7; at low pH 67% arsenic removal occurred as the interfacial pH increased, thus, forming Cu(OH)₂. Arsenate ions displaced hydroxyl groups of electro-generated Cu(OH)₂ giving rise to insoluble complex, along with hydroxide ion and water (41).

Titanium-titanium electrodes. Titanium electrodes were also used for removing arsenic from water with a mediocre 58% efficacy (34). Bissen et al. (42) reported that As(III) was less adsorbed as compared to As(V) on TiO₂. Therefore, they speculated that partial oxidation of As(III) might occur and the oxidized As(V) adsorbed onto hydroxides of titanium.

Miscellaneous electrodes. Combinations of different electrodes were also used for arsenic remediation. The most efficient combinations are Cu-Zn, Cu–Fe, Cu–Al, Fe-Al, carbon-steel, steel-steel, Fe-stainless steel, and mild

steel-stainless steel. XRD analysis of Cu-Al electrode pair byproduct showed the presence of tenorite [syn-CuO], cuprite [syn-Cu₂O], diaspore [AlO(OH)] and bayerite [Al(OH)₃] as coagulants; with 97.5% as removal capacity (39,41). For Cu–Fe electrodes, the main by-products were tenorite [syn-CuO], cuprite [syn-Cu₂O] magnetite [Fe₃O₄] and sympesite; with the removal efficiency of 99.6%. (43–46).

Maldonado-Reyes *et al.* (34) studied the arsenic removal on Cu-Zn electrode pair and established the following mechanism: zinc ions were first released as Zn(II) cations with subsequent enhancement of the copper surface activity. Arsenates reacted with Zn(OH)₂ forming a complex of ZnHAsO₄ along with water and a hydroxide anion. The complex could be removed by precipitation and the removal efficiency of the electrode was found to be 73% (34).

OPTIMIZATION

The most important factors responsible for coagulation are electrode material, applied potential, pH of the solution, processing time, and ionic strength of the solution. The effect of these parameters on arsenic removal is summarized in the following subsections.

Electrode materials. The selection of electrode depends on the feasibility of redox reactions. Besides, the waste produced is also an important factor to determine electrode materials. Additionally, the eco-friendly natures of electrode materials are also crucial in this technique (33). Gomes *et al.* (35) studied the effect of electrode material for the removal of arsenic, as shown in Table 1. The authors studied three electrode pairs *viz.* Al-Fe, Fe-Fe and Al-Al with different pH ranges. With Al-Fe electrode the pH range was 4.0 to 10 and it is clear from the table that the best pH was 4.0 having 99.6% as the removal efficiency and 13.4 ppm as arsenic residual concentration.

Similarly, Fe-Fe electrode also resulted into removal efficiency of 99.6% for 13.4 ppm initial concentration. Al-Al electrodes were very efficient at pHs ranging from 2.4 to 6.0 but with water containing low Arsenic amounts. The percentage removal efficiency was 97.2 to 97.8% at all pH values with 13.4 ppm as arsenic initial concentration giving a low 0.3 ppm residual concentration. From these results it may be concluded that Fe-Fe and Al-Fe electrodes are the best for removing large Arsenic amounts and Al-Al electrodes for final purification (35).

Effect of pH. In EC, pH is an important controlling factor for arsenic removal and a slight change may affect removal efficiency drastically. In case of arsenic, a small increase of pH may occur during experimentation due to sorption reaction of As(V) and As(III). Both species release hydroxyl groups from sorbent as a result of ligand exchange process (47–49). The importance of pH in conventional coagulation is well documented and both species of arsenic behaved differently at different pHs. Kumar *et al.* (33) studied the

TABLE 1 Effect of Electrode Materials and pHs of Solution for the Removal of Arsenic (35)

Electrode materials	pH	Initial arsenic conc. (ppm)	Residual arsenic	Removal efficiency (%)
Al-Fe	4.0	1.42	300.0 ppb	78.9
		13.4	54.0 ppb	>99.6
		123.0	17.0 ppm	86.1
		1230	129.0 ppm	89.5
	6.0	1.4	95.0 ppb	>93.0
		123.0	1.5 ppm	98.8
	10.0	1.4	120.0 ppb	91.5
		123.0	11.0 ppm	91.3
	2.4	13.4	54.0 ppb	>99.6
Fe-Fe	2.4	13.4	375.0 ppb	97.2
		13.4	295.0 ppb	97.8
	6.0	13.4	335.0 ppb	97.5
Al-Al	4.0	13.4	295.0 ppb	97.8

effect of pH on iron electrodes and performed experiments by maintaining pH via HCl/NaOH. The authors calculated the removal efficiency of As(V) and As(III), in the range of pH 6–8 and reported that there was no significant effect of pH on arsenic removal. Deniel et al. (50) also studied pH effect on iron electrodes and observed that arsenic removal increased with an increase in pH; ranging from 6–10.

It might be due to the fact that at high pH metal polymeric hydroxides are formed more easily helping arsenic coagulation. Furthermore, Balasubramaniana et al. (46) confirmed this fact and established that removal efficiencies increased with an increase in pH from 7.0 to 11.0. Similarly, Gomes et al. (35) studied pH effect on arsenic removal and found that for three electrode pair *viz.* Al-Fe, Fe-Fe and Al-Al, the best removal efficiency was at pH 2.4 for Fe-Fe and Fe-Al electrodes when the initial conc. of arsenic was 13.4 ppm (Table 1). They observed a very little effect of pH on arsenic removal with Al-Al electrodes (Table 1). Moreover, Figure 2 shows effect of pH for Al-Fe electrode pair for 1.42 and 123.0 ppm initial concentration of arsenic indicating the maximum removal at pH 6.0. It has also been observed that power consumption was slightly high at this pH due to variation of conductivity (51).

Effect of current density. The effect of current density on the efficiency of EC is not well documented. However, the different views have been put forward by various workers and advocated the influence on the treatment efficiencies. As the current density increases, metal ions are abundantly produced at the anode augmenting the porous flock production, which aids arsenic removal (46, 52–54). According to Zhao et al. (55), current density controls the coagulant dosage rate, the bubble production rate and bubble size and the floc growth. Hence, it increased the efficiency of arsenic removal. Although others described no significant effect of current density

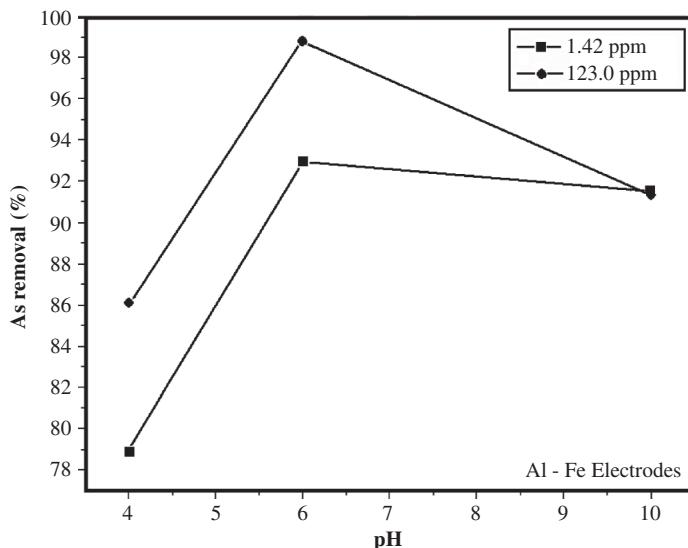


FIGURE 2 Effect of pH on the arsenic removal with aluminum-iron electrode pair and 1.42 ppm (closed squares) and 123 ppm (closed circles) initial arsenic concentrations (adapted from Ref. 35).

on the EC efficacy (39,48,56). Maldonado-Reyes *et al.* (34) studied the effect of current densities with time for arsenic removal with different electrodes (Figure 3).

In Figure 3a the electrodes used and the current densities were Fe-Fe and 1.5, 3.0 and 12.0 mA.cm^{-2} , respectively, with 100 ppb as arsenic initial concentration. It is clear from this Figure that maximum arsenic removal occurred at 12.0 mA.cm^{-2} current density with respect to time. On the other hand, Figure 3b shows effect of Fe-Fe, Zn-Zn and Cu-Cu electrodes with respect to time at 12.0 mA.cm^{-2} current density. The Zn-Zn electrodes resulted into maximum removal of arsenic at this current density. Arsenic removal was 3 and 6 times faster on Zn-Zn electrode than on Fe-Fe and Cu-Cu electrodes, respectively. This was due to a lower anodic potential of Zn-Zn electrodes in comparison to Fe-Fe and Cu-Cu electrodes (34).

Effect of processing time. Normally, in EC arsenic removal is fast at the beginning followed by a slow decrease which may be due to reducing concentration of arsenic. Iron hydroxide generated at the anode forms complexes and, therefore, a rapid initial removal of arsenic occurs. As the time proceeds, the arsenic concentration decreases and the generated hydrous ferric oxide concentration increases. Arsenic removal can become negligible after a certain period of time as the dissolved arsenic remains in too small amount. It has been observed that about 50–60% of initial arsenic removal occur within 5–10 min. of the process (33).

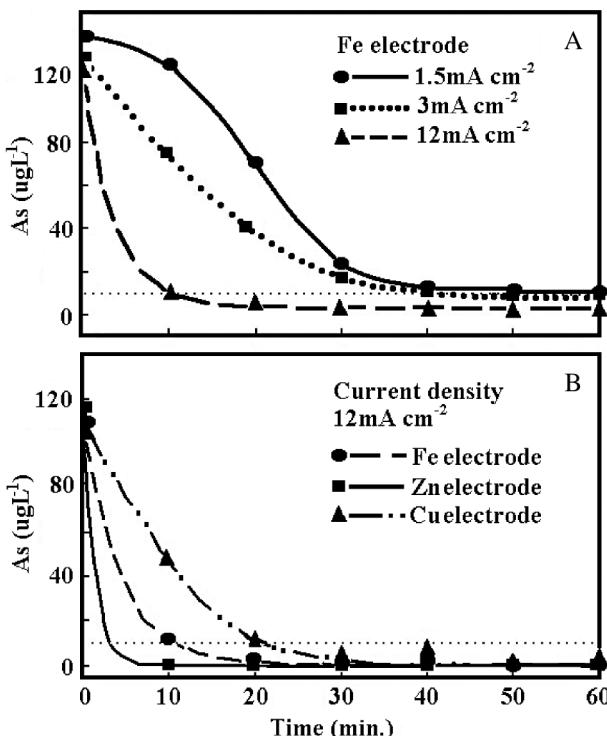


FIGURE 3 Effect of processing time on the arsenic removal using different electrodes along with various current densities.

A. Iron electrodes with 1.5, 3.0 and 12 mA.cm^{-2} current densities.

B. Iron, zinc and copper electrodes with 12 mA.cm^{-2} current density.

Horizontal grey dotted line: 10 $\mu\text{g/L}$ (or ppb) WHO tolerated maximum arsenic concentration in drinking water (adapted from Ref. 34).

The effect of time period on arsenic removal with different electrodes and current densities can be observed from Figure 4, which shows fast removal initially followed by a decrease. Maldonado-Reyes et al. (34) studied the effect of time on arsenic removal by taking different electrodes (Fe-Fe, Zn-Zn, Cu-Cu and Cu-Zn). Arsenic concentrations studied were 76.0–130.5, 68.0–125.3, 75.5–126.5 and 96.0–130.0 ppb for Fe-Fe, Zn-Zn, Cu-Cu and Cu-Zn electrodes, respectively, at 1.5 mA.cm^{-2} current density. In all cases arsenic removal was moderate initially, which become almost constant with respect to time. About 90% of arsenic was removed after 30 minutes in all cases (33).

Effect of ionic concentrations. EC is also controlled by various concentrations of ions in arsenic removal. In natural water the maximum ions are sodium, potassium, calcium, magnesium, chloride, sulfate, nitrate, phosphate, etc. We have carried out a detail search of literature but found few papers of the ionic effect on arsenic removal. These studies indicate that

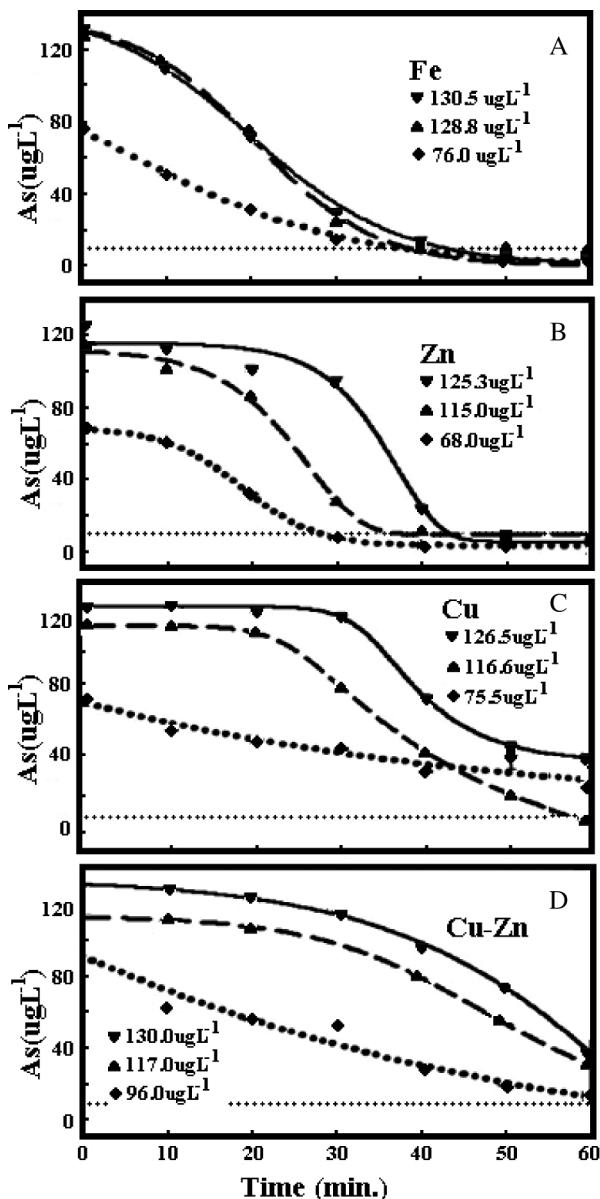


FIGURE 4 Effect of processing time with different electrodes and various arsenic concentrations.

- A. Iron electrodes with initial arsenic conc. of 76 to $130.5 \mu\text{g/L}$.
- B. Zinc electrodes with initial arsenic conc. of 68 to $125.3 \mu\text{g/L}$.
- C. Copper electrodes with initial arsenic conc. of 75.5 to $126.5 \mu\text{g/L}$.
- D. Brass (copper-zinc) electrodes with initial arsenic conc. of 96 to $130 \mu\text{g/L}$.

Current density: 1.5 mA.cm^{-2} . Horizontal dotted line: $10 \mu\text{g/L}$ (or ppb) WHO tolerated maximum arsenic concentration (adapted from Ref. 34).

metal ions removal is also controlled by the amount of various electrolytes present in natural water (51). Pinisakul et al. (44) studied the effect of some salts (KNO_3 , NaNO_3 , KCl and NaCl) on arsenic removal with iron electrodes. The authors reported that arsenic removal efficiency was lower in case of NO_3^- salt (electrolyte) as compared to Cl^- electrolyte.

It was due to the production of less total suspended solid (TDS) by NO_3^- than Cl^- salt. Moreover, it was also observed that E^0 potential values were negative for KCl and NaCl salts. Contrarily, these values were positive for KNO_3 and NaNO_3 salts. Therefore, these reactions can occur easily minimizing OH^- formation giving less Fe(OH)_2 and Fe(OH)_3 producing less TDS. Similarly, Lakshmi pathiraj et al. (57) studied the effects of NaCl , Na_2SO_4 and NaNO_3 and found that in case of NaCl electrolyte arsenic removal was much higher (98%) as compared to Na_2SO_4 (80%) and NaNO_3 (75%), which might be attributed to the production of a passive film in the presence of SO_4^{2-} and NO_3^- ions, impeding the dissolution of metal ions.

Effect of arsenic oxidation states. The removal efficiencies also depend on the oxidation states of arsenic. Wan et al. (58) carried out this study and reported that the removal of As(V) is fast in comparison to As(III). The authors also reported that As(III) is first converted to As(V) resulting into an increase in As(V) concentration following a decrease with respect to time. It was estimated that about 25% As(III) converted into As(V).

Electrodialysis

IUPAC defines electrodialysis (ED) as an electrochemical separation process in which ions are removed by using ion selective or semi-permeable membranes; under the influence of an electric field (59–64). For a simple ED setup, five components are required, which include the DC power supply to enhance ions migration, electrodes (where oxidation/reduction occur), membranes; providing transport of counterions and blocking of co-ions; solvent (used as the continuum for ions transport by filling the space between electrode and membrane) and electrolyte (the current carrier between cathode and anode) (65). ED is a widely accepted separation technique and has been used for the removal of both cations and anions (66–68). The industrial applications of ED include the production of potable water from brackish water, removal of metals from wastewater, demineralization of whey etc (69–71).

MECHANISM OF REMOVAL

The principle of electrodialysis depends on the electrical potential difference across an alternating series of cation and anion exchange membranes between an anode and a cathode. The feed solution containing both positive and negative ions enters the membrane stack to which a voltage is applied,

thus, causing the migration of the ions toward their respective electrodes. The cation exchange membranes allow the transfer of cations but check the transfer of anions. Similarly, the anion exchange membranes allow the transfer of anions but check the transfer of cations. An ionic solution is circulated around the electrodes to maintain conductivity of the membrane stack while preventing other potentially corrosive ions to the feed solution from contacting the electrodes (72).

APPLICATION OF ELECTRODIALYSIS

Of course, ED has been used for the removal of some ionic species but only one paper describes the removal of arsenic from sawdust by using this method. The work of this paper is discussed herein. Ribeiro et al. (68) used ED for the batch removal of arsenic from saw dust. The schematic diagram of the technique is shown in Figure 5. ED cell is divided into three compartments in which the side compartments are anode and cathode, respectively, while the central compartment has sawdust. The electrode compartment and the saw dust are separated by ion exchange membranes with cation exchange membrane on cathode side and anion exchange membrane on anode side, respectively.

The electrode compartments also contain 10^{-2} M solution of NaNO_3 ; as an electrolyte. The electrodes used were platinized titanium bars. The current used was 0.2 mA/cm^{-2} for 30 days time duration. The authors reported 99% arsenic removal by this method. The authors (68) extracted 26.7, 98.7, 96.6 and 92.2% arsenic from sawdust by using distilled water, 2.5% oxalic acid, 5.0% oxalic acid and 7.5% oxalic acid, respectively. Arsenic was removed from these solutions by using ED under the experimental conditions mentioned here. Furthermore, the authors calculated the amount of arsenic in anolyte, catholyte, cathode, anion exchange membrane and cation exchange membrane, separately and respectively. The values of arsenic concentrations reported are given in Table 2. A perusal of this table indicates that

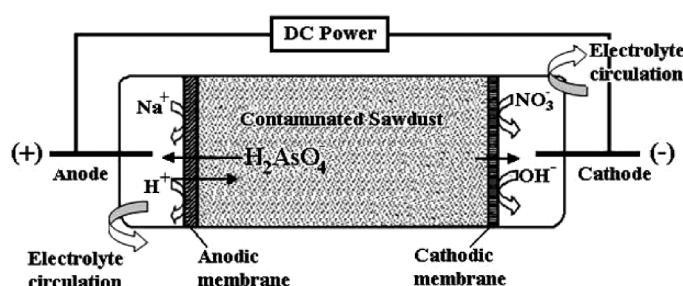


FIGURE 5 Basic layout of the electrodialysis unit for batch Arsenic remediation of contaminated wet saw dust (adapted from Ref. 68).

TABLE 2 The Amounts of Arsenic (ppm) Retained in Different Parts of Electrodialysis Unit (68)

Cell section	Expt. 1	Expt. 2	Expt. 3	Expt. 4
Anolyte	54.5	248.7	210.3	235.3
AN	4.1	7.7	8.3	6.0
CAT	0.2	1.4	2.3	3.0
Catholyte	nd	9.1	9.4	14.1
Cathode	nd	1.4	2.2	1.0

AN: Anion exchanger membrane, CAT: Cation exchanger membrane and
nd: not detected.

anolyte and cathode contain maximum and minimum amounts of arsenic, respectively.

FUTURE PERSPECTIVES

A literature survey indicates good applications of electrochemical techniques for the removal of cationic and anionic species from water but only few papers deal with arsenic removal. There are many types of electrochemical techniques that may be used successfully for the removal of arsenic species. The most important techniques capable of removing arsenic are electrocoagulation, electrodialysis, electrodeposition, electroflootation, and electrooxidation. The future of these techniques is quite bright due to the fact that they are economic and eco-friendly in nature. The arsenic removal may be obtained in the form of coagulant, which may be used as building material. In case of electrodeposition and electrodialysis techniques, arsenic may be used for various metallurgical and medicinal industries.

Arsine gas may also be generated during removal process, which may be used for the preparation of some medicines and pesticides. Briefly, there is no disposal problem with arsenic after its removal by using electrochemical techniques. The applications of these techniques are not fully developed at large industrial scale and are under their developmental stages. That is why only few units are available describing their applications at commercial scale (73). Recently, the Electrochemical Arsenic Remediation (ECAR) program was developed by University of California – Berkeley to treat industrial amounts of drinking water in Bangladesh by solar powered electrochemical units (74). Keeping these views into consideration, it may be assumed that the future of electrochemical techniques for arsenic removal is quite bright (75).

CONCLUSION

Electrochemical methods are simple, fast, inexpensive, easily operable and eco-friendly in nature. Besides, purified water is potable, clear, colorless

and odorless with low sludge production. There is no chance of secondary contamination of water in these techniques. In addition to these points, the removed arsenic by these techniques may be used for further useful processes. The electrochemical paraphernalia can be fabricated and operated easily at pilot and large scales for water supply to the communities. Our experience and future prediction dictate us that there is no problem for these techniques for their applications at pilot and commercial scale but unfortunately, much work has not been done in this direction. We believe that in near future electrochemical methods will be the choice for arsenic removal world widely; after their complete development within one decade. Let us hope for the bright future of these techniques for arsenic removal.

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