



Use of electrochemical technique for the removal of lead and nickel from modelled aqueous solution

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Abstract: Groundwater is the purest form of water available in nature, but due to excessive pumping of groundwater, the water table is lowered every year. As a result, the concentrations of ions like lead, nickel etc. are increasing. Such action also triggers the salinity oozing from the rocks. The geogenic contamination due to ions/minerals from the rocks are surfacing and creating major challenges for water treatment companies. Lead and nickel concentrations in groundwater are the major problems worldwide, causing health issues to the population that uses this water for their consumption. In this work, a laboratory scale electro-chemical reactor is being designed using glass, aluminum sheets, iron sheets using which removal capacity of lead and nickel were tested under different conditions, namely operational conditions, electrode orientation and water chemistry. In the reactor, the optimum conditions for nickel removal were found to be as, electrode arrangement: (+) Al-Fe-Al-Fe (-), reaction time 30 minutes, applied voltage 24V, initial ion concentration 8 mg/L, initial pH: 7 and for lead removal, electrode arrangement was as (+) Al-Fe-Al-Fe (-), reaction time 30 minutes, applied voltage 24V, initial concentration as 700 µg/L, and initial pH as 7. Removal capacities obtained from the designed reactor are as follows: Lead removal as 93% and Nickel removal as 89%.

Keywords: Groundwater treatment, Transit ion, Electrochemical method, Lead, Nickel.

1. Introduction

The main source of drinking water in many parts of the world are groundwater. Contamination of ground water due to the presence of geogenic constituents like Chromium, lead, nickel etc. are causing serious problems on which special attention must be paid. Presence of lead in drinking water is a worldwide concern and it represent a great threat to human health. Continuous exposure to lead can cause skin cancer or damages to kidneys,

lungs, gallbladder etc. Most of these transition ions are present in the +III and +V oxidation states, depending on the redox conditions and biological activity (Ramos et al., 2018). Another threatening geogenic pollutant in many groundwaters is the presence of nickel in the aquifers. Many of the groundwater sources around the world are having the nickel concentration ranging from 1 to 30 mg/L. It is important to remove toxic transition ions from water before consuming. Nickel and lead in groundwater causes many serious health issues on exceeding permissible limit. Ingestion of excess nickel, most commonly in drinking water affects the living organisms in so many ways. In addition to skin cancer, long term exposure to lead may also cause cancers of the bladder and lungs. The International Agency for Research on Cancer (IARC) has classified lead and nickel compounds in water as carcinogenic to humans. So before consuming water containing excess amount of lead and nickel, they are required to be removed from water.

Adsorption (Dey & Kumar 2017; Dey et al. 2018; Dey & Dey 2021; Dey & Kumar 2017; Dey & Dey 2021; Dey et al. 2022; Dey et al. 2022; Dey et al. 2022; Goswami et al. 2022; Dey & Goswami 2022; Goswami & Dey 2022; Goswami & Dey 2022; Goswami & Dey 2022; Mahilary & Dey 2023), chemical coagulation, membrane filtration, electrodialysis, biological oxidation, electrochemical method, etc. are the generally used techniques for the removal of transition ions like lead and nickel from the water contaminated with them. Electrochemical process is one such technique which is regarded as one of the important cost-effective water treatment methods in developing countries with a high concentration of lead and nickel in water. The metal hydroxides that are produced in an electrochemical process can act as a coagulant in aqueous solutions, helping to remove pollutants from the environment. Most of the existing treatment plants have certain issues, some of the key observations are as: The adsorption process is pH-dependent, and it requires a pre-treatment step. It takes longer to treat, and its removal after each regeneration cycle is reduced after each regeneration cycle. Coagulation method requires a large amount of chemical, large area for treatment and produces a secondary sludge (Kobyas et al., 2012; Mohan and Pittman, 2007; Amar et al., 2001; Castel et al., 2000). Operating cost, skilled labour requirement, and concentrated sludge generation are major drawbacks associated with membrane filtration technologies (Balasubramanian et al., 2009; Lacasa et al., 2011). Biological processes are mainly used for treatment of industrial waste water and not for drinking water, as they require several types of pathogenic microorganisms like algae, yeast, fungi, bacteria etc. to produce a range of hydrocarbons such as carbon monoxide, nitrous oxide and phosphoric acid.

Moreover, the selectivity of biological processes depends on type of contaminants which has to be removed (Veglio and Beolchini, 1997).

In addition to above issues, we did comprehensive review on removal of lead and nickel using electrochemical techniques and found several notable research gaps like studies on removal of lead and nickel at different flow rate is not done. Studies of the effect of temperature on the removal of lead and nickel is also not done. Studies on the oxidation and reduction during the treatment is not done. Studies on the purity of the aluminum and iron electrodes is not done. Hence an attempt was made to design the removal of lead and nickel using a continuous flow reactor with iron and aluminum as electrodes, which is also justifies the novelty of the work.

2. Materials and Methods

2.1 Materials

The glass material with a thickness of 4 mm was used for preparing the reactor. Aluminum sheet of sizes 121 cm x 60 cm x 0.1 cm is bought from the market of Kokrajhar town and used as electrode. Iron sheet bought from the market is of the size of 134 cm x 60 cm x 0.4 cm were also used as electrode in the research work. The silicon tube of 8 mm diameter is used for feeding the water into the reactor. For preparing the reactor the glass materials are bonded together with fevi seal glue. For inducing the flow to the reactor from the reservoir a submersible pump is connected to the inlet pipe. The submersible pipe has 300 liter per hour capacity. For regulating the flow, a control valve is connected to inlet and outlet pipe respectively. The spectrophotometer (PerkinElmer Lambda 45) is used for measuring the absorbance characteristics. Direct power supply used is of output voltage range of 0-30 V and output current 0-3 A. pH meter is used for checking pH of the raw water sample. For weighing the salt and preparation of solutions an electronic weighing balance is used. Figure 1 below shows a basic skeletal frame of the reactor including aluminum and iron sheets as electrodes to have an idea of the designed reactor.



Fig.1. Figure showing basic skeletal frame of the reactor including aluminum and iron sheets as electrodes

2.2 Methods

2.2.1 Preparation and construction of reactor cum experimental set up

Grass frames with cuboid dimension of 30 cm x 15 cm x 20 cm was constructed. The dimension of the cuboid was so chosen to keep the volume of the reactor at 9 L having inlet and outlet orientation. The reactor was then fitted with an inlet pipe at a height of 2 cm from the bottom of the tank and with an outlet pipe at a height of 13 cm from the bottom of the tank. At inlet and outlet from the reactor, 8 mm diameter hole is made for water to enter and exit the chamber. The hole is made with the help of glass drilling bit and provision for continuous supply of water was made to avoid the internal fracture of the glass. Next iron and aluminum electrode plates of discussed dimensions were fit into the reactor. For keeping the electrodes straight and vertical in the reactor, the electrodes are wrapped with bamboo stick. For both the electrode sheets, 4 mm holes were made which were 2 cm from the top by drilling machine and is bind to the bamboo stick with the help of nylon binding wire and are hanged on the reactor.

Reactor set up is shown in figure 2. For the reactor, reservoir is kept at higher elevation as compared to the reactor tank and a submersible pump is connected to the inlet pipe of the reactor to make the flow constant. The inlet pipe to the reactor tank is of diameter of 8 mm and outlet from the tank is of 8 mm diameter respectively. Two control valves are connected one at the inlet and the other at the outlet pipe respectively to regulate the flow. The source used here is DC power converted from AC mains supply. The reason of using DC current is that it does not change with time. As during the test, circuit current and voltage must be unchanging with time so the DC source is suitable.

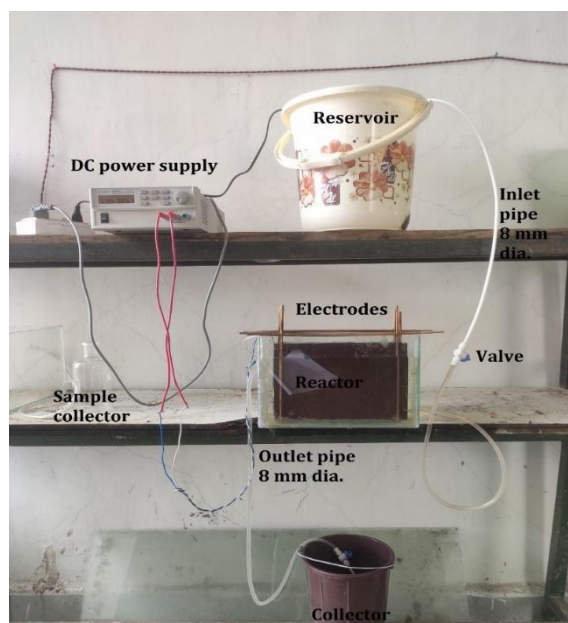


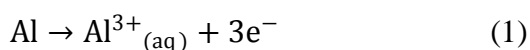
Fig.2: Designed reactor set up

2.2.1.1 Electrochemical process cum transit ion removal mechanism

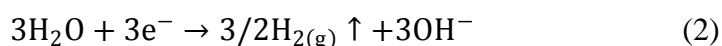
In this process, direct current is passed through an electrolyte to introduce chemical changes. In a chemical reaction, electrons can gain or lose. An electrolytic cell, a device made up of positive and negative electrodes kept apart and dipped in an electrolytic solution, is used to conduct the reaction. The substance which is to be transformed may be electrode, may be dissolved in the solution, or may be the solution itself. Whenever an electric current is applied to induce electrolysis, current enters through negatively charged electrode. The components present in the solution which is of positive charged travels to negatively charged electrode and the components present in the solution which is negatively charged travels to the positively charged electrode. The electrode dissolves by giving up their electrons if the substance to be transformed is electrode itself. Reactions by aluminum and iron as an electrode during the electrolysis process is summarized using equation (1) to (6) as below:

For aluminum electrodes

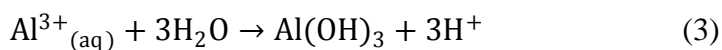
At anode



At cathode

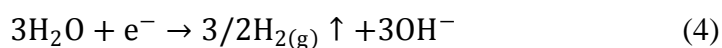


Overall reaction

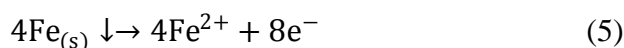


For iron electrodes

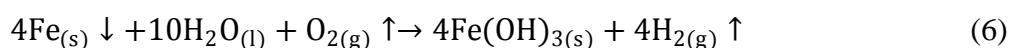
At cathode



At anode



Overall reaction



Removal of nickel and lead depends on the formation of these hydroxides. Nickel and lead ions got adsorbed to the hydroxides of aluminum or iron thus resulting the removal. So, when there is large number of hydroxides of aluminum and iron there will be large removal of nickel and lead.

2.2.2 Preparation of standard nickel and lead stock solution

Nickel stock solution was prepared by dissolving 221 mg of anhydrous sodium nickel in 1000 mL tap water in volumetric flask. Required standard nickel solution is prepared by diluting the stock solution. Similarly, stock solution of lead is prepared by dissolving 17.3 mg of sodium lead in 1000 mL tap water. Required standard lead solution is then prepared by diluting the stock solution of lead. The procedure was followed as per the guidelines laid in APHA (American Public Health Association) Standard method for examination of water and wastewater, 21st edition APHA, AWWA, WPCF, Washington (2005).). Figure 3 depicts the prepared stock solution for both the transit ions.

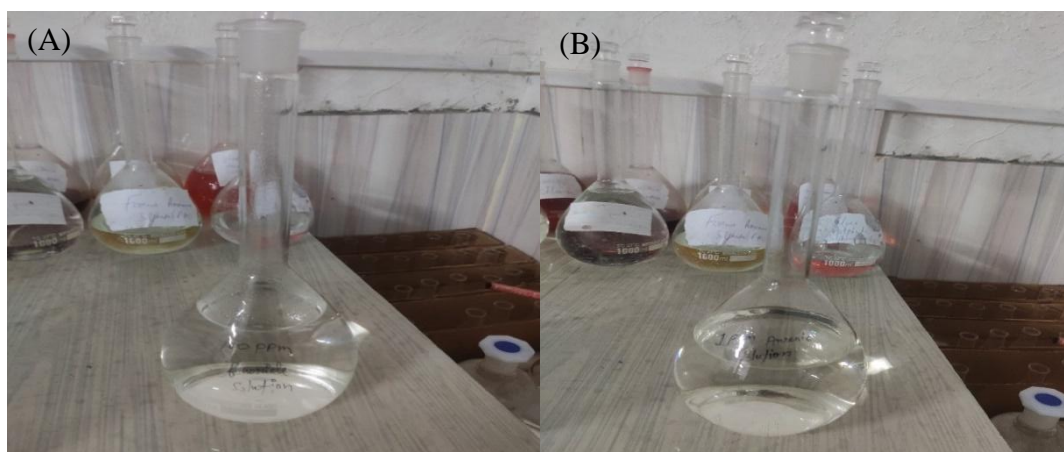


Fig.3. Prepared stock solutions for (A)Nickel&(B)Lead

2.2.3 Preparation of reagents

2.2.3.1 Reagent preparation for nickel determination

At first, SPADNS solution was prepared by mixing 500 ml of distilled water with 958 mg of SPADNS (sodium 2-1,8-dihydroxy-3,6-naphthalene disulfate). Next, Zirconyl-acid reagent was prepared as follows: 133 mg of zirconyl chloride octahydrate is dissolved in around 25 mL of distilled water to create the zirconyl-acid reagent. 350 ml of concentrated HCl was added to this, and up to 500 mL mark, distilled water was used to dilute the solution. Finally, Acid zirconyl-SPADNS reagent was made by adding equal volume of SPADNS and zirconyl-acid reagent which was used for nickel determination.

2.2.3.2 Reagent preparation for lead determination

First, potassium iodide solution was prepared by mixing 100 mL of distilled water with 15 g of potassium iodide. Brown bottle was used for the storage of the solution. Next, stannous chloride solution was prepared by mixing 40 g of lead free stannous chloride ($\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) with the concentrated HCl. After that, lead acetate solution was prepared by mixing 10 g of lead acetate [$\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 3\text{H}_2\text{O}$] into 100 mL distilled water. Next, silver diethyl dithiocarbamate reagent was prepared by mixing 200 mL of chloroform into 410 mg of 1 ephedrine, followed by the addition of 625 mg of silver diethyl dithiocarbamate and the amount being increased to 250 mL with more chloroform. It is cleaned and kept in a brown bottle. Alternatively, 1 g of silver diethyl dithiocarbamate is dissolved in 200 ml of pyridine. It is stored in brown bottle. Stock lead solution was as: While diluted to 1000 ml with distilled water, 1.32 g of lead trioxide is dissolved in 10 ml of distilled water that also contains 4 g of

sodium hydroxide which gives 1 ml = 1 mg of lead. Intermediate lead solution: 5 ml stock solution is diluted to 500 ml with distilled water. 1.00 ml = 1.00 µg lead. Standard lead solution: 10 ml intermediate lead solution is diluted to 100 ml with distilled water. 1.00 ml = 1.00 µg. Figure 4 shows the reagents prepared for nickel and lead.

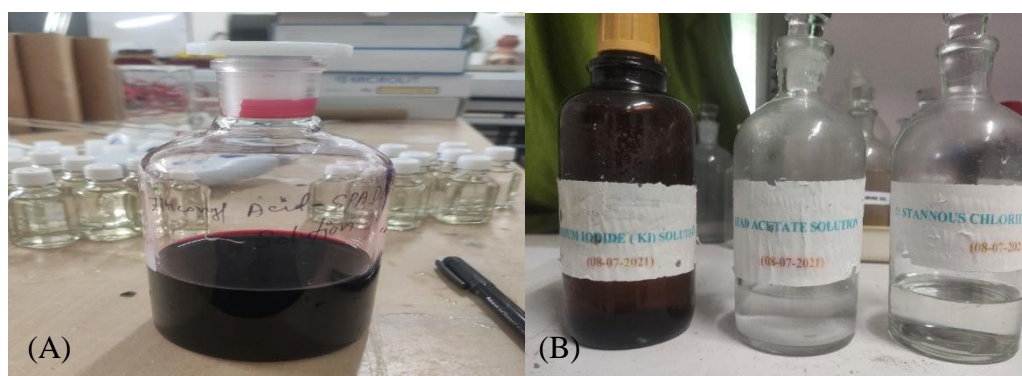


Fig.4.(A)SPADNS-acid zirconyl reagent for Nickel determination (B) Reagent for lead determination

2.2.4 Calculation of flow rate and hydraulic retention time

For measuring the flow rate, the flow through the pipe is regulated with the help of the flow regulator. A beaker of 100 ml is taken and the time required to fill up the beaker is noted with the help of the stop watch. All the reading were taken thrice. The flow rate is then calculated using equation (7).

$$Q = \frac{V_b}{t} \text{ ml/s} \quad (7)$$

Where, Q = Flow rate, V_b = Volume of beaker, t = time required to fill up the beaker

Similarly, the Hydraulic Retention Time, is estimated by using equation (8).

$$\text{HRT} = \frac{V_r}{Q} \quad (8)$$

Where, V_r = Volume of the reactor

2.2.5 Development of standard curve

2.2.5.1 For Nickel

The nickel standard sample was created by mixing the appropriate amounts of standard nickel solution with distilled water to achieve a concentration between 2,4,6,8 and 10 mg/L. In the

volumetric flask, 5 ml of SPADNS solution and 5 ml of zirconyl acid solution are pipetted to each standard, respectively. In order to obtain readings of the standard's absorbance, the spectrophotometer is adjusted to zero absorbance with reference solution. For optimum absorbance values, $\lambda_{\max} = 395$ nm was considered for nickel.

2.2.5.2 For Lead

Preparation of trivalent lead: A clean generator bottle is filled with 35 ml of sample using a pipette. Following each addition, thoroughly mix together with 5 ml of strong hydrochloric acid, 2 ml of potassium iodide solution, and 8 drops of stannous chloride. 15 minutes time is taken for the reduction of lead to its trivalent form. Preparation absorber and scrubber: glass wool is impregnated in the scrubber with acetate solution. Too wet condition was avoided because water will be carried over into the reagent solution. In absorber tube, 4 ml of silver diethyl dicarbamate reagent is pipetted. Arsine generator and measurement: 3 g of zinc is added to the generator, and then immediately scrubber absorber assembly is attached. The connectors are all properly secured. It was held for 30 minutes so that lead could be fully evaluated. To make sure that all of the arsine is released, the generator is slightly warmed. The solution is directly poured into a 1 cm cell from the absorber, and the absorbance at $\lambda_{\max} = 520$ nm is measured using reagent blank as a reference. Preparation of standard curve: standard solutions containing 0, 20, 70, 100, 143, 200 and 285 $\mu\text{g/L}$ concentrations of lead is prepared and treated as mentioned above. Absorbance vs. concentration of lead was plotted and analyzed.

Concentration of lead of the unknown solution can be obtained by the following formula:

$$\text{Lead conc., mg/L} = \frac{M}{V}$$

Where, M = mass in μg of lead in 4 ml of final solution, and V = volume of sample in ml.

3. Results and Discussion

3.1 Design Parameters

3.1.1 Determination of Discharge

The experiments were run at two conditions i.e., when the valve is fully opened and when it is half opened. The discharge is measured by taking volume in 100 ml beaker and the time is recorded until the beaker is filled and then the discharge is calculated by dividing volume of beaker by time. Table 1 lists the discharge with respect to corresponding valve opening percentage.

Table 1: Estimation of discharge

Sl. No	Valve opening (%)	Volume used (V_b) (ml)	Time (s)	Discharge (L/min)
1	100%	100	10	0.6
2	50%	100	20	0.3

3.1.2 Determination of hydraulic retention time

For calculating the hydraulic retention time (HRT), the volume of the tank is divided by the discharge obtained from the table 1. The data for HRT are given using table 2.

Table 2: Hydraulic retention time of reactor

Sl. No	Valve opening (%)	Volume (V_r) (L)	Discharge (L/min)	HRT (min)
1	100%	9	0.6	15
2	50%	9	0.3	30

Based on the experiment conducted to estimate the hydraulic parameter (Table 1), the HRT was found to be ranging from 15 min to 30 min. The HRT of the reactor is given in table 2.

3.2 Results for nickel removal determination

3.2.1 Standard curve for nickel

It can be observed from table 3 that absorbance of nickel decreased with increase in initial nickel concentration. Results of the same are depicted using figure 5.

Table 3: Development of standard curve for nickel

Sl. No.	Initial nickel concentration (mg/L)	Absorbance reading
1	2	0.3407
2	4	0.2907
3	6	0.2402
4	8	0.2224

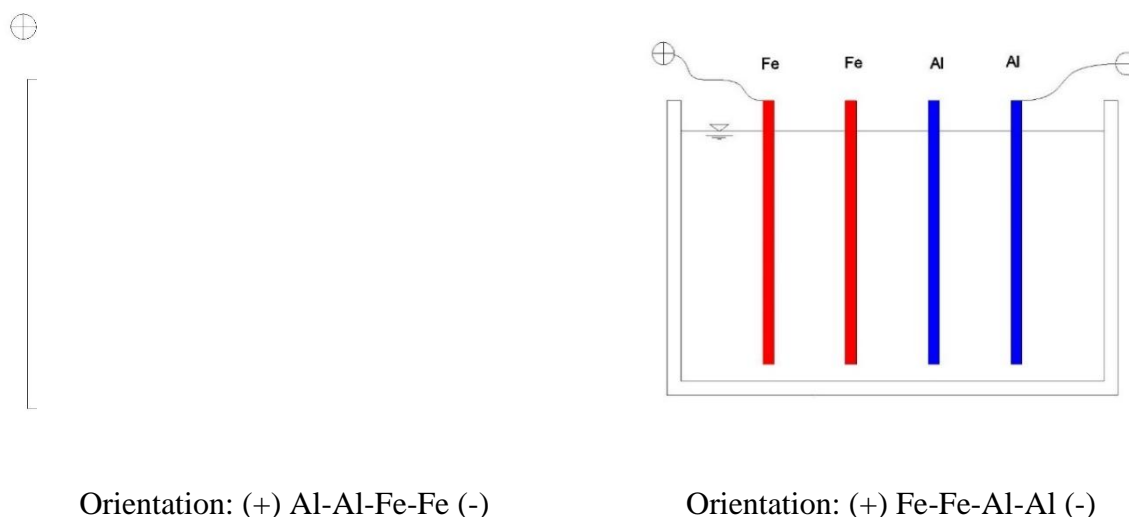


Fig. 6: Electrode arrangements for nickel removal

Table 4: Effect of electrode orientation on nickel removal

Sl. No.	Orientation	Initial concentration (mg/L)	Final concentration (mg/L)	% removal
1	(+) Fe-Al-Fe-Al (-)	8	2.32	71
2	(+) Al-Fe-Al-Fe (-)	8	0.88	89
3	(+) Fe-Fe-Al-Al (-)	8	2.64	67
4	(+) Al-Al-Fe-Fe (-)	8	1.12	86

From table 4 it was revealed that nickel removal is maximum for the electrode arrangement as: (+) Al-Fe-Al-Fe (+), where 89% of the nickel is removed whereas lowest removal is observed for the arrangement of (+) Fe-Fe-Al-Al (+) where 67% nickel is removed suggesting that for the present work, (+) Al-Fe-Al-Fe (+) is the best pattern of arrangements for the electrodes for maximum nickel removal from the solution.

3.2.3 Effect of reaction time

For this experiment, initial nickel concentration is taken as 8 mg/L, applied voltage 24V, current 2A, electrode arrangement (+) Al-Fe-Al-Fe (-). To ascertain the impact of reaction time on nickel elimination, a series of experiments are run for 15, 30, and 45 minutes. Figure

7 below displays the time dependency of nickel removal by electrochemical method at various reaction times. Here arrangement is bipolar and aluminum is connected to positive DC power supply and iron to negative. Table 5 shows that maximum nickel removed is at 30 minutes of treatment time where 87% of the nickel is removed. Beyond 30 minutes there is no increase in nickel removal.

Table 5: Effect of reaction time on nickel removal

Sl. No.	Time (min)	Initial concentration (mg/L)	Final concentration (mg/L)	% of removal
1	10	8	4.01	49
2	20	8	2.56	68
3	30	8	1.04	87
4	45	8	1.2	85

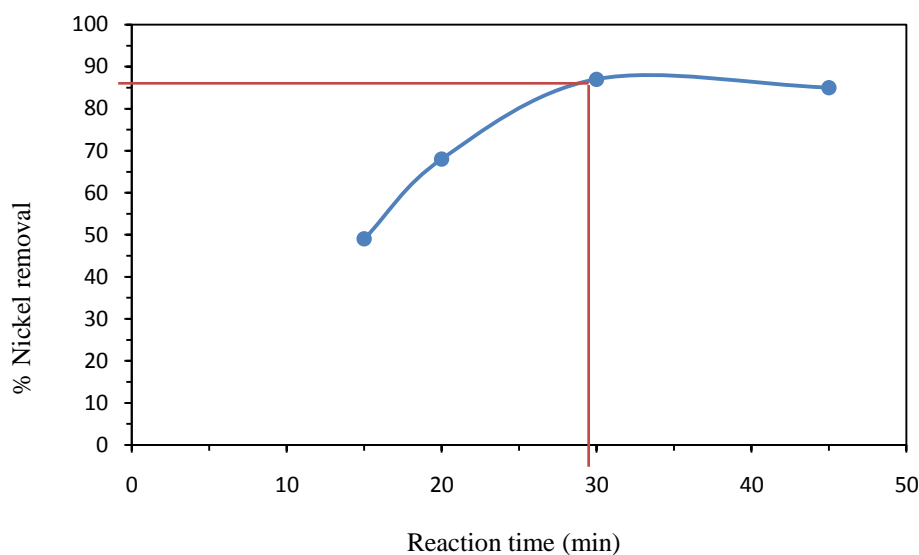


Fig. 7: Effect of reaction time on nickel removal

3.2.4 Effect of applied voltage

The effect of applied voltage is studied in the laboratory. The power supplier used is DC meter having voltage range from 0-30 V and the current is from 0-3 A. The removal of nickel in the reactor is examined in 12, 18, 24 and 30 V respectively. The applied current is kept constant at 2 A and electrode arrangement as (+) Al-Fe-Al-Fe (-). The effect of applied voltage is studied by taking 9 L of solution having nickel concentration 8 mg/L with reaction

time of 30 minutes and inter electrode distance as 2.5 cm. From table 6, it can be observed that at 24 V, maximum of 84% of the nickel is removed. The reason is that at higher voltage on electrodes, ion production is increased which leads to the production of hydroxides of metal i.e., $\text{Al}(\text{OH})_3$ in the solution resulting an increase in the removal efficiency (Battula et al. (2014)). But after some time, there is rise in the OH^- which results in an increase in pH of the solution, hence reduction of removal. Results of the same are presented using figure 8.

Table 6: Effect of applied voltage on nickel removal

Sl. No.	Applied voltage (V)	Initial concentration (mg/L)	Final concentration (mg/L)	% of removal
1	12	8	3.6	55
2	18	8	2.4	70
3	24	8	1.28	84
4	30	8	1.84	77

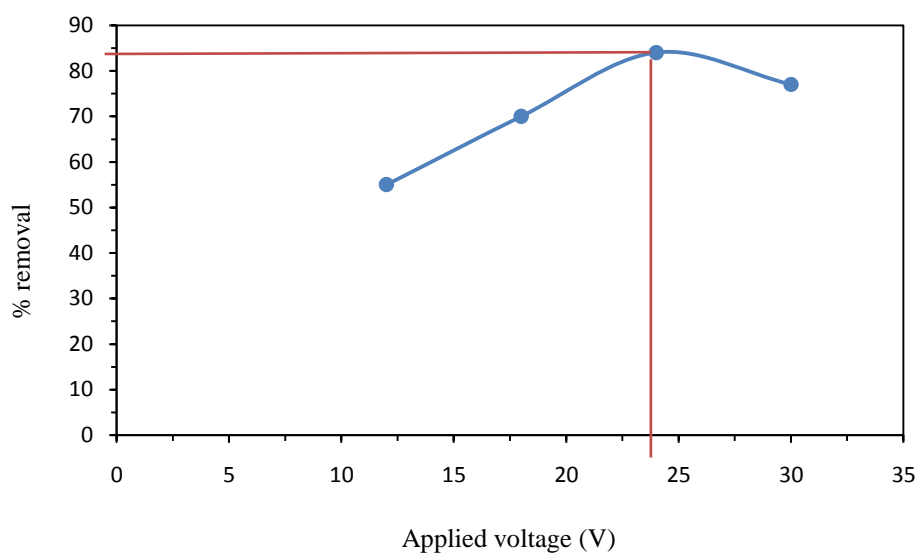


Fig. 8: Effect of applied voltage on nickel removal

3.2.5 Effect of initial concentration

For this, nickel solutions with concentrations of 2, 4, 6, 8 and 10 mg/L are prepared and analyzed for removal capacity. Other parameters considered for experimentation were, applied voltage 24 V, current 2 A, electrode arrangement as (+) Al-Fe-Al-Fe (-), inter

electrode distance as 2.5 cm, and pH as 7. Table 7 shows that the maximum removal capacity of the plant was found for initial nickel concentration of 8 mg/L with a removal of 85%. Results of the same are also presented using figure 9. This can be explained by the theory of dilute solution. In dilute solution, formation of the diffusion layer at the vicinity of the electrode causes a slower reaction rate, but in concentrated solution the diffusion layer has no effect on the rate or migration of metal ions to the electrode surface (Battula et al. 2014).

Table 7: Effect of initial concentration on nickel removal

Sl. No.	Initial concentration (mg/L)	Final concentration (mg/L)	% of removal
1	2	1.2	40
2	4	1.04	74
3	6	1.36	77
4	8	1.2	85
5	10	1.7	83

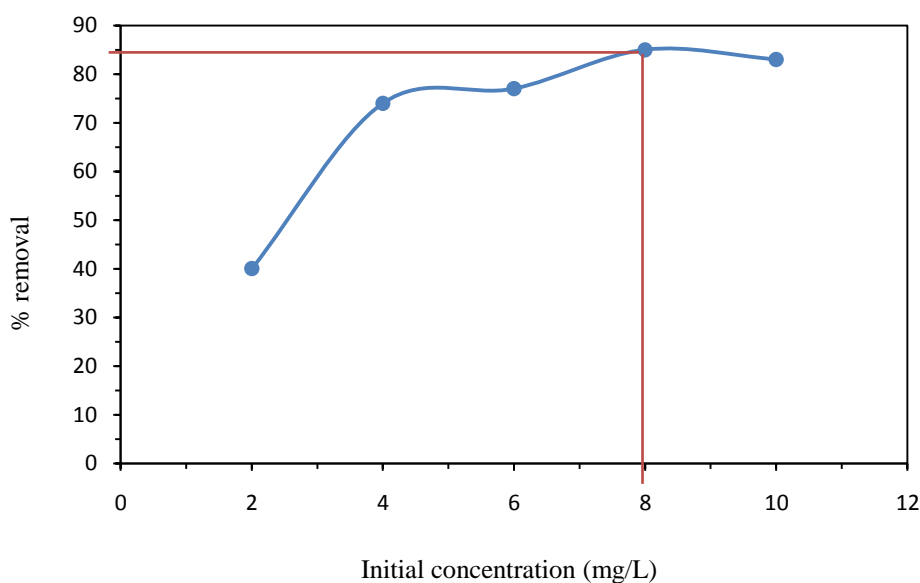


Fig. 9: Effect of initial concentration on nickel removal

3.2.6 Effect of pH

The effect of pH on nickel removal is studied for initial nickel concentration of 8 mg/L at applied voltage 24 V, current 2 A, electrode arrangement as (+) Al-Fe-Al-Fe (-). The removal of nickel in the reactor is examined in the pH range from 5-9 at room temperature for reaction time of 30 minutes. By adding 0.1M HCl or 0.1M NaOH solution, the pH of the solution is regulated. From the results (refer table 8), it can be apprehended that variation in pH significantly impacts the removal efficiency of the reactor, where, for the neutral pH of 7, the removal was maximum with 88% and for both acidic and alkaline conditions the removal was minimum which is attributed to the formation of large amount of $\text{Al}(\text{OH})_3$ flocs which attracts nickel ion, resulting in large amount of removal. Pictorial representation of the results are done using figure 10.

Table 8: Effect of pH on nickel removal

Sl. No.	pH	Initial concentration (mg/L)	Final concentration (mg/L)	% of removal
1	5	8	3.12	61
2	7	8	0.96	88
3	9	8	2.87	64

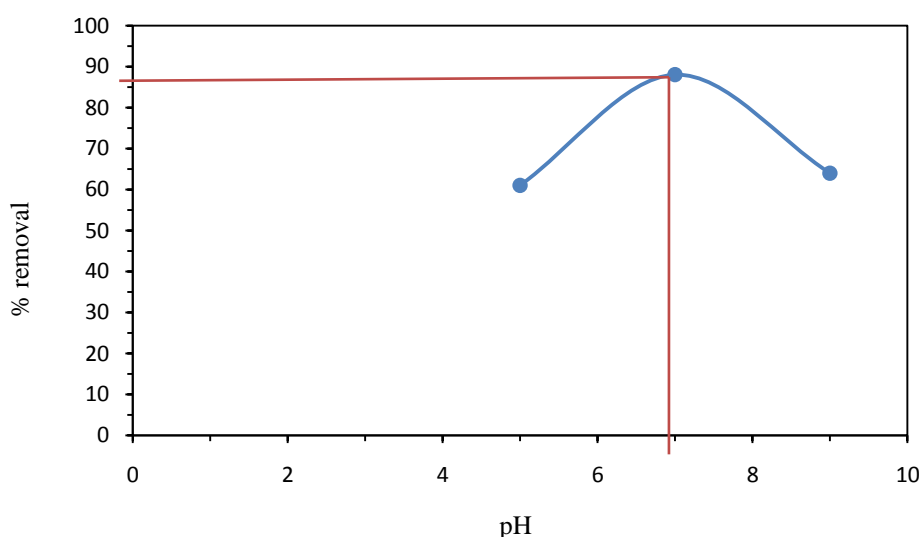


Fig. 10: Effect of pH on nickel removal

3.3 Results for lead removal determination

3.3.1 Standard curve for lead

Contrary to what has been observed for nickel, lead absorbance was directly proportional to the initial lead concentrations. Results are presented using Table and figure 11.

Table 9: Absorbance reading for lead

Sl. No.	Initial concentration (mg/L)	Absorbance reading
1	0.000	0.000
2	0.020	0.087
3	0.070	0.114
4	0.100	0.202
5	0.143	0.232
6	0.200	0.235
7	0.285	0.399

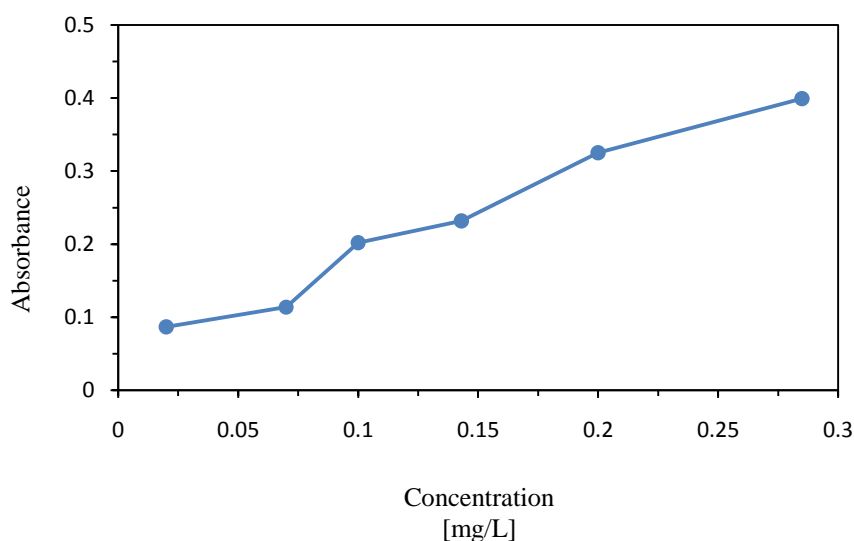


Fig. 11: Standard curve for lead

3.3.2 Effect of electrode orientation

Different electrode material and electrode combinations influences the performance of electrochemical process which we already saw in case of nickel removal. Now, for lead removal, initial concentration of lead is taken as 700 $\mu\text{g/L}$, applied voltage as 24V, current

2A, pH 7 and reaction time of 30 minutes. Experimental electrode orientation patterns are depicted using figure 12 and the effect of electrode orientations on lead removal are listed using table 10.

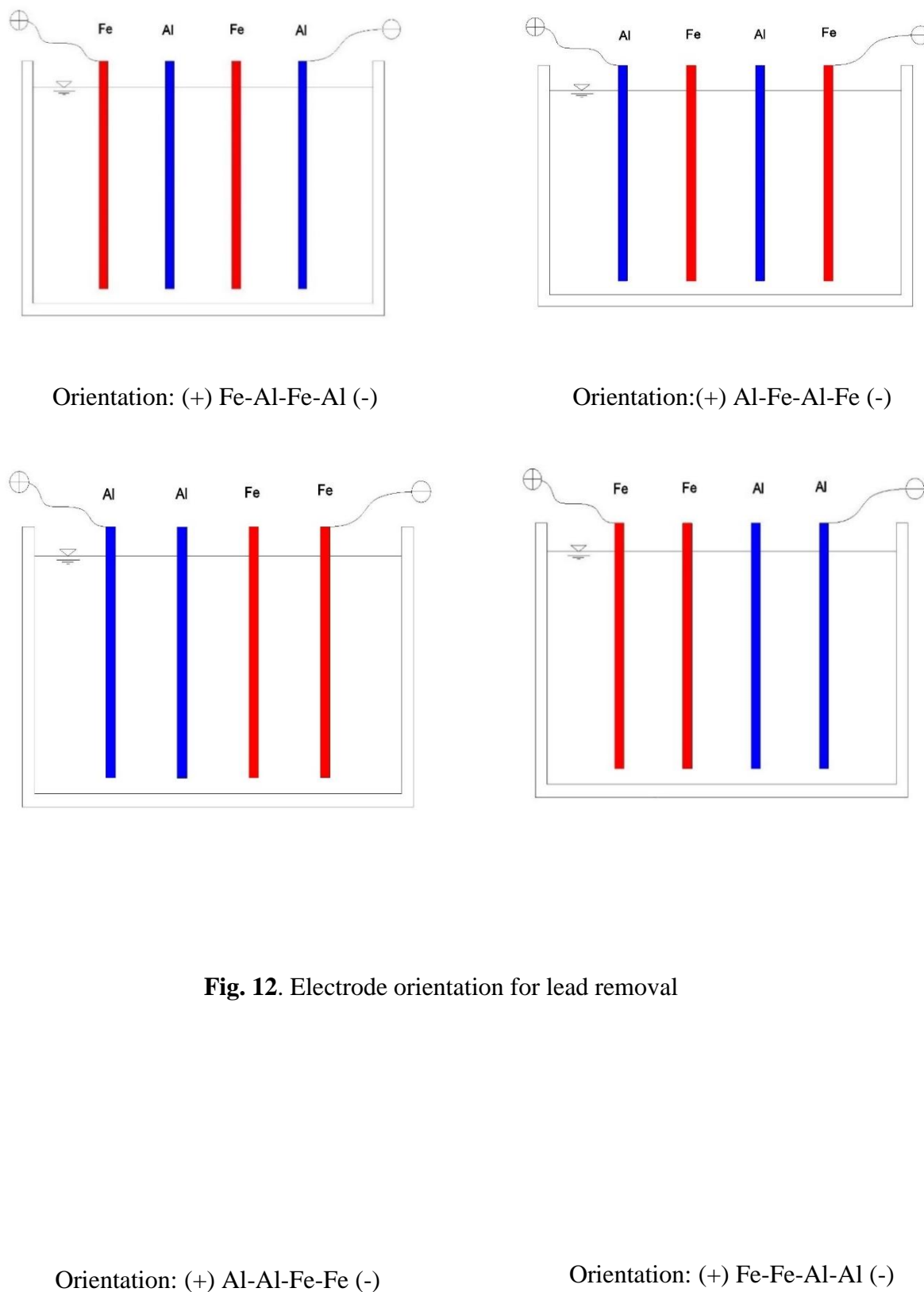


Fig. 12. Electrode orientation for lead removal

Sl. No.	Orientation	Initial concentration ($\mu\text{g/L}$)	Final concentration ($\mu\text{g/L}$)	% of removal
1	(+) Fe-Al-Fe-Al (-)	700	241	66
2	(+) Al-Fe-Al-Fe (-)	700	44	93
3	(+) Fe-Fe-Al-Al (-)	700	259	63
4	(+) Al-Al-Fe-Fe (-)	700	70	90

Table 10: Effect of electrode orientation on lead removal

From table 10 it is observed that maximum lead removal was obtained for the orientation as (+) Al-Fe-Al-Fe (-) with 93% lead removal and at the same time lowest removal is obtained for electrode orientation as (+) Fe-Fe-Al-Al (-) where 63% lead is removed. Similar kind of results were observed for nickel removal also.

3.3.3 Effect of reaction time

For this experiment, parameters chosen were as, initial lead concentration as 700 $\mu\text{g/L}$, applied voltage 24 V, current 2 A, electrode orientation (+) Al-Fe-Al-Fe (-). To ascertain the impact of reaction time on the elimination of lead, a series of experiments were run for different time intervals viz. 15, 30, and 45 minutes. Figure 13 below displays the time dependency of the electrochemical technique for removing lead at various reaction times. Here orientation is bipolar and aluminum is connected to positive DC power supply and iron to negative. Table 11 below shows that lead removal is maximum for 30 minutes and afterwards there was no improvement in lead removal w.r.t time.

Table 11: Effect of reaction time on lead removal

Sl. No.	Reaction time (min)	Initial concentration ($\mu\text{g/L}$)	Final concentration ($\mu\text{g/L}$)	% of removal
1	15	700	364	48

2	20	700	217	69
3	30	700	56	92
4	45	700	77	89

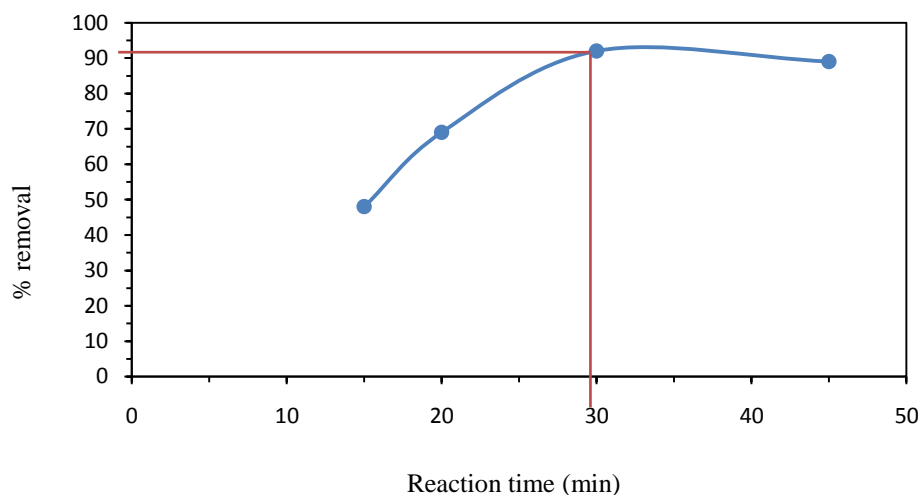


Fig. 13: Effect of reaction time on lead removal

3.3.4 Effect of initial concentration

For this 400, 500, 600, 700 and 800 $\mu\text{g/L}$ concentrations of lead are prepared and effects on the removal of lead is checked. The applied voltage 24 V, current 2 A, electrode arrangement as (+) Al-Fe-Al-Fe (-), inter electrode distance as 2.5 cm, pH as 7 is applied to the process. From table 12, it is revealed that removal of lead gradually increases from 400 $\mu\text{g/L}$ and maximum lead removal was achieved at the initial concentration of 700 $\mu\text{g/L}$, afterwards there is decrease in the removal beyond that concentration. This can be explained by the dilute solution theory. While the diffusion layer forms near the electrode in diluted solution, slowing down the reaction rate, it has no impact on the rate at which metal ions migrate to the electrode surface in concentrated solution (Battula et al. 2014). Results are also shown using figure 14.

Table 12. Effect of initial concentration on lead removal

Sl. No.	Initial concentration ($\mu\text{g/L}$)	Final concentration ($\mu\text{g/L}$)	% of removal
1	400	308	44
2	500	427	61

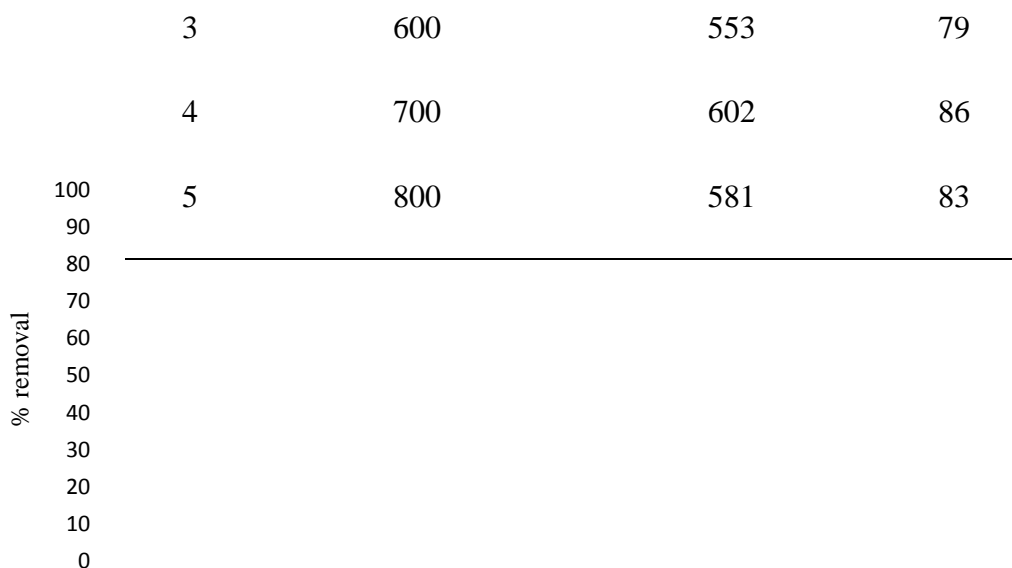


Fig. 14: Effect of initial concentration on lead removal

3.3.5 Effect of applied voltage

The effect of applied voltage is studied in the laboratory. The power supplier used is DC meter having voltage range from 0-30 V and the current is from 0-3 A. The removal of lead in the reactor is examined in 12, 18, 24 and 30 V respectively. The applied current is kept constant at 2A and electrode arrangement as (+) Al-Fe-Al-Fe (-). The effect of applied voltage is studied by taking 9 L of solution having lead concentration 700 µg/L with reaction time of 30 minutes and inter electrode distance as 2.5 cm. The table 13 shows that at applied voltage of 24 V almost 89% lead is removed and on further increase of applied voltage there is no rise in the removal of lead concentration. This is because, at higher voltage on electrodes, ion production is increased which leads to the production of hydroxides of metal i.e., Al(OH)₃ and Fe(OH)₃ in the solution resulting an increase in the removal efficiency (Battula et al. (2014)). But after some time, there is rise in the OH⁻ which results in an increase in pH of the solution so the removal is also reduced. Pictorial result is shown using figure 15.

Table 13: Effect of applied voltage on lead removal

Sl. No.	Voltage (V)	Initial concentration (µg/L)	Final Concentration (µg/L)	% Removal

1	12	700	253	64
2	18	700	162	77
3	24	700	79	88.7
4	30	700	94	86

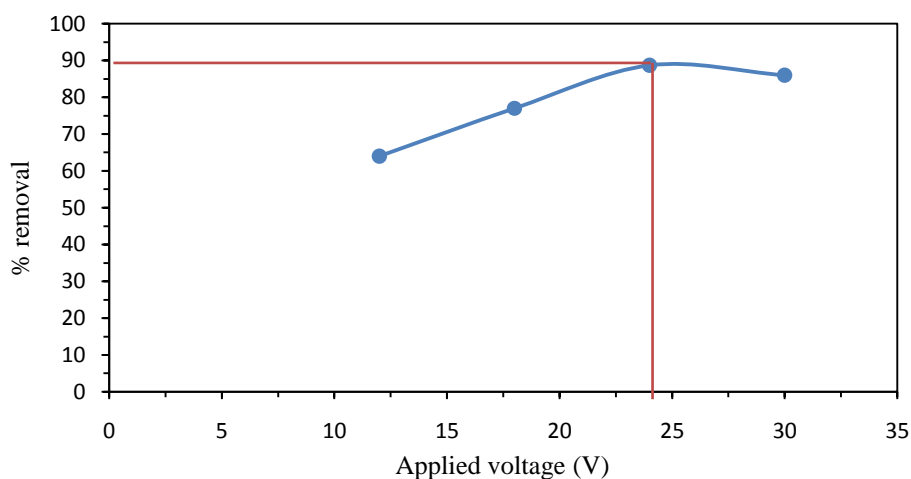


Fig. 15: Effect of applied voltage on lead removal

3.3.6 Effect of pH

The effect of pH on lead removal is studied for initial lead concentration of 700 µg/L at applied voltage 24 V, current 2 A, electrode arrangement as (+) Al-Fe-Al-Fe (-). The removal of lead in the reactor is examined in the pH range from 5-9 at room temperature for reaction time of 30 minutes. pH of the solution was regulated by mixing 0.1M HCl or 0.1M NaOH in the solution. Lead removal is maximum at neutral pH with 91% and for both acidic and alkaline condition lead removal is low. At neutral pH of 7 there is large formation of Al(OH)₃ floc which results in significant lead removal. Results are shown using table 14 and figure 16

Table 14: Effect of pH on lead removal

Sl. No.	pH	Initial concentration (µg/L)	Final concentration (µg/L)	% of removal
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1	5	700	177	75
2	7	700	65	91
3	9	700	213	69.5

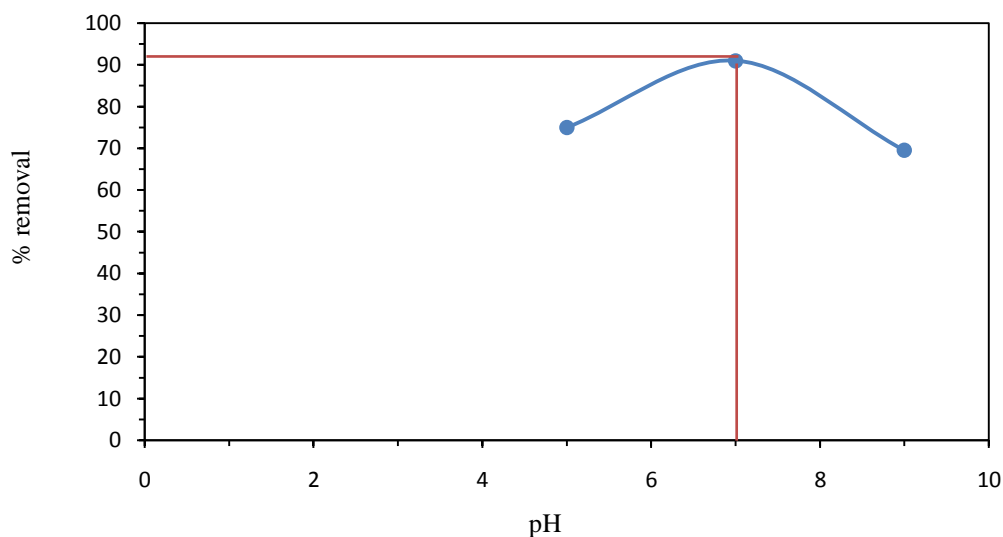


Fig. 16: Effect of pH on lead removal

4. Conclusion

From the present work and analysis of the data, the following conclusions can be drawn:

- From the analysis of results it is observed that for the maximum removal of nickel (89%) and lead (93%), following optimum parameter conditions were critical, which are summarized as: electrode orientation: (+) Al-Fe-Al-Fe (-) where the arrangement is bipolar and aluminum sheet is acting as positive electrode and iron sheet performed as negative electrode with interelectrode distance as 2.5 cm, voltage applied as 24 V, current as 2 A, initial concentration of 8 mg/L and pH as 7.
- The reaction time needed for maximum nickel (87%) and lead (92%) removal is 30 minutes at initial concentration 8 mg/L, applied voltage as 30 V, current 2 A with pH of the water sample as 7, electrode arrangement as (+) Al-Fe-Al-Fe (-).
- The applied voltage for the maximum removal of nickel (84%) and lead (88.7%) is 24 V, other parameters being initial concentration as 8 mg/L, current as 2 A, pH as 7, electrode arrangement as (+) Al-Fe-Al-Fe (-).

- The required optimum initial concentration for maximum removal of nickel (85%) and lead (86%) is 8 mg/L, at applied voltage 24 V, current 2 A, pH as 7, reaction time of 30 minutes and electrode arrangement as (+) Al-Fe-Al-Fe (-).
- Maximum removal of nickel (88%) and lead (91%) is at pH of 7, other parameters as initial concentration 8 mg/L, applied voltage 24 V, current 2 A, electrode arrangement as (+) Al-Fe-Al-Fe (-), reaction time of 30 minutes.

Summarily, it was observed that use of electrochemical method is a competitive and effective way to remove harmful transit ions from water. This method can be practically employed to remove harmful chemicals and minerals from groundwater.

5. References

Balasubramanian, N. Kojima, T. Basha, C. A. and Srinivasakannan, C. (2009). *Removal of lead from aqueous solution using electrocoagulation*.

Bard, A. J. and Faulkner, L. R. (2000). *Electrochemical Methods*, Wiley, New York, NY, USA, 2nd edition.

Behbahani, M. Alavi Moghaddam, M. R. and Arami, M. (2011). *Techno-economical evaluation of nickel removal by electrocoagulation process*.

Bhagawan, D. Saritha, P. Shankaraiah, G. and Himabindu, V. (2019). *Nickel removal from groundwater using hybrid cylindrical electrocoagulation reactor*.

Bockris, J. M. and Reddy, A. K.N. (1997). *Electrochemistry: Ionics*, Plenum Press, New York, NY, USA, 2nd edition.

Canizares, P. Jimenez, C. Martinez, F. Saez, C. and Rodrigo, M. A. (2007). *Study of the electrocoagulation process using aluminum and iron electrodes*.

Chavalparit, O. and Ongwande, M. (2009) "Optimizing electrocoagulation process for the treatment of biodiesel wastewater using response surface methodology," *Journal of Environmental Sciences*, vol. 21, no. 11, pp. 1491–1496.

Dey, A.K. and Dey, A. Selection of optimal Processing Condition during Removal of Methylene Blue Dye Using Treated Betel Nut Fibre Implementing Desirability Based RSM approach. Response surface methodology in Engineering Science (2021). ISBN: 978-1-83968-918-5.

Dey, A.K., Dey, A., 2021. Selection of optimal processing condition during removal of Reactive Red 195 by NaOH treated jute fibre using adsorption. Groundw. Sustain. Develop. 12, 100522.

Dey, A.K., Dey, A., Goswami, R., 2022. Selection of optimal performance characteristics during adsorption of Methyl red dye using sodium carbonate treated jute fibre. Desalination Water Treat. 260, 187–202.

Dey, A.K., Dey, A., Goswami, R., 2022. Adsorption characteristics of methyl red dye by Na₂CO₃-treated jute fibre using multi-criteria decision making approach. Appl. Water Sci. 12 (8), 1–22.

Dey, A.K., and Goswami, R., Cationic dye removal using surface treated activated carbon as an adsorbent, Environmental Science: *Environmental Science: Water Research & Technology*, 2022, 8, 2545 – 2566.

Dey, A.K., Kumar, U., 2017. Adsorption of Reactive Red 195 from polluted water upon Na₂CO₃ Modified Jute Fibre. Int. J. Eng. Technol. 9 (3S), 53–58.

Dey, A.K., Kumar, U., Dey, A., 2018. Use of response surface methodology for the optimization of process parameters for the removal of Congo Red by NaOH treated jute fibre. Desalination Water Treat. 115, 300–314.

Dey, A.K., Dey, A., Goswami, R., 2022. Fixed-bed column analysis for adsorption of Acid scarlet 3R dye from aqueous solution onto chemically modified betel nut husk fibre. Desalination Water Treat. 252, 381–390.

Dey, A.K., Kumar, U., 2017. Adsorption of anionic azo dye Congo Red from aqueous solution onto NaOH-modified jute fibre. Desalination Water Treat. 92, 301–308.

Dey, A.K., and Goswami, R., Synthesis and application of treated activated carbon for cationic dye removal from modelled aqueous solution, *Arabian Journal of Chemistry*, Volume 15, Issue 11, November 2022, 104290, <https://doi.org/10.1016/j.arabjc.2022.104290>.

F. R. Espinoza, F. R. A. N. M'odenes. A. N., P. S. Theodoro et al. (2012). "Optimization of the iron electro-coagulation process of Cr, Ni, Cu, and Zn galvanization by-products by using response surface methodology," *Separation Science and Technology*, vol. 47, no. 5, pp. 688–699, 2012.

Garcia-Lara, A. M. Montero-Ocampo, C. Equihua-Guillen, F. Camporredondo-Saucedo, J.E. Servin-Castaneda, R. and Muniz-Valdes, C.R. (2014). *Lead Removal from Natural Groundwater by Electrocoagulation Using Response Surface Methodology*.

Goswami, R., Dey, A.K., 2022. Use of anionic surfactant-modified activated carbon for efficient adsorptive removal of crystal violet dye. *Adsorp. Sci. Technol.*, 2357242.

Goswami, R., Dey, A.K., 2022. "Positive Impact of Environment due to Covid-19 lockdowns in parts of India: a review". *Environ. Eng. Manage. J.* 21 (4), 559–568.

Goswami, R., and Dey, A.K., Activated carbon from agricultural residues: a review, *Desalination and water treatment* 278 (2022) 283-292.

Jadhav, S. V. Bringas, E. Yadav, G. D. Rathod, V. K. Ortiz, I. and Marathe, K. V. (2015). *Lead and nickel contaminated groundwaters: a review of current technologies for contaminants removal*.

Kobyas, M. Gebologlu, U. Ulu, F. Oncel, S. and Demirbas, E. (2011). *Removal of lead from drinking water by the electrocoagulation using Fe and Al electrodes*.

Kumar, P. R. Chaudhari, S. K. Khilar, K. C. and S. P. Mahajan, S. P. (2004). "Removal of lead from water by electrocoagulation," *Chemosphere*, vol. 55, no. 9, pp. 1245–1252, 2004.

Lacasa, E. Canizares, P. Saez, C. Fernandez, F. J. and Rodrigo, M. A. (2011). *Removal of lead by iron and aluminium electrochemically assisted coagulation.*

Liu, R. Gong, W. Lan, H. Yang, T. Liu, H. and Qu, J. (2012). *Simultaneous removal of arsenate and nickel by iron and aluminum binary oxide.*

Massart, D. L. Vandeginste, B. G. Muydens, L. M. C. Jong, S. Lewi, P. J and Verbeke, J. S. (1997). *Handbook of Chemometrics and Qualimetrics: Part A*, Elsevier, Amsterdam, The Netherlands.

Mameri, N. Yeddou, A. R. Lounici, H. Belhocine, D. Grib, H. and Bariou, B. (1998). *Defluoridation of septentrional Sahara water of North Africa by electrocoagulation process using bipolar aluminium electrodes.*

Gomes, J. A. G. Daida, P. Kesmez, M. Weir, M. Moreno, H. Pagra, J. R. (2005). *Lead removal by electrocoagulation using combined Al-Fe electrode system and characterization of products.* B139. 220–231.

Murthy, S. Shivaswamy, M. Mahesh, S. and Thappa, S. H. (2019). *Simultaneous Removal of Lead and Nickel from Groundwater using Batch Electrochemical Coagulation Process-Role of Aluminum with Iron Electrodes.*

Mahilary, H.K., and Dey, A.K., Preparation and application of carboxylated and mechanically attrited carbon for adsorptive removal of crystal violet dye, *Environmental Science: Environmental Science: Water Research & Technology*, 2023, **9**, 861 – 882.

Nell, J.A., Livanos, G. (1988). Effects of nickel concentration in seawater on growth and nickel accumulation by Sydney rock oyster (*saccostrea-commercials*) and flat oyster (*oyster-angasi*) spat. *Water Res.* 22, 749e753.

Roussar, I. Micka, K. and A. Kimla, A. (1986). *Electrochemical Engineering II*, Elsevier Science.

Sandoval, M. A. Fuentes, R. Thiam, A. Salazar, R. (2021). *Lead and nickel removal by electrocoagulation process: A general review.* Vol. 753.

Singh Thakur, L. and Mondal, P. (2016). *Simultaneous lead and nickel removal from synthetic and real groundwater by electrocoagulation process: Parametric and cost evaluation.*

Sivakumar, M. and Emamjomeh, M.M. (2009). *Nickel removal by a continuous flow electrocoagulation reactor.*

Vasudevan, S. Kannan, B. S. Lakshmi, J. Mohanraj, S. and Sozhan, G. (2010). *Effects of alternating and direct current in electrocoagulation process on the removal of nickel from water.* J. Chem. Technol. Biotechnol. 86, 428e436.

Wang, J. W. Bejan, D. and Bunce, N. J. (2003). *Removal of lead from synthetic acid mine drainage by electrochemical pH adjustment and coprecipitation with iron oxide.*

Zhao, X. Zhang, B. Liu, H. and Qu, J. (2011). *Simultaneous removal of lead and nickel via an integrated electro-oxidation and electrocoagulation process.*

Zewge, F. Chandravanshi, B. S. (2006). *Removal of excess nickel from water by aluminum hydroxide.*