

Arsenic Removal from Ground Water Using Solar Hybrid Capacitive Deionization Electrodialysis Module

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Abstract

Arsenic is among one of the most toxic naturally occurring metallic elements present in water resources. Disposal of untreated wastewater into large water bodies pollutes the surface and underground water resources due to leaching of toxic metals, chemicals, and other species. Arsenic in water causes many water borne diseases for human beings as it is considered a potent human carcinogen, associated with risk of cancer of skin, lungs, urinary bladder, liver, and kidney. According to the report of Pakistan Council of Research in Water Resources and United Nations Children's Emergency Fund Sindh and Punjab are two major provinces of Pakistan affected by Arsenic contamination. Still there is no proper treatment plant for the removal of Arsenic contamination from drinking water resources in interior Sindh areas. There are several techniques to remove arsenic from water i.e. oxidation, coagulation, ion exchange, membrane process and adsorption. Those samples were treated upon the CDIE module in which each sample at different parameter like concentration, voltage, and time. Other parameters like pH, resistivity, conductivity, and power consumption, most importantly the cost of membranes, electrodes and module were also measured accordingly because it was the solar hybrid cost effective work to remove the arsenic from ground water. Treated samples were tested on the Arsenic-Kit, and the results were generated accordingly, showing 97.5%, 89.333% and 75% removal percentage of Arsenic from ground water. All the parameters were set at optimized conditions to get maximum efficiency at low cost and less efforts.

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1. Introduction

Water is the need for all the life on this planet, human being and all other living things are unable to survive without safe and clean water. The underground water is an essential source of water supply all over the globe. Unfortunately, this ground water is started to contaminate from time to time with natural occurring chemicals and due to increase in anthropogenic activities, one of the most dangerous naturally chemical found in water is Arsenic. The main objectives of this study was to fabricate the Solar-Hybrid Capacitive De-ionization Electro-dialysis Module (CDIE) along with preparation of Heterogeneous Membranes and Capacitive Electrodes for Arsenic removal to conduct parametric experiments and analyze the data to evaluate the Arsenic removal efficiency of CDIE Module.

1.1. Arsenic

Arsenic is among one of the most lethal naturally occurring metallic elements present in water resources. As in water is serious natural calamity and public health hazard which originates from both anthropogenic as well as geological sources. Drinking water contaminated with Arsenic is the worldwide problem which causes severe health hazards to humans. Disposal of untreated wastewater into large water bodies pollutes the surface and underground water resources due to leaching of toxic metals, chemicals and others species. This has further aggravated the Arsenic poisoning in drinking water. As in water causes many water borne diseases for human beings such as skin, lungs and cancer type diseases. It also damages the marine life. Inorganic As is considered a potent human carcinogen, associated with risk of cancer of skin, lungs, urinary bladder, liver and kidney. Pakistan is also facing serious public health adversities due to Arsenic contamination. According to the report of Pakistan Council of Research in Water Resources (PCRWR) and United Nations Children's Emergency Fund (UNICEF) Sindh and Punjab are two major provinces of Pakistan affected by Arsenic contamination. Still there is no proper treatment plant for the removal of Arsenic contamination from drinking water resources in interior Sindh areas. As reported the Arsenic concentration in underground water is higher than the

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WHO limits. This study comprises fabrication of Solar Capacitive Deionization Electro dialysis Module and it's applicability for removal of Arsenic contamination from underground drinking water resources. This study helps in developing appropriate technology that could be cheap, simple to use and easily adaptable for domestic purposes.

1.2. Electrodialysis

IUPAC recognized electro dialysis (ED) as “membranes supported separation method” In which ions are sent through an ion-selective membrane by the impact of an electrical field”. As ED is an electrochemical separation process or we can say mass transportation can be carried out. In which ion exchange membranes are responsible for the movement of ions by the electrical potential difference or DC power supply voltage. The driving force is required for the transfer of ionic species which is present in source water. Two electrodes, anode (positively charged) and cathode (negatively charged) are placed through the ion separation process developed and the raw water can be obtained into two categories one is diluted and another is concentrated.

1.3. Capacitive Deionization

Capacitive deionization is mostly known as capacitive desalination, electrochemical desalination or flow through capacitor. It is comparatively a new method of desalination in which porous carbon is used as an electrode for ion adsorption because carbon has an incredible potential concerning the desalination process. It operates on a very low temperature, pressure and voltage therefore it had been considered as a most cheap, low energy and high yield contender to reverse osmosis (RO) and electro dialysis (ED). It has a wide application range from water softening to sea water desalination. CDI electrochemically removes ions from saline water. Both positive and negatively charged ions move towards their oppositely charged electrodes. CDI removes a vast range of ionic contaminants with high recovery rates. It has a water recovery almost 90% than all the other processes of desalination.

1.4. Solar Power

Solar Power is a source of energy which is used to convert sunlight into electricity by using a Photo Voltaic Cell (PVC) installed on a panel in a certain number connected in a series circuit. Solar Energy or sunlight is converted into electrical energy through the photo voltaic effect. These Solar panels are installed facing towards the sun to catch the maximum amount of light to get semiconductor elements to transfer the electrons to produce the Direct Current (DC). It is a renewable source of energy along with being environment (Eco) friendly having zero emission of harmful and toxic elements into the atmosphere like carbon, lead etc.

2. Methodology of Experiments

2.1. Process of Methodology

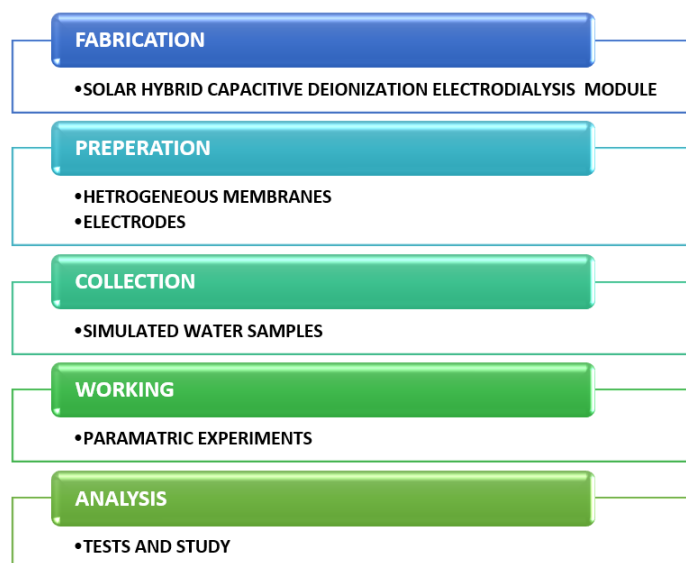


Fig. 1: Process of Methodology

2.2. Simulated Water Sample Preparation

From the 1 ppm (1000ppb) stock solution available in the laboratory, three samples of 50, 75, and 100 ppb solutions were made. 20 ml of a 1ppm (1000 ppb) arsenic solution was added to 1 liter (1000ml) of distilled water to get a 50 ppb sample. To create a 75 ppb sample, 1 liter (1000 ml) of distilled water was mixed with 13.333 ml of 1 ppm (1000 ppb) arsenic solution. Similarly, 10 ml of a 1ppm (1000 ppb) arsenic solution was added to 1 liter (1000ml) of distilled water for a 100 ppb sample.

2.3. Solar-Hybrid Capacitive De-Ionization Electro Dialysis Module Development

The electro dialysis module is constructed of white planar glass. This module measures 5.1 inches long, 5.2 inches wide, and 5.6 inches tall. The module's holdup volume is computed as follows:

$$\text{Volume of Module} = \text{Length} \times \text{Width} \times \text{Height}$$

$$V_{\text{module}} = 148.512 \text{ inch}^3 \text{ or } 2.433 \text{ L}$$

Glass has a thickness of 0.2 inch (5.08 mm). The module's volumetric weight is computed using Eq (1).

$$\text{Volumetric Weight in Kilogram} = \frac{\text{Width} \times \text{Length} \times \text{Height (in cm)}}{W_v = 0.4056 \text{ kg}} \times 6000 \quad (1)$$

2.4. Preparation of the Membranes

The cationic and anionic resins are used to create two cationic and anionic membranes. Membranes have dimensions of 5inch*5inch (25 inch²). Cationic Membrane was labelled and Anionic Membrane as CEX and AEX respectively. The initial weight of each membrane is 0.003 kg. These membranes are covered with 0.009 kilograms of cationic resin and 0.004 kilograms of epoxy resin, as well as 0.009 kilograms of anionic resin and 0.004 kilograms of epoxy resin. The membranes are dried for 150 minutes in an electric oven at 80o degrees Celsius, then cooled for 1 hour at 31o degrees Celsius in the air.

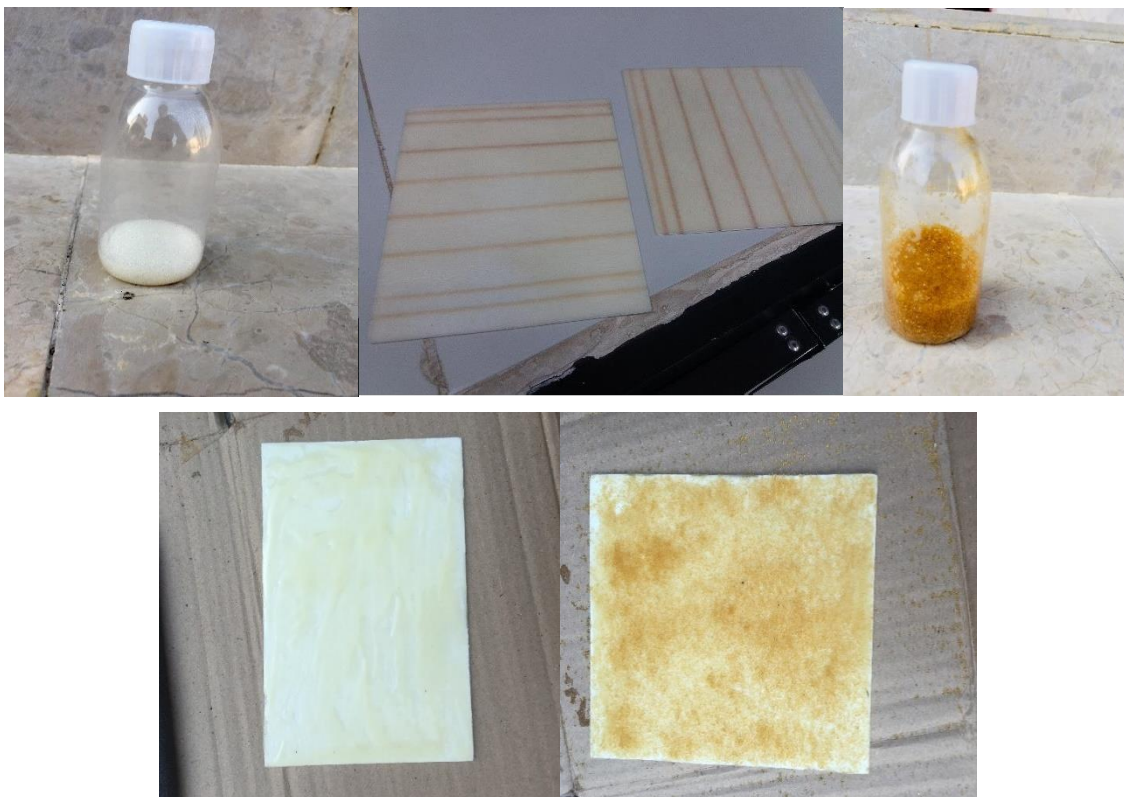


Fig. 2: Resins, Non-Coated Membranes, and Epoxy-Resin Coated Membranes

2.5. Capacitive Electrodes Preparation

Two (2) Copper (Cu) conductors were purchased from the marketplace. The copper-wire weighs 3.175g and the length of copper-wires is 6.5-inches respectively each. Activated-Carbon (AC) was crushed in the ball-mill having particle size of 10- μ m. The 8 grams incited carbon is mixed with the 2 grams epoxy sap latch and covered over the copper-wires. The capacitive cathodes were dried out in an electric oven at 80° C for half hour. The anodes are then chilled for 5-hours at room-temperature.



Fig. 3: Prepared Capacitive Electrodes



Fig. 4: Top View of the Developed Module

2.6. Running Solar CDED Module

The module was filled with 1 liter of SAP-1 in the dilute area and 250ml+250ml bottled water in the concentrate section. The electrodes were attached to the membrane. The electro dialysis module is divided into three chambers. The central container is dilute, while the other two are concentrate compartments. The CEX was connected to the cathode, whereas the AEX- was connected to the anode. The electrodes were connected to the DC power supply. The voltages are set at 10, 15, and 20 volts. The voltages were varied after 30, 45, and 60 minutes, respectively. This process was repeated for SAP-2 and SAP-3 also.

2.7. Sample Collection

When the CDED Module was turned on, Sample-1 (50 ppb) was set to run for 30, 45, and 60 minutes, with the voltage set at 10, 15, and 20 volts, respectively. After 30, 45, and 60 minutes, a 10ml pipet was used to collect the treated samples in a 100ml sampling vial. The electro dialysis chamber was then emptied and washed with distilled water. Sample-2 (75 ppb) was run for 30, 45, and 60 minutes, with the voltage set at 10, 15, and 20 volts, respectively. After 30, 45, and 60 minutes, a 10 ml pipet was used to collect the treated samples into a 100ml sampling vial. The electro dialysis chamber was then emptied and washed with distilled water.

Sample-3 (100 ppb) was run for 30, 45, and 60 minutes, with the voltage set at 10, 15, and 20 volts, respectively. After 30, 45, and 60 minutes, a 10 ml pipet was used to collect the treated samples into a 100ml sampling vial. The electro

dialysis chamber was then emptied and washed with distilled water.

2.8. Testing of the Samples

When all of the samples were gathered, they were ready to be examined in the laboratory using the MQuant® Arsenic Test kit, which analyses trivalent and pentavalent arsenic in drinking water and mineral water, spring and well water, ground and surface water. The ranges of the Arsenic kit are 0.005 - 0.50 mg/l As.

The arsenic kit includes a tube with 100 test strips. 1 bottle of As-1 reagent, 1 bottle of As-2 reagent, 1 bottle of As-3 reagent, 1 red dosing spoon, 1 green dosing spoon, and 2 reaction bottles with screw caps

The testing began with SAP-1 (30 minutes and 10 volts), and 60 cc of SAP-1 was filled to the mark in the reaction container. Reagent As-1 (two drops) was added and stirred. Reagent As-2 was introduced with a red dosing spoon and stirred until thoroughly dissolved. Reagent As-3 was added with a green dosing spoon and the reaction container was immediately recapped with a screw cap. The black test strip holder that came with the screw cap was turned up, with the white dot facing out. Inserted the test strip as far as the mark, response zone first, then completely depressed the test strip holder. Allow for a 20-minute stand time, rotating twice or three times to avoid any contact between the test strip and the solution. Similarly, this procedure was repeated for all the samples including SAP-2 and SAP-3.

3. Results and Discussion

The Arsenic (As) removal percentage or filtration percentage is determined using the Eq. (2):

$$Removal \% = \frac{C_i - C_f}{C_i} \times 100 \quad (2)$$

Here:-

C_i = Arsenic Concentration (Initial) At Inlet

C_f = Arsenic Concentration (Final) At Outlet

3.1. Arsenic (As) removal percentage of SAP-1 at 10 V and 30 minutes

From the experiments the following values were achieved.

C_i = 50ppb (0.05 mg/l)

C_f = 2ppb (0.002 mg/l)

Voltage = 10V

Time = 30 Minutes

Putting these values in Eq. (1), the removal percentage was calculated as follows:

% Removal = 96%

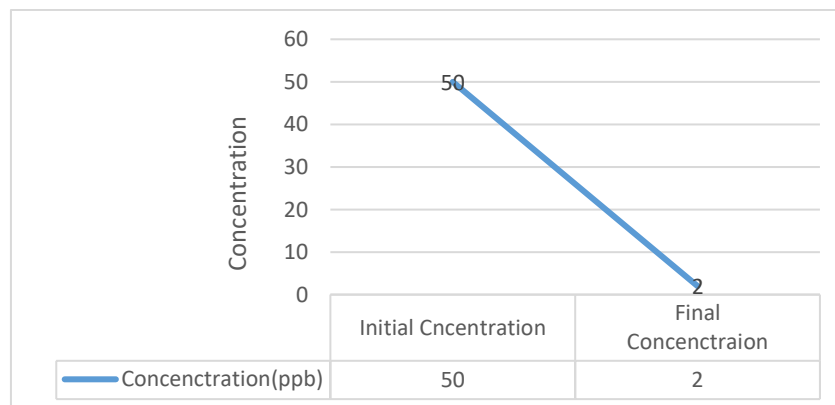


Fig. 5: Concentration Variation for SAP-1 at 10 V and 30 minutes

3.2. Arsenic (As) removal percentage of SAP-1 At 15 V and 45 Minutes

From the experiments the following values were achieved.

$C_i = 50\text{ppb}$ (0.05 mg/l)

$C_f = 1.75\text{ppb}$ (0.0015 mg/l)

Voltage = 15V

Time = 45 Minutes

Putting these values in Eq. (1), the removal percentage was calculated as follows:

% Removal = 96.5%

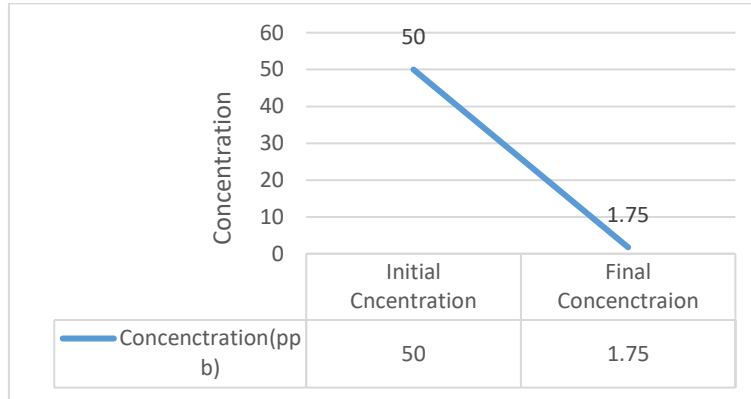


Fig. 6: Concentration Variation for SAP-1 at 15 V & 45 minutes

3.3. Arsenic (As) removal percentage of SAP-1 at 20 V and 60 Minutes

From the experiments the following values were achieved.

$C_i = 50\text{ppb}$ (0.05 mg/l)

$C_f = 1.25\text{ppb}$ (0.0015 mg/l)

Voltage = 20V

Time = 60 Minutes

Putting these values in Eq. (1), the removal percentage was calculated as follows:

% Removal = 97.5%

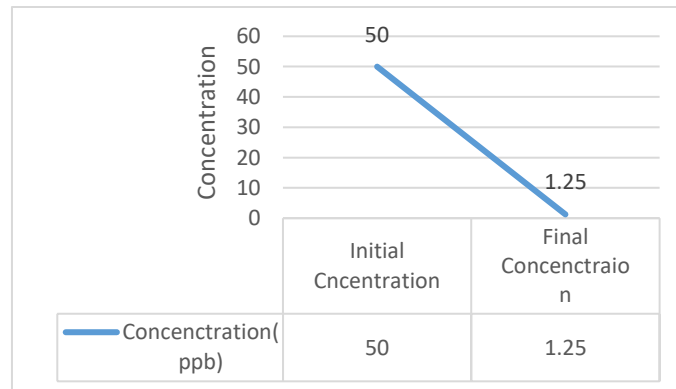


Fig. 6: Concentration Variation for SAP-1 at 20 V & 60 Minutes

3.4. Comparative Analysis of concentration Variation % Removal for SAP-1

Comparing these results, considering different parameters, it has been analyzed that the Experiment # 3 has maximum Arsenic removal percentage as shown in Fig. 3.4.

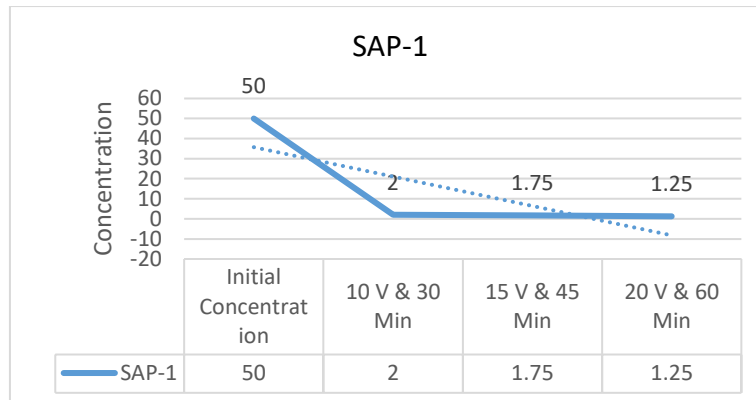


Fig. 7: Comparative-Analysis of SAP-1

3.5. Arsenic (As) removal percentage of SAP-2 at 10 V and 30 Minutes

From the experiments the following values were achieved.

$C_i = 75\text{ppb}$ (0.05 mg/l)

$C_f = 15\text{ppb}$ (0.015 mg/l)

Voltage = 10V

Time = 30 Minutes

Putting these values in Eq. (1), the removal percentage was calculated as follows:

% Removal = 80%

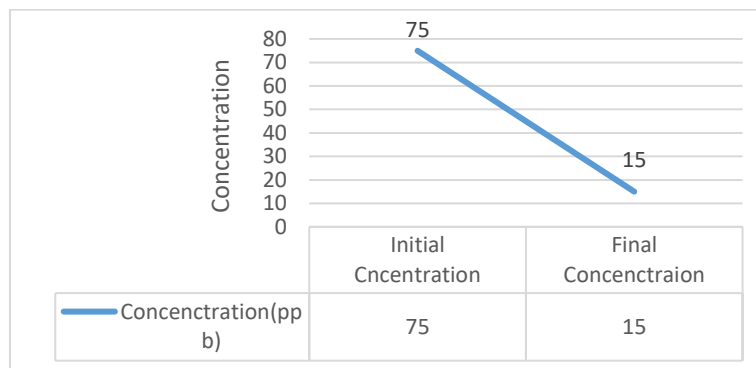


Fig. 8: Concentration Variation for SAP-2 at 10 V & 30 Minutes

3.6. Arsenic (As) removal percentage of SAP-2 at 15 V and 45 Minutes

From the experiments the following values were achieved.

$C_i = 75\text{ppb}$ (0.075 mg/l)

$C_f = 10\text{ppb}$ (0.010mg/l)

Voltage = 15 V

Time = 45 Minutes

Putting these values in Eq. (1), the removal percentage was calculated as follows:

% Removal = 86.666%

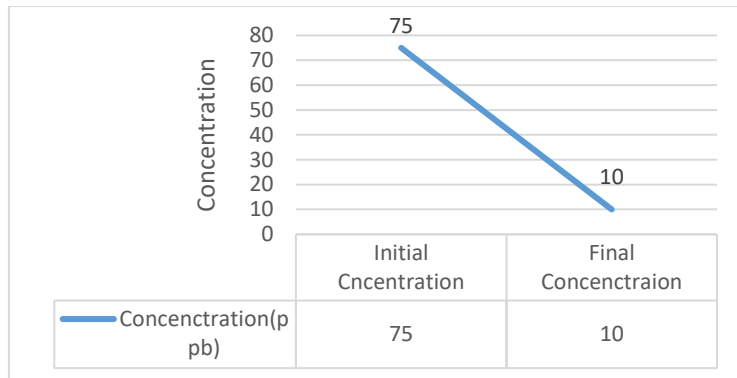


Fig. 9: Concentration Variation for SAP-2 at 15 V & 45 Minutes

3.7. Arsenic (As) removal percentage of SAP-2 at 20 V and 60 Minutes

From the experiments the following values were achieved.

$C_i = 75\text{ppb}$ (0.075 mg/l)

$C_f = 8\text{ppb}$ (0.008 mg/l)

Voltage = 20 V

Time = 60 Minutes

Putting these values in Eq. (1), the removal percentage was calculated as follows:

% Removal = 89.333%

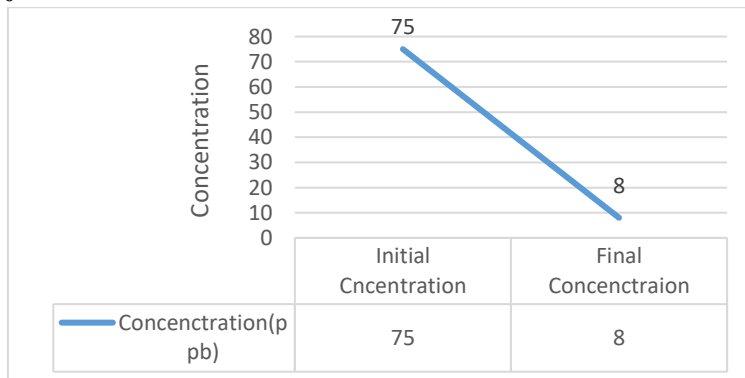


Fig. 10: Concentration Variation for SAP-2 at 20 V & 60 Minutes

3.8. Comparative Analysis of concentration Variation % Removal of SAP-2

Comparing these results, considering different parameters, it has been analysed that the Experiment # 3 has maximum Arsenic removal percentage.

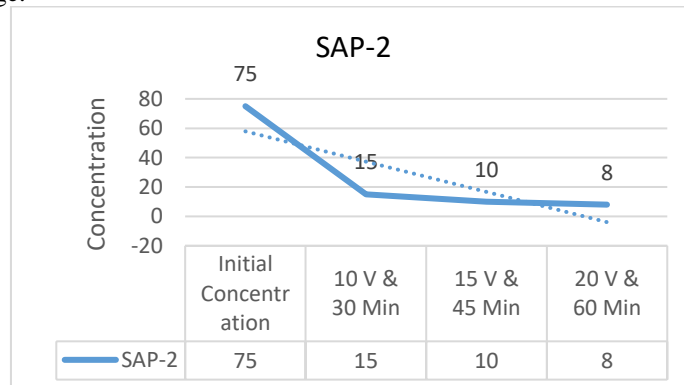


Fig. 11: Comparative-Analysis of SAP-2

3.9. Arsenic (As) removal percentage of SAP-3 at 10 V and 30 Minutes

From the experiments the following values were achieved.

$C_i = 100\text{ppb}$ (0.075 mg/l)

$C_f = 30\text{ppb}$ (0.03mg/l)

Voltage = 10 V

Time = 30 Minutes

Putting these values in Eq. (1), the removal percentage was calculated as follows:

% Removal = 70%

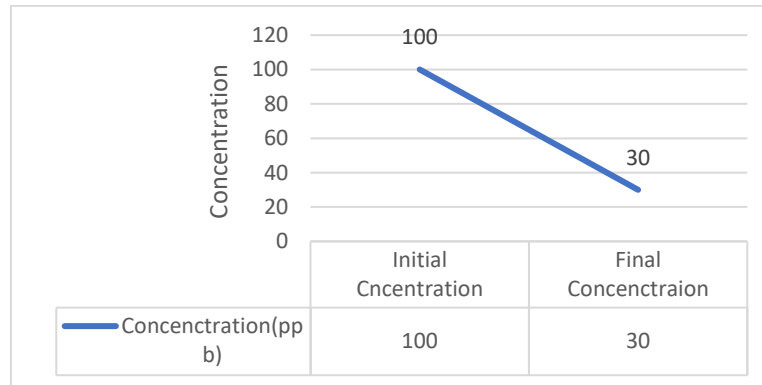


Fig. 12: Concentration Variation for SAP-3 at 10 V & 30 Minutes

3.10. Arsenic (As) removal percentage of SAP-3 at 15 V and 45 Minutes

From the experiments the following values were achieved.

$C_i = 100\text{ppb}$ (0.075 mg/l)

$C_f = 28\text{ppb}$ (0.028mg/l)

Voltage = 15 V

Time = 45 Minutes

Putting these values in Eq. (1), the removal percentage was calculated as follows:

% Removal = 72%

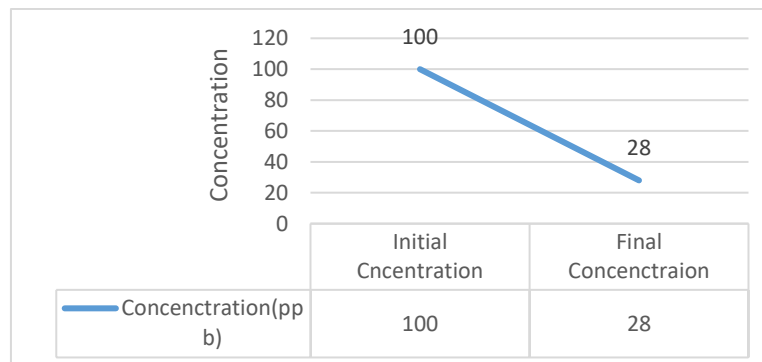


Fig. 11: Concentration Variation for SAP-3 at 15 V & 45 Minutes

3.11. Arsenic (As) removal percentage of SAP-3 at 20 V and 60 Minutes

From the experiments the following values were achieved.

$C_i = 100\text{ppb}$ (0.1 mg/l)

$C_f = 25\text{ppb}$ (0.025mg/l)

Voltage = 20 V

Time = 60 Minutes

Putting these values in Eq. (1), the removal percentage was calculated as follows:

% Removal = 75%

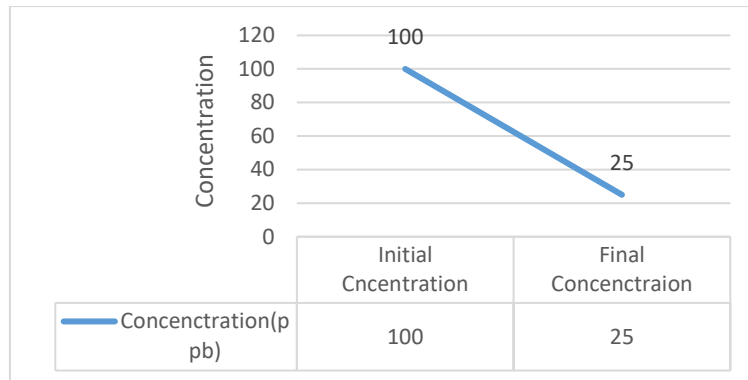


Fig. 12: Concentration Variation for SAP-3 at 20 V & 60 Minutes

3.12. Comparative Analysis of Concentration Variation % Removal

Comparing these results, considering different parameters, it has been analyzed that the Experiment # 3 has maximum Arsenic removal percentage as shown in Fig. 13.

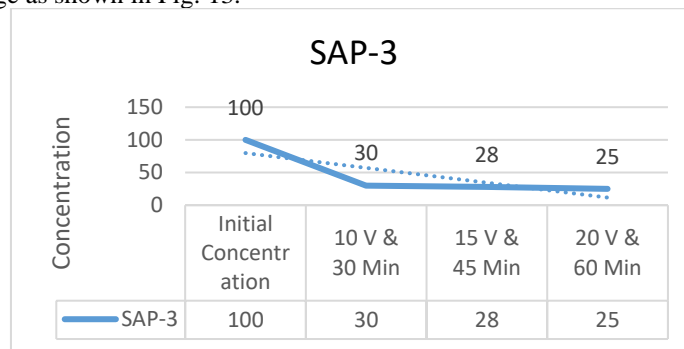


Fig. 13: Comparative-Analysis of SAP-3

3.13. Overall Comparative Analysis of Concentration Variation/ % Removal

It was analysed that the maximum Arsenic removal was observed in SAP-1 having concentration 50 ppb at 20 V and 60 Volts. It is due to the current supplied which increased the conductivity of the water which resulted in maximum ion transport towards their respective electrodes in maximum time duration.

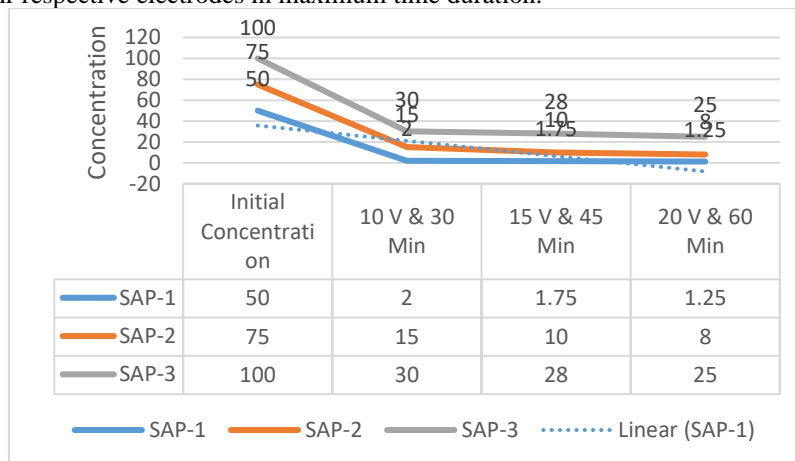


Fig. 14: Overall Comparative Analysis

3.14. Resistivity of Samples

The resistivity of the module is calculated by changing the current flow at Three different voltages: 10, 15, and 20 V,

which was measured by EC meter from HACH company. The $V = IR$ formula is used to calculate the resistance.

Table 1: Current and Resistance of Samples at Different Voltages

Voltage (V)	10	15	20
Current (amp)	0.10	0.13	0.16
Resistance (Ω)	100	115.384	125

The lowest resistivity was measured at 10 volts because it created less ionic activation energy, according to the analysis of all three samples. After 10 volts, resistance fluctuated more at 15 volts than it did at 10 volts. The maximum resistance was recorded at 20 volts due to the high activation energy of ionic transport.

3.15. Conductivity of Samples

The conductivity of each sample is measured at various voltages using a specific set of cationic and anionic membranes. Using an EC meter from the HACH Company, the conductivity of water samples was determined to be 11.84 mS/cm. Table 2 shows the conductivity of SAP-1 after 30, 45, and 60 minutes of deionization at voltages of 10, 15, and 20 V.

Table 2: Conductivity of the Samples at Different Voltages

Sample	Voltages (Volts)	Conductivity (mS/cm)
SAP-1	10	1.05
SAP-2	15	6.1
SAP-3	20	10.31

Increasing the voltages during the first sample analysis improves the conductivity of water. This increase in conductivity is caused by ionic transport. Increased conductivity in the concentrate portion is also known as deionization with voltage rise.

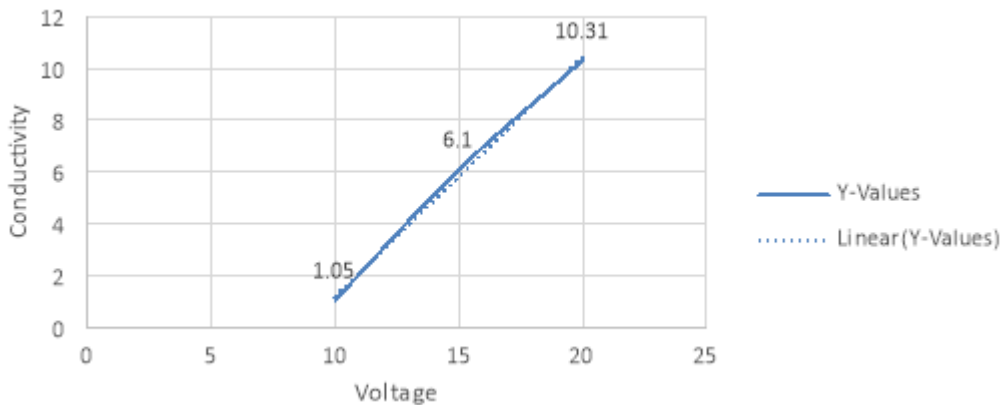


Fig. 15: Comparative Analysis

3.16. Temperature and pH Variation of the Samples

The temperature and pH of water samples vary slightly, as indicated in Table 3.

Table 3: Temperature and pH of SAP 1, 2 & 3 at different voltages

Sample No	Voltage (Volts)	Temperature (Degree Centigrade)	pH
SAP-1	10	29.8	8.4
SAP-2	15	31.4	8.4
SAP-3	20	32.4	7.1

The temperature and pH of the samples did not change much. The pH variance between samples is substantially less.

3.17. Power Consumption

At 15 V, the optimum efficiency of Solar-Hybrid CEDD Module occurs. As a result, we must consider it perfect for

Solar-hybrid CDED Module, as the maximum time of Solar-Hybrid CDED Module during trial was kept 1 hour.

Table 4: Consumed Power on Samples

Sample	Power ($W=A \times V$) (Watts)	Electricity ($KWh= KW \times hr$) (KWh)
SAP-1	1.68	0.00168
SAP-2	2.24	0.00224
SAP-3	3.41	0.00341

3.18. Cost Analysis

3.18.1. Cost of Membranes

The cost of membranes was discovered to be as under:

Table 5: Cost of Membranes Pair in PKRs

Code Of Membrane	Cost Of Membranes in PKR	Pair Price
CEX	20	40
AEX	20	40

Table 6: Cost of Resins

Code Of Membrane	Cost Of Resin/ Gram	Weight Of Resin (g)	Total Cost of Resin (PKR)
CEX & AEX	2.4	18	43.2

Table 7: Cost of Binder (Epoxy) On Each Pair of Membrane

Code Of Membrane	Binder (Epoxy Resin) Price/Gram in PKRs	Weight Of Binder (Epoxy Resin) (Grams)	Binder Cost on Each Membrane Pair in PKRs
CEX, AEX	0.55	4+4	4.4

3.18.2. Cost of Electrodes

Table 8: Cost of Electrodes

Code Of Electrode	Weight Of Activated Carbon (Grams)	Cost Of Activated Carbon Per Gram	Cost Of Binder In PKRs	Net Cost on Electrode In PKRs
EC-1	9+9	6	2x0.55	109.1
EC-2	9+9	6	2x0.55	109.1

4. Conclusion

The Merging of capacitive deionization with the electro dialysis assists with upgrading the general cost effect and low saline side-effect for deionization. Considering using of actuated carbon as a capacitive anode that likewise use as an adsorbent, the Arsenic can be taken out proficiently. The resistivity(R) of the SOLAR-CDED framework changes with respect to voltage (V). As the de-ionization happens, it is contrarily corresponding to the resistivity(R) of the entire system (diluted, films, and concentrated). The arsenic evacuation of the water expanded as the augmentation of voltage. The measure of expulsion is straightforwardly needy to current sat back. The expulsion rate straight forwardly relies upon the measure of current provided. There is a moment all over in the pH of concentrate and weaken area. There is minute all over in the temperature because of stream of electrons that causes enhance in the dynamic energy. The free particles movement, quickly to concentrate section as the voltage (V) amplifies, which origins decrease number of

particles in the distil partition and subsequently the de-ionization of weaken happens. The hybridizing of CD and ED arises in the form of modest low-voltage (V) framework which would settle the arsenic defiled water-issues in Pakistan.

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