Chemical Engineering for Good Challenge
2018 Competition Submission

How Chemical Engineering Can Be Applied to Solve World Problems on a Micro Scale

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Lead AIChE Chapter

University Name & Location: San Jose State University, [San Jose, CA]

Team Lead Mohammad Haider

Team Lead email: [redacted]

Team Lead phone: [redacted]

Collaborating AIChE Chapter - *optional*

University Name & Location: Dawood University of Engineering [Karachi, Pakistan]

Team Lead Javeria Ahmed

Team Lead email: [redacted]

Team Lead phone: [redacted]

Partner Organization(s) - *optional* ______________________________

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Title of Submission: ______________________________

Submission Type: _X_ underutilized technology ___technology toolkit

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Contest entries must address '**How chemical engineering can be applied to solve world problems on a micro scale**". Three prizes of $3000, $1500, and $1000 will be awarded as unrestricted grants to the winning chapters. If judges determine that there are less than three submissions worthy of award than fewer prizes will be awarded. An additional bonus prize of $500 will be awarded for the best submission by a collaboration of a US AIChE chapter and an international AIChE chapter.

Submissions are directed at problems that could be implemented by engineering service organizations in partnership with communities (often small and rural) in the developing world. Micro scale refers to the size, cost, and sophistication of the project (not molecular size). Typically these partners have limited technical sophistication, capital, and funds to cover operating expenses. Utilizing appropriate, sustainable (in the broadest sense) technology is critical. This competition is open to all AIChE student chapters, and entrants are encouraged to partner with other organizations experienced in doing this kind of work. Teams may be of any size, and may include students, faculty and professional engineers. AIChE chapters may collaborate and submit a joint entry.

Submissions should utilize chemical engineering technology and skills (beyond the hydraulics calculations commonly used in designing water systems). Entries will either focus on one chemical engineering-based technology that is currently underutilized by teams working on international service projects (**ISP**) ***or*** provide a useful toolkit for ISP teams to identify, select, and utilize existing chemical engineering-based technologies to solve specific problems.

Attach to this cover page the information requested below for your type of submission. All submissions to be in electronic format. *Only materials in English language will be considered.*
1. Recommendation of the application of a specific technology, available today, that is not currently utilized in ISP projects.

   A. Define the specific community problem being addressed
   B. Describe the specific technology and how it is based on chemical engineering principles; provide electronic copies of or public links to references (papers, descriptions of commercial applications & offerings, patents, other supporting material)
   C. Describe what kind of data would be required to design / customize this technology for ISP projects

Describe what kind of data would be required to design / customize this technology for ISP projects

Experiments of carbon in the form of graphene and activated carbon were conducted.

ANALYSIS OF CURRENT METHODS
Graphene

Activated Carbon
Considering basic materials available, an FCDI experiment was conducted.
Initial TDS value

Following the literature

Experiment 1:

- Charcoal

· Aluminium
· Battery

These four items have the potential to desalinate water in conjunction with each other. The cactus acts as an ion exchange membrane, the aluminium as the electrodes,

D. Describe why this technology would be appropriate for implementation in partner communities. . Include consideration of technical, maintenance, financial, and cultural sustainability. Provide estimated typical costs for initial installation, maintenance, and operation.

Important Information

- the latest information for this competition is always available at **https://www.aiche.org/ace4g**
- **submission deadline**: **November 23, 2017**
- Submit this completed form by deadline date to **ace4g@aiche.org**
- All submissions, references, and supporting materials must be in English language
- The contents of all contest submissions may be made public, with appropriate credits given to the original submitters
- You may direct questions to Alan Zagoria at **ace4g@aiche.org**

A. Define the specific community problem being addressed.
Water is a basic necessity for all living organisms; presently, though, many fatalities still occur from the consumption of non-potable water. Therefore, water purification is vital for ensuring that proper health standards are met for human consumption. Despite heavy metals and toxic pathogens existing in untreated water, humans ingest the ill-inducing water as a means of survival. Waterborne diseases are common and can lead to other maladies such as diarrhea, cholera, typhoid, guinea worm disease and dysentery. Approximately 3.4 million people die annually because of these diseases and infections [1].

The world population is ever increasing and requires more drinking water, leading to many countries suffering from water scarcity. It is estimated that more than 1.2 billion people do not have access to purified water [1]. As a result many factors contribute to the depletion of clean water including climate change. Global warming results in higher temperatures and lower rainfalls, especially in Asia, which causes a shortage of water. Alongside being a human necessity, industries, like medicine, food and farming, require freshwater to operate. Other contributing factors to water shortages include an increased number of droughts and groundwater being used faster than can be regenerated.

Contaminated water is one of the biggest global threats. Although, there are many methods of purifying water, such as reverse osmosis, filtration, sedimentation, and fluoridation, there is still a desperate need for clean water. In developed countries such as United States, investment in clean water is possible, but in developing countries such as Pakistan, Afghanistan, and Africa, their government are much less likely to invest in such projects.

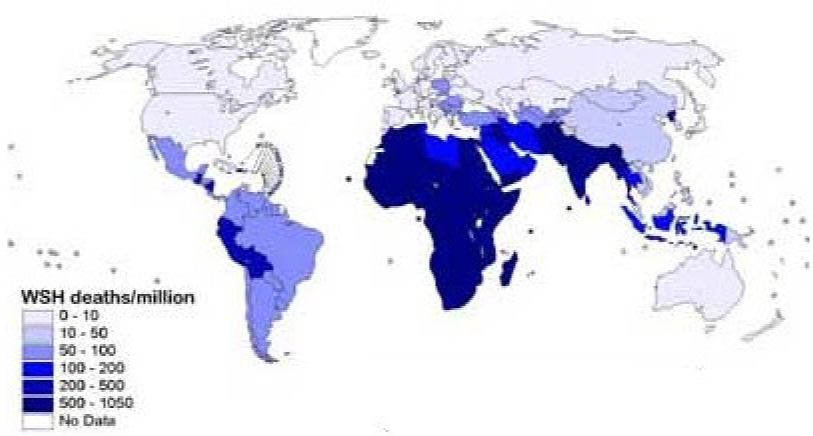

FIGURE 1: Estimation of deaths from unsafe water, sanitation and hygiene by WHO

There are many methods of purification of water, and one of them is desalination. In this process, excess or unwanted salt and minerals are removed from the water. When the contaminated water is gone through desalination process, it is not necessary that it removes all the salts. Desalinated water is mostly used by industries, animal consumption, irrigation and many more. One of the biggest side product is NaCl. The cost of setting up a desalination plant is very high. It cost 1 million dollar(USD) for every one thousand cubic meter[2].

B. Describe the specific technology and how it is based on chemical engineering principles; provide electronic copies of or public links to references (papers, descriptions of commercial applications & offerings, patents, other supporting material)

With a growing need for clean water, several desalination technologies were researched and it was determined that a type of capacitive deionization (CDI) called flow-electrode capacitive deionization (FCDI) would be the most appropriate. FCDI has been shown in literature to be more efficient than current CDI systems due to its potential to achieve improved energy efficiency, stable system performance, and simplistic design capabilities [3]. Traditional CDI systems involve a discontinuous cycle of electrosorption and regeneration using capacitive mixing that depends on concentration gradients. FCDI continuously cycles its electrolyte solution to extract the exchanged ions while maintaining a constant desalination process. This improves the energy efficiency to desalinate water by allowing the ions to transfer across the membrane surface once [3]. In addition, FCDI allows the regeneration of the carbon slurry electrodes to be carried outside of the flow cell instead of in the same cell providing faster discharge and salt release compared to other CDI technologies. An example of the FCDI system is shown in **Figure 3** Using FCDI, a hollow cylindrical ion exchange stack was developed using the materials listed in **Table A**. To ensure an efficient FCDI system, a high capacitance and low resistance is required.

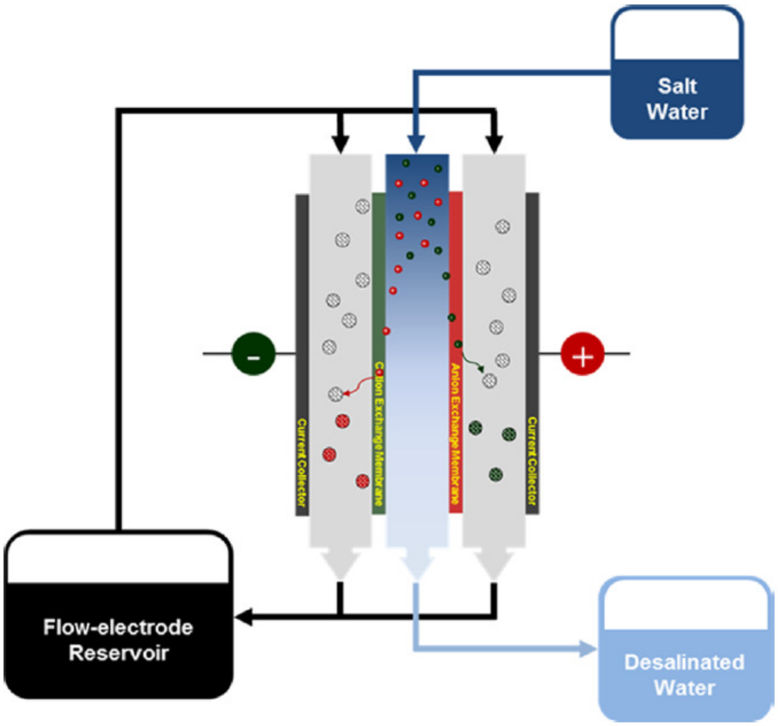

Figure 3: A simplified FCDI unit cell was made based on literature [4]

The primary components include 1) flow-electrode reservoir, 2) electrodes, and 3) ion exchange membrane. As an attempt to make this technology readily available for use, simple materials are utilized in construction of this FCDI unit.

TABLE A: List of material required for FCDI

Flow-electrode reservoir	**Electrodes**	**Ion exchange membrane**	**Power source**
Charcoal	2 sheets of aluminum foil	Cactus (*Opuntia*)	Battery (9V)
DI water			
Salt			

The assembly layers were as follows (from top to bottom)

Anode
Activated carbon slurry
Cactus
Salt water
Cactus
Activated carbon slurry
Cathode

The salt water was desalinated using a batch process and a 9V battery supplied constant voltage that passed through the assembly for 25 minutes.

Figure 4: Experimental setup for FCDI

The flow-electrodes were made from activated carbon (AC), deionized (DI) water, and NaCl. The AC is sourced from charcoal and mechanically cut up with pliers. A porous slurry is then made by adding DI water to the AC in a ratio of approximately 50:1. Next, 11.59 g of salt was added and comprised about 1.13% of the total solution. The mixture is then mixed continuously using a stir bar and hot plate for 30 minutes to ensure a uniform solution.

For the electrodes, aluminum foil was used due to its availability and malleability. Aluminum's high conductivity makes it a perfect material for current to run through the entire system.

The ion exchange membranes were made using an *Opuntia* species of cacti. Cacti is abundant, eco-friendly, and versatile. In addition, cacti's porous capabilities allow it to act as a bio-absorber and biofilter. Literature has shown that experiments utilizing *Opuntia* cacti for wastewater treatment have demonstrated an efficiency greater than 95% in chemical oxygen demand (COD) removal [5].

Meanwhile, AIChE DUET Chapter experimented with CDI and used graphene coated sand as electrodes, but the experiment increased the TDS in the water by applying constant voltage of 9V. Comparative experimental studies were done by synthesizing and using sand composites including graphene oxide coated sand particles, graphene oxide, graphene oxide-silver nanoparticles composites, and graphene from sugar to test their adsorption capabilities. Beds of sand are commonly used throughout the world to filter drinking water. The particle size of sand and surface modifications characterize the efficiency of sand in removing contaminants from water [6].

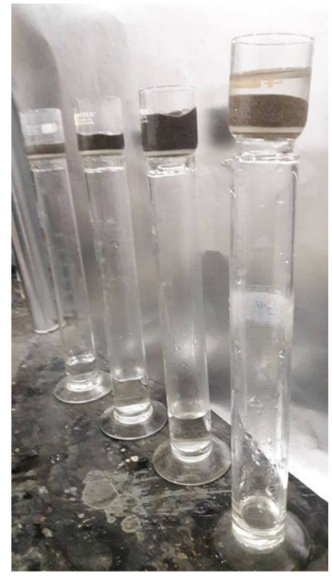

Figure 5: Experimental setup for Different Graphene-Sand Composites

The sand is effective for total suspended solids (TSS) but have a little to no effect on TDS. As a basic definition, salinity is the total concentration of all dissolved salts in water [7].

Graphene Oxide Characterization

Graphene and its nanocomposite material will be characterized using several methods, including Fourier Transform Infrared (FTIR), and Scanning Electron Microscopy (SEM).

a. FTIR can be used to assess the functional groups within keratin, and changes of functional groups due to raw materials and processing of graphene. We plan to use FTIR to help us understand the roles of each processing step with respect to structural changes of the graphene adsorbent.
b. SEM will be used to visualize the graphene oxide powder before and after it is processed and annealed with the sand With SEM, we will be able to better assess the porosity and morphology of the graphene oxide as adsorbent.

A. SYNTHESIS OF GRAPHENE OXIDE (GO) FROM CITRIC ACID:

Graphene coated sand was synthesized from citric acid. 4 g of citric acid was dissolved in 10 ml of DI water, and then heated and stirred simultaneously for 2 hours at 200°C. After heating for 10 mins, the color of the mixture will undergo a color change from pale yellow to orange representing the ending point. An NaOH solution (40 mg/L) was added dropwise to neutralize the solution to PH 7. Sand particles were prepared by washing with DI water, followed by drying. Sand was added to the neutralized solution in a 1:1 ratio. The solution was then heated using a muffle furnace for 2 hours. In the first hour, the temperature was maintained at 350°C and during the second hour the temperature was increased and maintained at 450°C. [8]

Figure 6. (A) GO coated Sand (After Annealing) and (B) GO Coated Sand (Crushed)

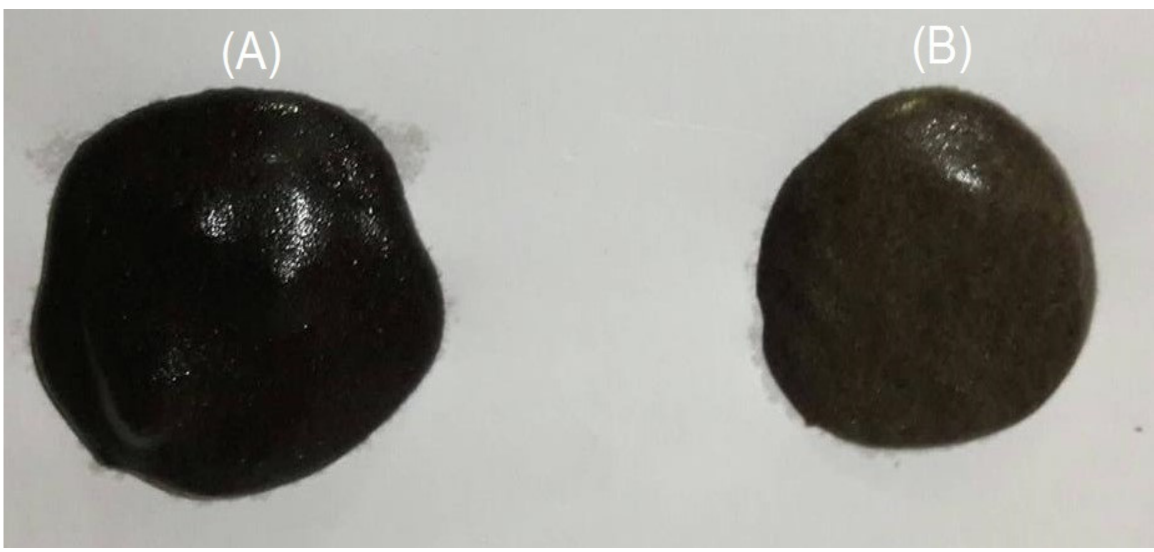

Figure 7 (A) Graphene Oxide Coated Sand Particles and (B) Washed River Sand

B. SYNTHESIS OF SILVER NANOPARTICLES (AgNPs)

Silver nanoparticles were synthesized using a special type of leaf species *Azadirachtaindica*. Fresh leaves were collected from Dawood University and prepped by rinsing with DI water 2 to 3 times. 20 g of the leaves were placed in a beaker filled with 200 ml of DI water and boiled at 100°C for 25-35 min. The extract was then left to cool down at room temperature and separated using filter paper.

0.2 g of silver nitrate was added to 1.0 mL of distilled water. The solution was then mixed with the leaf extract and resulted in the synthesis of silver nanoparticles.

After the synthesis of GO, we added the solution of silver nanoparticles in sand and GO-coated sand, resulting in a sand-AgNPs composite and a graphene oxide-Ag NPs composite respectively. [9]

Figure 8: Sand-Silver Nanoparticles Composite

C. SYNTHESIS OF GRAPHENE FROM SUGAR

Common sugar (sucrose) and river sand were used to create a solution. The sugar was dissolved in DI water, then the sand was mixed in the solution of requisite amount. The solution was heated using a muffle furnace for 2 hours at a temperature of 750°C. The heated solution was then mixed with sand and left to cool at room temperature.

Different adsorbents of graphene-sand composites were made and compared for slow sand filtration to decrease the Total Dissolved Solids (TDS).[10]

C. Describe what kind of data would be required to design / customize this technology for ISP projects

FCDI is a dynamic step process in which adsorption and desorption occur simultaneously. This type of CDI has flowing electrodes. The data required for designing the technology would be kinetic transport of ions into and out of porous electrodes, electrosorption isotherms, and fouling potential of organic matter on electrodes [11]. Salt rejection is based on selectivity of electrodes and ion exchange membranes. Other parameters include applied voltages, capacitance, and energy consumption[12].

The process of adsorption is usually studied through adsorption isotherm graphs, which displays the relationship between the amounts of adsorbate adsorbed on the surface of adsorbent and pressure at constant temperature.

Total Dissolved Solids level

In the experiments conducted, total dissolved solids (TDS) was the main determinant of water quality. TDS, generally measured in milligrams per unit volume of water, is the quantification of organic and inorganic dissolved particles within the solution. Currently, the EPA set the maximum concentration level tolerable for drinking water at 500 mg/L or 500 ppm. It is important to note the TDS of the initial water to determine the height of the packed bed or the voltage and time required for FCDI. All of these parameters are adjusted to the initial TDS level of the contaminated water. TDS values were measured throughout the experiments by an*Excelvan TDS & EC meter.*

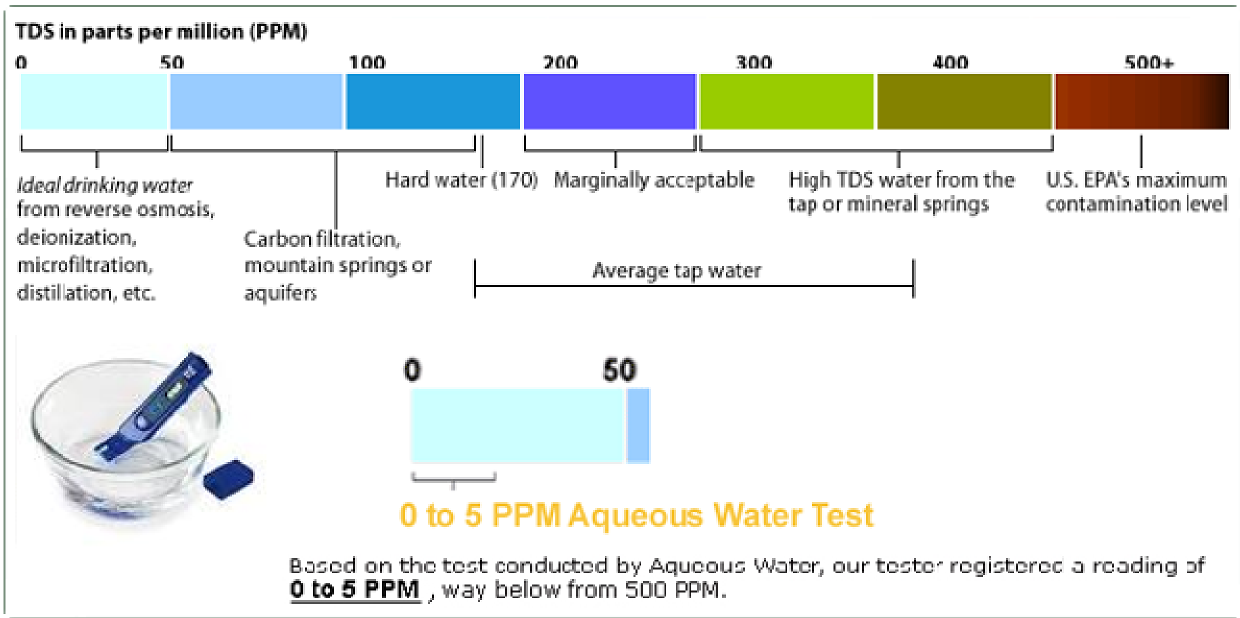

Figure 9: Acceptable TDS ranges in parts per million [2]

Table B: Results of groundwater TDS removal by using different adsorbents. The flow rate was 10 mL/min and was flowing by the application of gravity.

Sr. No.	Adsorbent in Column	TDS (ppm)		Difference (ppm)	Bed Length (mm)	Buchner Funnel (Used as column)
		Before	After			
1	Empty filter	3193	3000	193	15	#3
2	Empty filter	3173	2780	393	15	#4
3	GO-Sand	3193	2981	212	15	#4
4	GO-AgNPs	3193	2197	999	15	#4
5	Washed Sand	3193	3000	193	15	#4
6	GO-Sand (From Sugar)	3193	2579	614	15	#4

Table C: Results of GO-AgNPs as adsorbent at different Bed Height

Adsorbent Bed	TDS (ppm)		Bed Height (mm)
	Before	After	
GO-AgNPs	3193	2195	15
		2173	18
		2342	13

Voltage difference in Capacitive Deionization(CDI):

Different voltages at constant current of 1 ampere was applied across the capacitive deionization at 200 mg/L concentration of salt water using stainless steel as electrodes.

This data is of CDI using Normal River Sand and Stainless Steel as electrodes. Initial TDS value want 184 in 200 mg/L.

Table D: Results of CDI

Voltage (V)	Current (Amps)	TDS (ppm)	Concentration of salt (mg/L)
0.5	1.0	163	200
1.0	1.0	190	
5.0	1.0	184	
10.0	1.0	198	

According to Saleem et al., as applied voltage across the CDI increases, the lower the concentration of salt is in the water recovered [3]. This trend is demonstrated in the first graph of Fig. 10. The reduced salt concentration can also be associated to the reduction of TDS levels, which is seen in our data above.

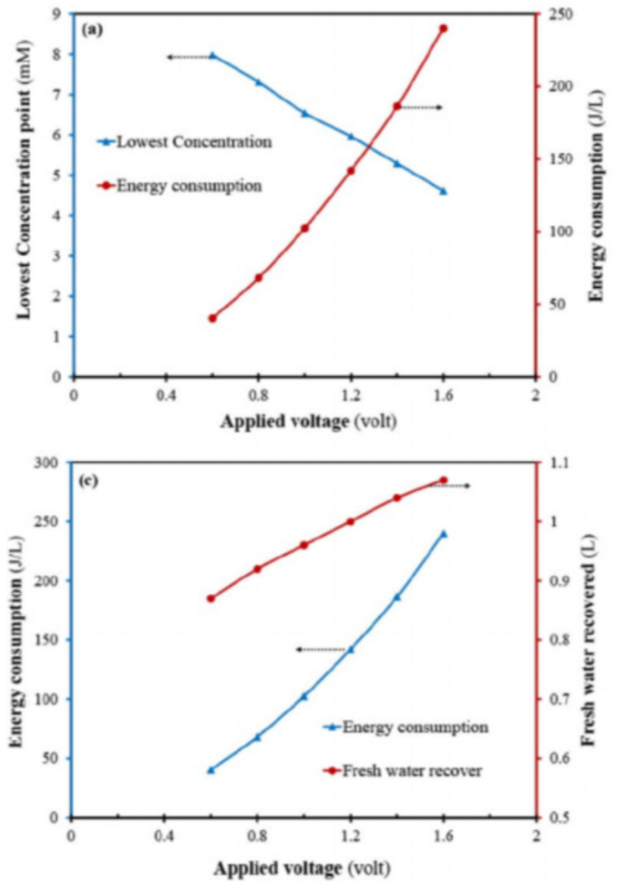

Figure 10: Applied voltage effects on CDI cell performance [3]

ACTIVATED CARBON MATERIALS

Table E: Flow-electrode reservoir

Material	Amount
DI H_2O	1.00 L
Charcoal	18.06 g
Salt (NaCl)	11.59 g

METHOD

To desalinate the water, 9V from the battery was applied to the FCDI unit for 25 minutes, and then the water was analyzed through UV/VIS spectrophotometry.

A total of four experiments were conducted/measured.

Table F: FCDI parameters for experiment

Experiment	Description

1	DI water, run in the UV/VIS 3 times, as the blank.
2	Salt water (10.5 g of salt in 100 ml of DI water)
3	Saltwater run through the FCDI unit for 25 minutes
4	Saltwater run through the FCDI unit for 25 minutes, and then filtered using filter paper to remove the cacti sap

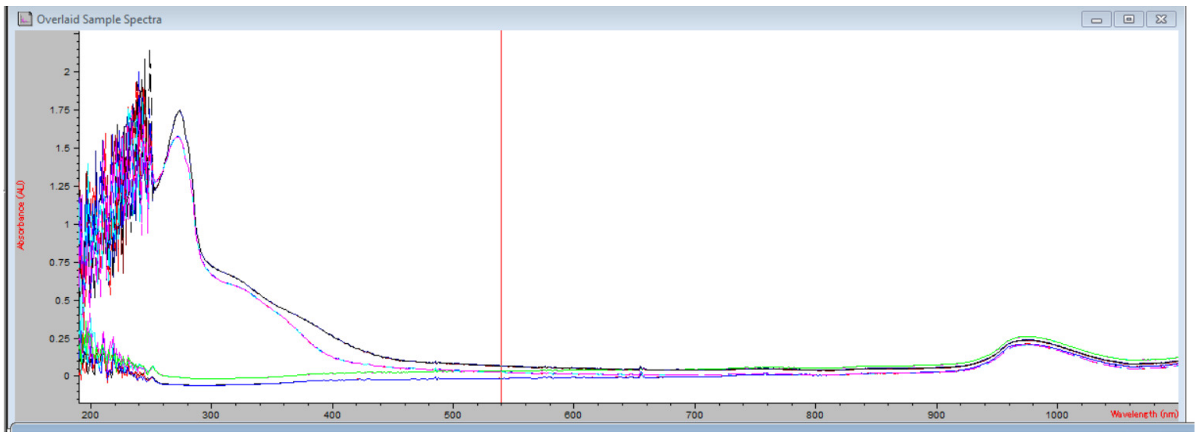

Figure 11. UV/VIS Spectrophotometer results for Flow Electrode Capacitive Deionization

#	Name	Abs<540nm>
1	DI	-1.3292E-2
2	DI	-1.3004E-2
3	DI	-1.3205E-2
4	Salt water C0	3.5456E-2
5	Salt water C0	3.5235E-2
6	Salt water C0	3.5717E-2
7	Product water C1	6.6348E-2
8	Product water C1	6.9961E-2
9	Product water C1	6.7991E-2
10	Filtered Product C2	2.5900E-2
11	Filtered Product C2	2.7194E-2
12	Filtered Product C2	2.6263E-2
13	Filtered Product C2	2.6803E-2

Experiment	**Average Absorbance**
1 - DI Water	-0.1316
2 - Salt Water	0.3547
3 - FCDI	0.6810
4 - FCDI + Filtered	0.2654

ANALYSIS FOR THE UV/VISUAL SPECTROPHOTOMETER:

To be considered desalinated, the absorbance value should be between that of the DI water value of 0 and the original salt water absorbance of 0.35. Experiment 3 showed an increased absorbance of 0.68 compared to DI water and salt water, which may have been attributed to the cactus sap. To remove this cactus sap, filter paper was used. The water was then analyzed. Results demonstrate desalination of water since Experiment 4’s water had an absorbance value of 0.2654.

ENERGY CONSUMPTION FOR FCDI:

The energy consumption of the FCDI device based on literature for 1.0 L of salt water was 1.983 kWh/m^3 [13]. The FCDI device used for experimentation used a sample of 100 ml of salt water, to which a constant voltage of 9V was applied for 25 minutes as a DC current source. The energy consumption of our device was 0.1485 kWh. The reason our device had a higher energy consumption is because our controlled experiment was treated as a batch process as opposed to a flow system.

PROTOTYPING AND DESIGNING

A prototype graphene-based sand filtration system or FCDI will be designed, constructed, and demonstrated. Based upon the demonstration and effectiveness of the technology for particulate matter and saline reduction, design modifications will be made in an iterative manner. Once the required effectiveness of the process for treating water is met, a scaled up model will be designed. The scaled up model will be considered the commercial model that will be used by the clientele.

D. Describe why this technology would be appropriate for implementation in partner communities. Include consideration of technical, maintenance, financial, and cultural sustainability. Provide estimated typical costs for initial installation, maintenance, and operation.

Pakistan is one of the top 10 countries with the most limited access to clean water, with only 39% of Pakistanis having access to safe drinking water. Particularly, the saline water is a basic problem in Thar, Sindh. As a deserted area with high salinity, it presents an opportunity for the AIChE DUET team members residing in the rural areas to manage, maintain and assess any projects implemented there. AIChE DUET will be assigning the duties to audit the project. The goal is to create a cost-effective method for water desalination in order to encourage more people to use this sustainable technique of purifying drinking water and prevent incidences of waterborne diseases that may lead to death.

Technical sustainability will be addressed by giving workshops in collaboration with the University to the targeted community. Inclusion of all parties will be top priority and to insure participation 5% contribution will be collected from the community, which will led to financial and cultural sustainability. All parties including students, NGOs, faculty, community, and local government would sign a partnership which will specify the roles and responsibilities to make the project successful in the long term.

Pros and Cons for Graphene Based Sand Filters are as follows;

PROS:

- Graphene-Sand Bed can be easily integrated with the conventional sand filters used in developing areas

- Low cost maintenance
- Low investment is required
- Raw materials are easily available
- More efficient than conventional sand filter
- Graphene filters have immense potential to improve water purification, increasing the amount of freshwater available.[14]

CONS:

- Requires greater area for the filtration
- Flow rate is low as the process relies on gravity to filter water
- Need High Temperature
- Less efficient than FCDI

Alternatively, FCDI (Flowing Capacitive Deionization) can work with low voltage and it is portable to use.

Pros and Cons for FCDI are as follows;

PROS:

- FCDI requires low constant voltage 1.2V-4V
- Device is portable
- Easy operation
- Easy to scale up the process
- Low maintenance costs
- Can easily be ran from any abundant energy source including solar panels
- Continuous cycle for electrolyte renewal
- Higher energy efficiency
- Based on natural materials

CONS:

- Ion exchange membrane needs to be replaced
- Cactus sap needs to be managed during desalination
- Membrane needs to be a fresh cactus

Table G: Cost breakdown for Graphene Oxide Coated Sand from Sugar:

Sr. No.	Material	Bulk Quantity	Cost

1	Sugar	1.00 kg	$0.60
2	River Sand	Found in Abundance	$0.00

Table H: Cost breakdown for GO Coated Sand from Citric Acid:

Sr. No.	Material	Quantity	Unit Cost
1	Citric Acid	1.00 kg	$1.50
2	NaOH	1.00 kg	$1.30

Table I: Cost breakdown for GO-NPs Composite:

Sr. No.	Material	Quantity	Bulk Cost
1	AgNO3	25.00 g	$25.00
2	GO	4.00 gms	$2.80

In Pakistan, 21 million out of the total population of 207 million do not have access to clean water. Pakistan is a clean water-deprived country as access to safe drinking water in rural and urban areas is declining [15]. The Multidimensional Poverty Index is a broader concept of poverty than income and wealth alone. It reflects the deprivations people experience with respect to health, education and standard of living. Thus, it is a more detailed way of understanding the extent of poverty. Since its development by OPHI and UNDP in 2010, many countries, including Pakistan, have adopted this methodology as an official poverty estimate, complementing consumption or income-based poverty figures. The report also found that the decrease in multidimensional poverty was slowest in Balochistan, while poverty levels had actually increased in several districts in Balochistan and Sindh during the past decade [16].

Potable water is a necessity, and with almost 98% of the total volume of water being salt water [17], a promising and cost-effective desalination method is being sought. Economic viability was the primary focus when considering desalination technologies. FCDI is an attractive option when considering costs.

The SJSU-AIChE FCDI set-up costed a total of $25.57 with the breakdown as follows:

Table J: Cost Breakdown for FCDI

Material	Base Cost	Amount	Unit Cost
Charcoal	$0.001797/g	18.062 g	$0.032
DI water	$18.39/L	1 L	$18.39
Salt	$0.0299/g	11.5918 g	$0.3466
Aluminum foil	$0.03975/ft^2	2 ft^2	$0.0795
Cactus (*Opuntia*)	$0.7375/cactus	4 cacti	$2.95
Battery	$2.99/count	1 battery	$2.99
Rubber seal	$0.393/ft	2 ft	$0.786
Total			**$25.57**

In Pakistan, 1.5 liters of water sells for 53.92 Rs or $0.40 USD [18].

Since 39% of the Pakistan population is considered poverty limits, a long-term solution like this FCDI should be considered. Cacti are abundant and can easily be regrown. Typically, a 9V battery can operate for about 50 hours [19]. If each run was about 25 minutes, then there could be a total of 14 runs at 25 minutes each. Reducing the run time may be possible by increasing the activated carbon concentration within the slurry. A ratio of 50:1 demonstrates desalination potential. Literature values used 10:1 of water to activated carbon for the slurry, and had desalination efficiencies between 15-20% [4].

Battery operation time:

A circuit that draws 10 mA powered by a 9 volt rectangular battery will operate about 50 hours: 500 mAh /10 mA = 50 hours The cell voltage of alkaline cells steadily drops with usage from 1.54 volts to about 1 volt when discharged. The voltage is near 1.25 volts at the 50% discharge point. Alkaline cells exhibit a slightly increased capacity when warmed and the capacity drops significantly at temperatures below freezing. [19]

In conclusion both chapters agree that FCDI is a better water purification device. FCDI is more efficient if better ion exchange membranes were used but the maintenance cost may be higher. FCDI is portable and due to its low voltage consumption it can be used within the household. With an improvement in our experimental design of our device, we are certain it would yield better results. The FCDI device has a low energy consumption compared to the graphene coated sand. The FCDI setup is a simple build and uses natural resources whereas the graphene coating of sand needs to be made in a high temperature setting.

APPENDIX

Currently, common forms of desalination include reverse osmosis, electrodialysis, and thermal distillation. Much literature into energy requirements and cost exist and have been condensed into Table K.

Table K: Common desalination technology energy requirements and costs.[20]

Desalination technology	**Energy requirements to desalinate 1 L of water**	**Cost**
Thermal Distillation (MSF)	~211.5 kJ heat	$0.80 - $1.50 / m^3
Reverse Osmosis	2-5 kWh/m^3	$0.70 - $3.20 / m^3 depending on plant size[21]
Capacitive Deionization	0.1 kWh/m^3[22]	
Flow-electrode Capacitive Deionization	0.02 kWh/m^3	
Graphene	0 kWh/m^3	

Table L: Cost Estimation for FCDI

Material	**Bulk Cost**
Charcoal	$4.89/6 lbs
DI water	$18.39/1L
Salt	$14.95/ 500g
Aluminum foil	$7.95 / 200 sq ft roll
Cactus (*Optunia*)	$2.95 / 4 Cacti
Battery	$2.99/ count
Rubber seal	$12.59/ 32 ft

REFERENCES:

[1] “Waterborne Diseases.” *Drinking Contaminated Water Can Lead to Waterborne Diseases.*, www.vestergaard.com/global-challenges/waterborne-diseases.

[2] “Cost of setting a desalination plant” posted by *SMIPP LTD.*

https://smipp.wordpress.com/2017/02/13/how-much-does-a-water-desalination-plant-cost/

[3] “Aqueous Purified Drinking Water.” *Aqueous | Purified Drinking Water*, www.aqueouswater.com/how-aqueous-remove-tds.html#.W_dBj-hKhDI.

[4] Flow-Electrode Capacitive Deionization Using an Aqueous Electrolyte with a High Salt Concentration, SeungCheol Yang, Jiyeon Choi, Jeong-gu Yeo, Sung-il Jeon, Hong-ran Park, and Dong Kook Kim, *Environmental Science & Technology* **2016** *50* (11), 5892-5899 DOI: 10.1021/acs.est.5b04640,

[5] F.BenRebah and S.M. Siddeeg.“Cactus as an eco-friendly material for wastewater treatment”. *Capacitive Deionization.* https://www.jmaterenvironsci.com/Document/vol8/vol8_N5/189-JMES-2637-Ben%20Rebah.pdf?fbclid=IwAR3NQwx4xPXdNvCib83x6RwVR9mxLf7rec1u6nNCX9mUYpAc1V52_bGaEoc ,

[6] Wetterau, Greg, and Sandeep Sethi .*Seawater Desalination Overview - American Water Works* ...www.awwa.org/portals/0/files/publications/documents/samples/30061_excerpt.pdf.

[7] Fondriest Environmental, Inc. “Conductivity, Salinity and Total Dissolved Solids.” Fundamentals of Environmental Measurements. 3 Mar 2014. Web. < http://www.fondriest.com/environmental-measurements/parameters/water-quality/conductivity-salinity-tds/ >.

[8] Blue luminescent graphene quantum dots and graphene oxide prepared by tuning the carbonization degree of citric acid,
Yongqiang Dong, Jingwei Shao, Congqiang Chen, Hao Li, Ruixue Wang, Yuwu Chi, Xiaomei Lin, Guonan Chen,
https://doi.org/10.1016/j.carbon.2012.06.002.

[9] Green synthesis of silver nanoparticles using Azadirachtaindica aqueous leaf extract,Shakeel Ahmed, Saifullah, Mudasir Ahmad, Babu Lal Swami, Saiqa Ikram,
Journal of Radiation Research and Applied Sciences,
https://doi.org/10.1016/j.jrras.2015.06.006.

[10] Graphene from Sugar and its Application in Water Purification
Soujit Sen Gupta, TheruvakkattilSreenivasanSreeprasad, ShihabudheenMundampraMaliyekkal, Sarit Kumar Das, and Thalappil Pradeep
ACS Applied Materials & Interfaces 2012 *4* (8), 4156-4163
DOI: 10.1021/am300889u

[11] http://www.who.int/heli/risks/water/en/webwshmap.jpg

[12] Saleem, Muhammad Wajid, and Woo-Seung Kim. “Parameter-Based Performance Evaluation and Optimization of a Capacitive Deionization Desalination Process.” *Desalination*, vol. 437, 2018, pp. 133–143., doi:10.1016/j.desal.2018.02.023.

[13]New insights into the mechanism of flow-electrode capacitive deionization,
Paz Nativ, Yuval Badash, YouriGendel,

Electrochemistry Communications
https://doi.org/10.1016/j.elecom.2017.01.008.

[14] Nicol, Will. “Stronger than Steel, Thinner than Paper, Graphene Could Be the Future of Tech.” *Digital Trends*, Digital Trends, 15 Nov. 2018, www.digitaltrends.com/cool-tech/what-is-graphene/.

[15] Jamal, Sana. “21 Million in Pakistan Don't Have Access to Clean Water: Report.” *GulfNews*, Gulfnews, 7 Nov. 2018, gulfnews.com/world/asia/pakistan/21-million-in-pakistan-dont-have-access-to-clean-water-report-1.2192988.

[16] “Pakistan's New Poverty Index Reveals That 4 out of 10 Pakistanis Live in Multidimensional Poverty.” *UNDP in Pakistan*, www.pk.undp.org/content/pakistan/en/home/presscenter/pressreleases/2016/06/20/pakistan-s-new-poverty-index-reveals-that-4-out-of-10-pakistanis-live-in-multidimensional-poverty.html.

[17] Castelo, Jeremiah. “What Is the Percentage of Drinkable Water on Earth?” *World Water Reserve*, 15 Nov. 2018, worldwaterreserve.com/water-crisis/percentage-of-drinkable-water-on-earth/.

[18] *Cost of Living in Pakistan*. www.numbeo.com/cost-of-living/country_result.jsp?country=Pakistan.

[19] *Battery Capacity,* http://www.techlib.com/reference/batteries.html

[20] A review on energy consumption of desalination processes,
Younes Ghalavand, Mohammad SadeghHatamipour& Amir Rahimi (2015) Desalination and Water Treatment, 54:6, 1526-1541, DOI:10.1080/19443994.2014.892837.

[21] *Breakwaters and Training Walls - The Good the Bad the Ugly - Advisian*, www.advisian.com/en-us/global-perspectives/the-cost-of-desalination#.

[22] Capacitive Deionization Technology™: An alternative desalination solution,
T.J. Welgemoed, C.F. Schutte,
Desalination,
https://doi.org/10.1016/j.desal.2005.02.054.