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Polymer coated Capacitive Deionization Electrode for Desalination: A mini review

DOI 10.1515/eetech-2016-0001
Received November 10, 2015; revised December 3, 2015; accepted December 7, 2015

Abstract: This mini review deals with a recently developing water purification technology, i.e. capacitive deionization. It presents the current progress achieved with polymer coated electrodes in capacitive deionization for desalination. The introduction covers capacitive deionization, application of polymer or polymer composite in capacitive deionization electrode, comparative study and discussion on fabrication of electrode. This paper aims at indicating novel research prospects in capacitive deionization technology for desalination.

Keywords: Capacitive Deionization, polymer coating, ion exchange, desalination, electrode

1 Introduction

This mini review presents the progress of the polymer coated electrode capacitive deionization technology. The objectives of this article are: (1) to present an introduction about capacitive deionization; (2) to describe broadly the application of polymer coated electrodes for capacitive deionization (3) comparison of different polymer coated capacitive deionization electrodes and (4) to discuss the polymer coating in capacitive deionization. Shortage of fresh water is an increasing concern on the earth, and requires suitable solutions to increase water availability [1, 2]. Most of the well-known desalination technologies such as reverse osmosis, thermal processes and electrodialysis need specialized and expensive infrastructure. On the other side capacitive deionization (CDI) signifies a novel and energy-efficient desalination technique. CDI has benefits of being an eco-friendly desalination technology, having lower energy consumption and working costs, simplicity in regeneration and maintenance compared with other conventional techniques of desalination [3, 4]. The main aspects of capacitive deionization are salinity, scalability, efficiencies of electrodes and cost effectiveness in comparison to other desalination techniques [5, 6]. Working mechanism of capacitive deionization operates in two steps, namely purification and regeneration. Purification step and regeneration step are schematically presented in Figure 1. In capacitive deionization porous electrodes are used to adsorb the salt ions from the salt solution. In purification step, when voltage is applied to electrodes cations and anions are attracted towards negatively and positively charged electrodes respectively, thus pure water will leave the capacitive deionization cell. When the electrode is saturated due to salt ion deposition on electrodes there is need of regeneration of electrode by applying a reverse voltage or short-circuit for desorption of ions from the electrode. A modified form of capacitive deionization is membrane capacitive deionization (MCDI). Only difference is cation and anion exchange membrane are used in front of the porous electrodes [7, 8]. Schematic of membrane capacitive deionization and polymer coated capacitive deionization are mentioned in Figure 2. Under the application of a potential to a capacitive deionization cell, counter ions are attracted to the surface of the electrode, concurrently co-ions expelled from the counter electrode [27]. Such “co-ion” effect could successfully be prevented by using ion exchange membranes in capacitive deionization. Membrane capacitive deionization shows adsorption capacity much higher than capacitive deionization without membrane. Also energy consumption was reduced providing an economical advantage of membrane capacitive deionization [28].

Materials of electrodes should have a sufficient electronic conductivity, high surface area, suitable pore size arrangement for removal of ions [9, 10]. Carbon material is mostly used for fabrication of electrodes due to its properties such as high surface area, better chemical stability and eco-friendliness [11]. Mainly activated carbon, carbon aerogel and mesoporous carbon are preferred for electrode production [11–13]. After improvement in research it was

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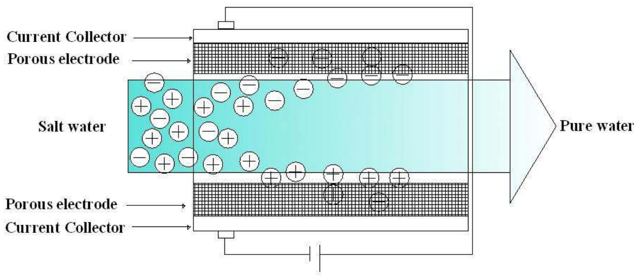
found that application of nanomaterials in electrode provides better response in desalination [14–16].



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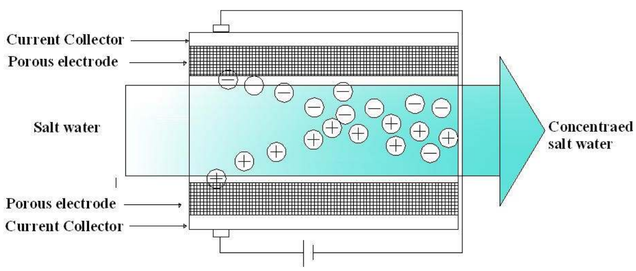
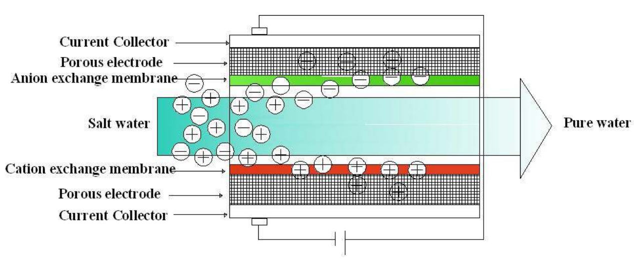


(b)

Figure 1: Schematic of capacitive deionization steps (a) Purification Step (b) Regeneration Step.



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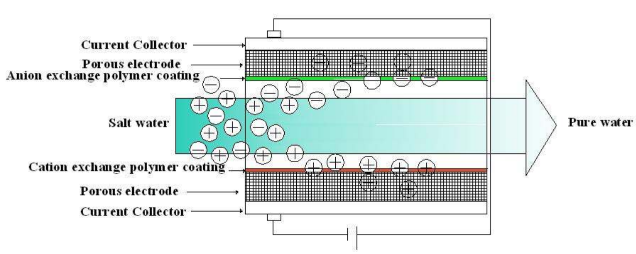

(b)

Figure 2: Schematic (a) membrane capacitive deionization and (b) polymer coated capacitive deionization.

In MCDI, there is need of strong physical pressure to create smooth contact between electrode and membrane. The diffusion layer on the membrane surface will become thick at low feed concentration of contaminants [17] such phenomena creates problem like a high interfacial resistance of the membrane. Such weaknesses or problems are solved by casting thin layers of the ion exchanger on the surface of carbon electrodes, which supports a decreased contact resistance between the electrode of MCDI and ion exchanger [18]. Basically two types of fabrication method are used: coating method and compressing method. Compressing method requires high pressure to fabricate the electrode from composite materials, conductive agent and binder material [19]. Recently researchers focus on the polymer coating electrode for capacitive deionization [20, 21, 25, 26].

2 Progress of polymer coated capacitive deionization electrodes

The current progress of various polymer coated capacitive deionization electrodes is comparatively and systematically shown in Table 1.

3 Discussion of various polymer coated electrodes fabrication

Kim and Choi [20] reported that for membrane capacitive deionization a cation-exchange polymer coated electrode was prepared by simple and inexpensive way. A mixture of poly(vinyl alcohol) and sulfosuccinic acid mixture was used as coating solution to introduce negatively charged ion-exchange groups. Such electrode was prepared at various crosslinking temperatures and sulfosuccinic acid contents. Electrode performance shows that the specific capacitance and the electric resistance of the coated carbon electrodes were affected strongly by the crosslinking temperature. Despite this, when compared with commercial ion-exchange membranes, the area resistance of the coated layer was relatively low [20]. Multiplication of specific surface area carbon and double layer capacitance (C_{dl}) is known as specific capacitance (C_{dl}/F cm^{-2}) [29].

Coating on carbon cloths was achieved by spraying with bromomethylated poly(2,6-dimethyl-1,4-phenylene oxide). Cation exchange and anion exchange layers are formed on electrode by sulfonation and amination respectively. Such novel electrodes improve weakness of mem-

Table 1: Comparison of various polymer coated capacitive deionization electrodes.

Polymer coated Electrode	Coating thickness (mm)	Surface Area (m^2/g)	Flow rate (ml/min)	Voltage (V)	Feed Concentration (mg/L)	Salt Adsorption (mg/g)	Percent removal (%)	Publication year and references
Carbon electrode coated with an ion-exchange polymer (a mixture of poly (vinyl alcohol) and sulfosuccinic acid)	0.01	–	20	1.5	200	–	85	2010 [30]
Bromomethylated poly (2, 6-dimethyl-1, 4-phenylene oxide) ion exchanger layered electrodes	–	–	4	1.8	100	–	83.4	2011 [18]
Ion selective polymer coating	0.0205		30	1.5	250	5.50	77.23	2013 [21]
Anion exchange polymer (dimethyl diallyl ammonium chloride) and cation exchange (polyethyleneimine) polymer into carbon nanotubes (CNTs) electrodes	–		50	1.2	50^a	–	93	2014 [22]
Polyaniline-modified activated carbon electrodes	–	618.4	–	1.2	250	3.15	–	2014 [23]
Polypyrrole/carbon nanotube composites		185.21	–	1.4	1000^a	43.99	–	2014 [24]
Coating-type polypyrrole/carbon nanotube composite electrode	0.3	–	–	1.4	1000^a	93.68	–	2015 [25]
Synthesized anion (aminated polysulfone) and cation (poly(phenylene oxide) exchange polymer coating on the electrodes	1-2	–	23	1.0	100	–	100	2015 [26]

Note: all feed solutions are NaCl , a: Initial conductivity of feed solution (μS/cm).

brane capacitive deionization by minimizing the interfacial resistance between the carbon electrode and ion exchanger layer [18].

Salt removal efficiency was improved and contact resistances decreases by combined used of ion selective membrane and polymer in CDI cell [21]. Application of polyethyleneimine (cation exchange polymer) and dimethyl diallyl ammonium chloride (anion exchange polymer) into carbon nanotube-based electrode shows better improvement in desalination due to decreased co-ion effect. It also enhanced the contact adhesion between electrodes and ion exchange polymers compared to contact adhesion between electrodes and commercial ion exchange membranes [22].

A composite electrode reported by Yan et al. (2014), with conducting polymer polyaniline and activated carbon electrode was prepared by in situ polymerization. Results show that composite had a higher ion removal capacity and faster ion removal rate than original activated carbon electrode. A blend of two materials decreased the number of micropores and increased conductivity. Polyaniline made the conducting chains which connected micro-activated carbon particles together and blocked most of the micropores [23]. Carbon nanotube and polypyrrole composite electrode was prepared by chemical oxidation method and sodium dodecyl benzene sulfonate was uesd as the dopant. The results prove that polypyrrole/carbon nanotube composites have specific capacitance enhanced three times compared to carbon nanotubes, they also indicated higher adsorption capacity [24]. Same material, i.e. polypyrrole/carbon nanotube composite electrode fabricated by coating methodology was reported by [25]. Performance of electrode shows that the coated electrode was significantly superior to the traditional compressed electrode in terms of the specific adsorption capacity and specific mass capacitance [25]. Coating of sulfonated poly (phenylene oxide) (cation exchange polymer) and aminated polysulfone (anion exchange polymer) on surface of commercial carbon electrodes is effective in reducing the "co-ion" effect [26].

4 Conclusion

Polymer coated capacitive deionization technology could be a capable technology for desalination. On the basis of reported literature the polymer coating improves the electrode performance, increases the specific capacitance and is effective in reducing the "co-ion" effect. Such electrodes improve weakness of membrane capacitive deionization by minimizing the interfacial resistance between the carbon electrode and ion exchanger layer. Evidence is reported that the coated electrode was significantly superior to the traditional compressed electrode in terms of the specific adsorption capacity and specific mass capacitance. Contact adhesion between electrodes and ion exchange polymers was enhanced compared to contact adhesion between electrodes and commercial ion exchange membranes. Thus, polymer coating is the promising method for modification of capacitive deionization electrodes and great progress of such electrode in desalination application is expected.

Acknowledgement: The authors are grateful to the Indian Institute of Technology Roorkee for providing the necessary facilities and to the Ministry of Human Resource Development, Government of India for providing financial support.

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