**ROLE OF CARBON NANOTUBES FOR WATER PURIFICATION**

**Tamanna Saharan, Manoj Kumar**

*Department of Chemistry, University Institute of Sciences, Chandigarh University, Gharuan, Mohali, Punjab, India – 140413*

**Email: 21tamannasaharan@gmail.com , manoj.e12044@cumail.in**

**ABSTRACT**

The briskly decreasing quality of unpolluted and potable water system constitutes a significant concern considering the present circumstances of world’s water resources. There are many purifiers which use different techniques like filtration, distillation, boiling, chlorination and oxidation. Presently Nano technology plays an important role in water purification techniques. The advancement in technology refers to an extensive range of tools, methods and utilization which involve particles on the approximate size scale of a few to hundreds of nano meters in diameter. Nano-filtration method has advantage over other conventional methods as for the passage of water through filters low pressure is required and moreover these filters can be cleaned easily by back flushing. Different types of chemicals (like arsenic, mercury etc.), bacteria, and sediments can be removed by using Nano-technology. This review introduces the use of carbon nanotubes (CNT’s) in removal of various artificial and natural contaminants that are present in water. The review paper is important for scientists, membrane technologists, industrialists, and geographers working in water purification domains. Furthermore, it will provide some insight on the creation of cost-effective and environmentally friendly nanostructured materials for water filtration.

**Keywords: CNT, Nano filtration, Graphene, Nano Technology.**

**INTRODUCTION**

Water is in great abundance on earth, being 97% water available in the oceans and only 3% fresh water. In reality we don’t have access to all of this 3% of fresh water because some of it is in polar icecaps and remaining is groundwater and in lakes and rivers. Increased industrialization and greater populations are further posing alarming challenges for safeguarding of fresh water and are responsible for water pollution [1-2]. In the present scenario, therefore it is one of the prime goals to purify the water and to provide access to safe drinking water globally. Few of the impurities present in the waste water are heavy metals, dissolved gases, organics, suspended impurities, microorganisms, colloids etc. [3-6]. The treatment techniques are adsorption, oxidation reduction, ion exchange, precipitation, membrane filtration, sedimentation etc. [7-10]. In water treatment system for removing impurities several methods came across time to time.  Nano technology is indeed the most popular for water filtration and desalination processes because of its flexibility of use, energy and space savings, low chemical inputs, and high efficiency [11-13]. Aside from that, the rising usage of membrane filtration can be ascribed to cheap costs and advancements in membrane quality. The principle on which the membrane filtration is based is to separate the impurities and organic and inorganic contaminants from pure water using semi-permeable membranes [14]. As a result, membranes that are being developed for water treatment need to achieve adequate water absorptivity, a well organised contaminant rejection or selectivity, good resistance to scaling, plenty of mechanical integrity. Therefore the engineers and scientists working in the waste water treatment field are continuously trying to develop good materials and techniques to improve the economy of membrane technology.

**Nanotechnology** is one major area which can prove to be path breaking in overcoming all these challenges in water purification. Nanotechnology is a branch of material science [15]. In general nanotechnology contains the structures whose size range lies between 1-100 Nano-meters in at least one dimension [16]. It also involves modifying or developing materials that lie in the same range. It makes the material smaller, lighter, faster, stronger and more resistant. Nanotechnology compels the ability to frame components of accurate machine and molecular size. To put it another way, ‘nanotechnology’ alludes to the assumed ability to construct items from the bottom up, using several tools and methods that are being defined to make high geared products.

 Depending on the strong inter panel character of nanotechnology there are

several research fields and various potential applications that involves nanotechnology

 Depending on the strong inter panel character of nanotechnology there are

several research fields and various potential applications that involves nanotechnology

 Depending on the strong inter panel character of nanotechnology there are

several research fields and various potential applications that involves nanotechnology

 Depending on the strong inter panel character of nanotechnology there are

several research fields and various potential applications that involves nanotechnology

**CNTs** are a class of multifunctional nanomaterial which can be best understood by relating it to the structure of graphene. Graphene has a single 2D sheet hexagonal structure. It contains the sheet of carbon atoms. Carbon Nano tube is nothing but simply a rolled-up sheet of graphene into a tube. This structure was discovered in 1991 by a Japanese scientist Sumio Iijima and was published in the *Nature* [17]. The CNT is categorized into two parts generally i.e. single-walled nanotube and multi-walled nanotube. Multi walled nanotube has several walls that are further classified into two parts [18-19]. One of which is called Russian Doll and the other is Parchment. In Russian doll structure instead of having one graphene sheet, it contains several concentric cubes. In Parchment structure there is basically a single sheet but it rolls itself like a multi-walled structure. The inter-tube distance in the first one is around 3.4 Å which is same as the interlayer separation of graphite. Another classification is based on the chirality. It can be either Chiral (Handed) or Achiral (Not handed). For chiral structures mirror plane should be absent whereas in case of achiral mirror will be present. So, we can conclude that achiral will be more symmetric. So, basically the SWCNT has three types (A) Arm chair (B) Zigzag (c) Chiral or helical. These types are formed by folding of graphene sheet in three different ways. The helical SWCNT is chiral while the zigzag and arm chair are achiral. Moreover, the arm chair shows electrical conductivity and the helical SWCNT acts as semiconductor.

The carbon Nano tubes have easy penetration power [20-21]. CNT’s have useful photoluminescence, absorption properties. They have exceptional mechanical stiffness and tensile strength. The main applications of CNTs are in breast cancer destruction, wind mill blades, filtration, CNT as Nano-cylinders, air craft stress reduction etc. [22] CNT’s are also used to trap tiny particles or ions from a solution. So, we can conclude that during filtration these can be used to separate particles of size greater than diameter of Nano tubes. CNT’s in case of Nano cylinders can be used to store the gas like H2 for energy and battery [23]. These have also been shown to absorb infrared light and may have applications in the IR optics industry as well [24]. Carbon Nano tubes show several important properties which include electron affinity and mechanical strength. CNTs are also known for exhibiting flexibility during functionalization, which authorize these materials to make it useful for waste water operations [25-28]. Nevertheless, with the quick improvement in the advancement and use of Nano-membrane that are working with remarkable properties custom fitted to the removal of aqueous impurities and pinpoint the expected heading for future examination.

There are various techniques available for the production of carbon Nano tubes. The best method to produce comparatively large amount of the CNT is chemical vapour decomposition [29-30]. In this method a catalyst is used and in the presence of it the carbon source is heated, so decomposition occurs hence CNTs are produced. There are several parameters that control the process like flow rate, choice of the recursive material, the temperature. Some challenges that arise from this process are that the yield is very low [31]. The principle on which adsorption is based is that it is a process where a material or various molecule or ions are deposited on a solid surface and they are physically and chemically attached to the surface [32-35]. There are four different sites where different molecules can be absorbed on the surface of carbon Nano tubes. It can be absorbed inside the carbonate tube if it is open, and can be absorbed between the channel and the CNT and the external growth or the external surfaces [36-39]. CNT can also be applied as a filler material or the membrane. After radiation of the carbon nanotubes the characteristics of membrane increase [40-42]. If the hydrophilicity is increased then the membrane gives high salt removal and antibacterial characteristics. The CNT are vertically aligned in the polymeric membrane so that the water molecule can flow beside the carbonyl tube due to hydrophobic effect [43-44]. This is because the carbonyl tube is hydrophobic furthermore the water molecule can flow through the space between the carbon nanotubes or through the poly-metric matrix itself. So, if the flux is high we can get more clean water in a shorter period of time.

**Role of CNT membrane in Desalination**

Desalination is basically nothing but the process of removing the salt from the surface or sea water [45-46]. It is known that generally the salt concentration found in sea water is around 35000 ppm and the target is to reduce the concentration to 500 ppm to make the water fit for drinking purpose. There are variable techniques that help to reduce the salt concentration which include thermal techniques, membrane techniques and by using carbon nanotubes etc. In this method the water flows extremely fast through the interior core of CNT. During protection of the CNT through CVD, the carbon nanotube can be deposited in a specific template and then the tips of the CNTs can be opened. It can therefore be used for the flow of various molecules or water molecules and can reject salt molecule. Another way to obtain the pure water is by aggregating the vertically aligned CNTs in which the main force that held together the carbonate is Vander Waal forces [47-49]. But the disadvantage in this process will be the low strength as the forces acting on it is very weak, and is not suitable for the application in desalination. To overcome from this problem polymer can be added in the spaces between the carbon molecules in the tubes so that they will hold the CNT together. So in case of open-ended CNT/Polymer composite membranes, the tip of the carbon nanotube must be opened and hence this will be the only channel available for the flow of water molecule. Similarly some researchers tried to form radically aligned CNTs. This is basically an in and out structure impurities stays within the system and the pure water comes out from it.

**Bucky paper CNT membranes**

Bucky paper CNT membrane has several advantages including the interconnected pore structure and high porosity. The main reason behind the introduction of CNTs Bucky paper membrane was to separate the emulsion of oil in water. For this process a polystyrene carbon nanotube Bucky paper was introduced which was effective around 99% in separating the oil in water emulsion [50-51]. The Bucky paper membrane size is mainly affected by two factors which includes the width to height ratio and surface effect. The pore size is inversely proportional to the aspect ratio [52].

In CNTs Bucky paper membranes two different types of pore structures are formed [53], the inter-bundle pores are of larger size and are formed between CNTs bundles. On the other hand intra-bundle pores are similar to the size of CNTs diameters. The inter-bundle pores are more effective for filtration process in comparison to intra-bundle pores because of the homogeneity of CNTs network. The pristine Bucky paper showed hydrophobic nature i.e. it was insoluble in water whereas the surface modified Bucky paper showed hydrophilic nature. These two were used for separating the oil-in-water emulsion.

**Current barriers and advance research**

 Carbon nanotubes have shown an amazing wastewater treatment potential because of its exceptional properties and physiochemical characteristics. To make the carbon nanotubes useful for water filtration, the important features are the large surface area of the nanotubes, fast water treatment, easy functioning and high adsorption rates. Studies have shown that CNTs affect the respiratory system. It has also been found that CNTs also trigger lung tumour. Another challenge to concern about CNTs is its cost, specifically SWCNTs. Because of the high cost of nanotubes it is not possible to do the research on larger scale. Although it is believed that the commercial production of CNT will help in price falling. There are also some concern about the application in real water treatment and desalination.

**CONCLUSION**

Carbon nanotubes have exhibited tremendous potential in water purification and there are various challenges and opportunities in case of nanotubes. Nano technology is indeed the most popular for water filtration and desalination processes because of its flexibility of use, energy and space savings, low chemical inputs, and high efficiency. Carbon nanotubes are acknowledged to break the reciprocation between membrane permeability and selectivity. Therefore these upgrade economy of membrane technology significantly. New composites based on these materials can be explored. Further research is required to discover the new applications and addressing challenges can lead to a breakthrough research in the field.

**REFERENCES:**

1. Aquatic Project WILD; Western Regional Environmental Education Council
2. Flying Start Science-Water; Kim Taylor
3. K.C. Saha, Review of arsenicosis in West Bengal, India – a clinical perspective, Crit. Rev. Environ. Sci. Technol. 33 (2) (2003) 127–163.
4. O.A.H. Jones, N. Voulvoulis, J.N. Leste, Human pharmaceuticals in wastewater treatment processes, Crit. Rev. Environ. Sci. Technol. 35 (4) (2005) 401–427.
5. S. Ayoob, A.K. Gupta, V.T. Bhat, A conceptual overview on sustainable technologies for the defluoridation of drinking water, Crit. Rev. Environ. Sci. Technol. 38 (6) (2008) 401–470. [4] X. Huang, M. Sillanpää, B. Duo, E.T. Gjessing, Water quality in Tibetan Palteau: metal contents of four selected rivers, Environ. Pollut. 156 (2) (2008) 270–277.
6. C.M. Ferguson, K. Charles, D.A. Deere, Quantification of microbial sources in drinking-water catchments, Crit. Rev. Environ. Sci. Technol. 39 (1) (2009) 1–40.
7. A. Da˛browski, Adsorption-from theory to practice, Adv. Colloid Interface Sci. 93 (1–3) (2001) 135–224.
8. Q. Jiuhui, Research progress of novel adsorption processes in water purification: a review, J. Environ. Sci. 20 (1) (2008) 1–13.
9. S.J.T. Pollard, F.E. Thompson, G.L. Mcconnachie, Microporous carbons from moringa oleiferahusks for water purification in less developed countries, Water Res. 29 (1) (1995) 337–347.
10. G. Reschke, D. Gelbin, Application of adsorption for water-purification – a literature-review, Chem. Technol. 34 (3) (1982) 114–120.
11. T.J. Phelps, A.V. Palumbo, B.L. Bischoff, C.J. Miller, L.A. Fagan, M.S. McNeilly, R.R. Judkins, Micron-pore-sized metallic filter tube membranes for filtration of particulates and water purification, J. Microbiol. Methods 74 (1) (2008) 10–16.
12. F. Macedonio, E. Drioli, Pressure-driven membrane operations and membrane distillation technology integration for water purification, Desalination 223 (1–3) (2008) 396–409.
13. A.K. Pikaev, Current status of the application of ionizing radiation to environmental protection: I. Ionizing radiation sources, natural and drinking water purification (a review), High Energy Chem. 34 (1) (2000) 1–12.
14. (Nicolaisen, 2002; Pendergast and Hoek, 2011).
15. S. Kumar, R. Rani, N. Dilbaghi, K. Tankeshwar, K.H. Kim, Carbon nanotubes: a novel material for multifaceted applications in human healthcare, Chem. Soc. Rev. (2017) 158–196.
16. A.G. Mamalis, L.O. Vogtl€ander, A. Markopoulos, Nanotechnology and nanostructured materials: trends in carbon nanotubes, Precis. Eng. (2004) 16–30.
17. ] Z. Wang, Z. Dai, Carbon nanomaterial-based electrochemical biosensors: an overview, Nanoscale (2015) 6420–6431.
18. P. Kara, A. de la Escosura-Muniz, M. Maltez-da Costa, M. Guix, M. Ozsoz, ~ A. Merkoçi, Aptamers based electrochemical biosensor for protein detection using carbon nanotubes platforms, Biosens. Bioelectron. (2010) 1715–1718.
19. S.K. Smart, A.I. Cassady, G.Q. Lu, D.J. Martin, The biocompatibility of carbon nanotubes, Carbon (2006) 1034–1047.
20. P.R. Dey, N.I. Das, Carbon nanotubes: it's role in modern health care, Int. J. Pharm. Pharmaceut. Sci. (2013) 9–13.
21. J. Che, T. Cagin, W.A. Goddard III, Thermal conductivity of carbon nanotubes, Nanotechnology (2000).
22. Lortz, R.; Zhang, Q.; Shi, W.; Ye, J. T.; Qiu, C.; Wang, Z.; He, H.; Sheng, P.; Qian, T.; Tang, Z.; Wang, N.; Zhang, X.; Wang, J.; Chan, C. T. (5 May 2009). *["Superconducting characteristics of 4-A carbon nanotube-zeolite composite"](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2678622)*. Proceedings of the National Academy of Sciences. **106** (18): 7299–7303. *[doi](https://en.wikipedia.org/wiki/Doi_%28identifier%29%22%20%5Co%20%22Doi%20%28identifier%29)*:*[10.1073/pnas.0813162106](https://doi.org/10.1073/pnas.0813162106)*. *[PMC](https://en.wikipedia.org/wiki/PMC_%28identifier%29%22%20%5Co%20%22PMC%20%28identifier%29)* *[2678622](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2678622)*. *[PMID](https://en.wikipedia.org/wiki/PMID_%28identifier%29%22%20%5Co%20%22PMID%20%28identifier%29)* *[19369206](https://pubmed.ncbi.nlm.nih.gov/19369206)*.
23. **[^](https://en.wikipedia.org/wiki/Carbon_nanotube%22%20%5Cl%20%22cite_ref-65%22%20%5Co%20%22Jump%20up)** Bockrath, Marc (1 March 2006). "The weakest link". Nature Physics. **2** (3): 155–156. *[doi](https://en.wikipedia.org/wiki/Doi_%28identifier%29%22%20%5Co%20%22Doi%20%28identifier%29)*:*[10.1038/nphys252](https://doi.org/10.1038/nphys252)*. *[S2CID](https://en.wikipedia.org/wiki/S2CID_%28identifier%29%22%20%5Co%20%22S2CID%20%28identifier%29)* *[125902065](https://api.semanticscholar.org/CorpusID%3A125902065)*.
24. <https://pubs.rsc.org/en/content/articlelanding/2013/cs/c2cs35335k/unauth>
25. B.S. Lalia, F.E. Ahmed, T. Shah, N. Hilal, R. Hashaikeh, Electrically conductive membranes based on carbon nanostructures for self-cleaning of biofouling, Desalination. 360 (2015) 8–12. doi:10.1016/j.desal.2015.01.006.
26. S. Li, G. Liao, Z. Liu, Y. Pan, Q. Wu, Y. Weng, X. Zhang, Z. Yang, O.K.C. Tsui, 88 Enhanced water flux in vertically aligned carbon nanotube arrays and polyethersulfone composite membranes, J. Mater. Chem. A. 2 (2014) 12171–12176. doi:10.1039/C4TA02119C.
27. C. Rizzuto, G. Pugliese, M.A. Bahattab, S.A. Aljlil, E. Drioli, E. Tocci, Multiwalled carbon nanotube membranes for water purification, Sep. Purif. Technol. 193 (2018) 378– 385. doi:https://doi.org/10.1016/j.seppur.2017.10.025.
28. M.H.D.A. Farahani, V. Vatanpour, A comprehensive study on the performance and antifouling enhancement of the PVDF mixed matrix membranes by embedding different nanoparticulates: Clay, functionalized carbon nanotube, SiO2 and TiO2, Sep. Purif. Technol. 197 (2018) 372–381. doi:https://doi.org/10.1016/j.seppur.2018.01.031.
29. Y.M. Manawi, Ihsanullah, A. Samara, T. Al-Ansari, M.A. Atieh, A review of carbon nanomaterials’ synthesis via the chemical vapor deposition (CVD) method, Materials (Basel). 11 (2018). doi:10.3390/ma11050822.
30. A. Abbas, B.A. Abussaud, Ihsanullah, N.A.H. Al-baghli, M. Khraisheh, M.A. Atieh, Benzene removal by iron oxide nanoparticles decorated carbon nanotubes, J. Nanomater. 2016 (2016) Article ID 5654129, 10 pages <http://dx.doi.org/10>.
31. H.A. Asmaly, B. Abussaud, Ihsanullah, T.A. Saleh, A. Alaadin, T. Laoui, A.M. Shemsi, V.K. Gupta, M.A. Atieh, H.A. Asmaly, B. Abussaud, T.A. Saleh, A. Alaadin, Evaluation of micro- and nano-carbon-based adsorbents for the removal of phenol from aqueous solutions, Toxicol. Environ. Chem. 97 (2015) 1164–1179. doi:10.1080/02772248.2015.1092543.
32. Ihsanullah, A. Abbas, A.M. Al-Amer, T. Laoui, M.J. Al-Marri, M.S. Nasser, M. 87 Khraisheh, M.A. Atieh, Heavy metal removal from aqueous solution by advanced carbon nanotubes: Critical review of adsorption applications, Sep. Purif. Technol. 157 (2016) 141–161. doi:10.1016/j.seppur.2015.11.039.
33. E. Salehi, S.S. Madaeni, L. Rajabi, V. Vatanpour, A.A. Derakhshan, S. Zinadini, S. Ghorabi, Novel chitosan/poly (vinyl ) alcohol thin adsorptive membranes modified with amino functionalized multi-walled carbon nanotubes for Cu(II) removal from water: Preparation, characterization, adsorption kinetics and thermodynamics, Sep. Purif. Technol. 89 (2012) 309–319. doi:10.1016/j.seppur.2012.02.002
34. S. Kang, M. Pinault, L.D. Pfefferle, M. Elimelech, Single-walled carbon nanotubes exhibit strong antimicrobial activity, Langmuir. 23 (2007) 8670–8673.
35. M.A. Atieh, Ihsanullah, and T. Laoui., Fabrication of carbon nanotube membranes, 96 (2017) U.S. Patent 9,776,140.
36. Ihsanullah, F. Patel, M. Khraisheh, M.A. Atieh, T. Laoui, Novel aluminum oxideimpregnated carbon nanotube membrane for the removal of cadmium from aqueous solution, Materials (Basel). 10 (2017). doi:10.3390/ma10101144.
37. P.M. Ajayan, Nanotubes from carbon, Chem. Rev. 99 (1999) 1787−1799.
38. Y.L. Zhao, J.F. Stoddart, Noncovalent functionalization of single-walled carbon nanotubes, Acc. Chem. Res. 42 (2009) 1161–1171. doi:10.1021/ar900056z.
39. K. Balasubramanian, M. Burghard, Chemically functionalized carbon nanotubes, Small. 1 (2005) 180–192. doi:10.1002/smll.200400118.
40. S. Iijima, Helical microtubules of graphitic carbon, Nature. 354 (1991) 56–58. doi:10.1038/354056a0.
41. X. Wang, Q. Li, J. Xie, Z. Jin, J. Wang, Y. Li, K. Jiang, S. Fan, Fabrication of ultralong and electrically uniform single-walled carbon nanotubes on clean substrates, Nano Lett. 9 (2009) 3137–3141. doi:10.1021/nl901260b.
42. L. Dumée, V. Germain, K. Sears, J. Schütz, N. Finn, M. Duke, S. Cerneaux, D. Cornu, S. Gray, Enhanced durability and hydrophobicity of carbon nanotube bucky paper membranes in membrane distillation, J. Memb. Sci. 376 (2011) 241–246. doi:10.1016/j.memsci.2011.04.024.
43. L.F. Dumée, K. Sears, J. Schütz, N. Finn, C. Huynh, S. Hawkins, M. Duke, S. Gray, Characterization and evaluation of carbon nanotube bucky-paper membranes for direct contact membrane distillation, J. Memb. Sci. 351 (2010) 36–43. doi:10.1016/j.memsci.2010.01.025.
44. Y. Baek, C. Kim, D. Kyun, T. Kim, J. Seok, Y. Hyup, K. Hyun, S. Seek, S. Cheol, J. Lim, K. Lee, J. Yoon, High performance and antifouling vertically aligned carbon nanotube membrane for water purification, J. Memb. Sci. 460 (2014) 171–177. doi:10.1016/j.memsci.2014.02.042.
45. S. Park, J. Jung, S. Lee, Y. Baek, J. Yoon, D. Kyun, Y. Hyup, Fouling and rejection behavior of carbon nanotube membranes, Desalination. 343 (2014) 180–186. doi:10.1016/j.desal.2013.10.005.
46. A. S. Brady-Estevez, S. Kang, M. Elimelech, A single-walled-carbon-nanotube filter for removal of viral and bacterial pathogens, Small. 4 (2008) 481–484. doi:10.1002/smll.200700863
47. S. Kang, M. Pinault, L.D. Pfefferle, M. Elimelech, Single-walled carbon nanotubes exhibit strong antimicrobial activity, Langmuir. 23 (2007) 8670–8673.
48. Y. Baek, C. Kim, D. Kyun, T. Kim, J. Seok, Y. Hyup, K. Hyun, S. Seek, S. Cheol, J. Lim, K. Lee, J. Yoon, High performance and antifouling vertically aligned carbon nanotube membrane for water purification, J. Memb. Sci. 460 (2014) 171–177. doi:10.1016/j.memsci.2014.02.042.
49. M. Yu, H.H. Funke, J.L. Falconer, R.D. Noble, High density, vertically-aligned carbon nanotube membranes, Nano Lett. 9 (2009) 225–229
50. W. Chan, H. Chen, A. Surapathi, M.G. Taylor, X. Shao, E. Marand, C.E.T. Al, Zwitterion functionalized carbon nanotube/polyamide nanocomposite, ACS Nano. 7 (2013) 5308– 5319.
51. Hu, Y.; Li, D.; Tang, P.; Bin, Y.; Wang, H. Comparative study of structure, mechanical and electromagnetic interference shielding properties of carbon nanotube buckypapers prepared by different dispersion media. Mater. Des. 2019, 184, 108175.
52. Zhang, J.; Jiang, D. Influence of geometries of multi-walled carbon nanotubes on the pore structures of Buckypaper. Compos. Part A Appl. Sci. Manuf. 2012, 43, 469–474.
53. Špitalský, Z.; Aggelopoulos, C.; Tsoukleri, G.; Tsakiroglou, C.; Parthenios, J.; Georga, S.; Krontiras, C.; Tasis, D.; Papagelis, K.; Galiotis, C. The effect of oxidation treatment on the properties of multi-walled carbon nanotube thin films. Mater. Sci. Eng. B 2009, 165, 135–138
54. C. Hoon, Y. Baek, C. Lee, S. Ouk, S. Kim, S. Lee, S. Kim, S. Seek, J. Park, J. Yoon, Carbon nanotube-based membranes: Fabrication and application to desalination, J. Ind. Eng. Chem. 18 (2012) 1551–1559. doi:10.1016/j.jiec.2012.04.005
55. B. Corry, Designing carbon nanotube membranes for efficient water desalination, J. Phys. Chem. B. 112 (2008) 1427–1434. doi:10.1021/jp709845u.