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# Comparative Analysis of Desalination Technologies: A Review

Himani Pathak[1*], Pawan Kumar Labhasetwar[2], Deepak J. Killedar[3]

[1.] *Research Scholar, Dept. of Civil Engg. & Applied Mechanics, Shri Govindram Seksaria Institute of Technology & Science, Indore (452003)*
[2] *Scientist & Head, Water Technology and Management Division, National Environmental Engineering Research Institute (NEERI), Nagpur – 440 020*
[3] *Professor, Department of Civil Engg. And Applied Mechanics, Shri G. S. Institute of Technology and Science, Indore (452003)*
* Corresponding Author *E-mail: pathakhimani97@gmail.com*

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***Abstract*-- With exponential increase of population and fresh water demand, water desalination is becoming the utmost important technology for the creation of new water from saline water like from seas and oceans. Several technologies are being applied to desaline the saline water with monitoring their performance. Depending upon the form of energy, amount of energy required, cost, chemical required and environmental impact these are being compared. In this article we are being able to summarize these technologies.**

**Key words - Desalination, Distillation, Membrane, Thermal, Adsorption, Chemical**

## I. Introduction

Water being one of the important pillar on which life stands, covers about three-fourth of the earth's surface, among which 97% of the water is in the form of seawater and 2% of it is trapped in the form of ice. Only 5% of total water is available as fresh water (Parfit et al. (1993); Service et al. (2006); Zhou et al. (2015)). Water is essential to fulfill basic purposes like drinking, bathing, washing etc. due to the increase in population as well the pollution leads us to the increase in demand and scarcity of fresh water. Because of this fresh water scarcity, 88 developing countries which is half of the world's population is facing severe problems and around 80-90% of them are facing various diseases and 30% of deaths are because of bad water conditions . With the increase in population the demand of fresh water has been doubled over 20 years (Engelman (2000); Hameeteman et al. (2013); Subramani et al. (2015)). It is government's duty to supply the freshwater to each and every citizen irrespective of their socio-economic status. The worldwide water desalination capacity is shown in Figure 1.

Since it is getting hard to access the fresh water thus getting the alternative options for the same is essential. Desalination is emerging as the important process to reach the demand. These desalination technologies can be carried out with in different ways like thermal, pressure, chemically and through adsorption, some of them are like Reverse Osmosis, Forward Osmosis, and Multi Stage Flash distillation etc.

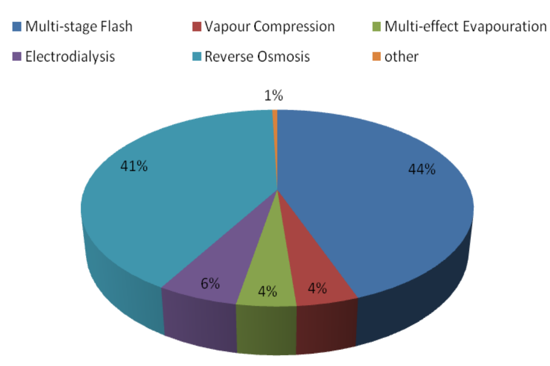


Fig 1: World Wide Desalination Capacity

Source: Wangnick et al. (1998)

## II. Desalination Techniques

There are various water purification technologies some of them are classified in Figure 2.

Since the time when humans were able to produce clean water artificially, these technologies became very vital. Some of such desalination processes are mentioned Table 1.

TABLE 1
Various Desalination Technologies

| Sr. No | Technology | Process | Advantages | Disadvantages | Sources |
|---|---|---|---|---|---|
| 1. | Multi-stage Flash Distillation | Generally have 20 stages<br>Here via evaporation fresh water is separated from brine<br>Prior to first stage, feed water is heated upto the temperature of first inlet.<br>Higher the temperature, higher will be the distillation rate and larger amount of vapor to be extracted | These plants are simpler to construct and operate<br>This gives a high level of purification<br>Feed water quality is not important as of others | Operation at higher temperature causes scaling problem<br>Even though it is an energy intensive process but can be overcome by cogeneration system<br>By adding more stages to improve efficiency leads to the increase in capital cost and operational complexity | Buros et al. (2000);<br>Hamed et al. (2001);<br>Khawaji et al. (1994) |
| 2. | Vapor Compression Distillation | Heat pump process based and mechanical energy works as a driving force<br>Basically pumps heat from low temperature to high temperature<br>Main elements are evaporator, compressor, condenser, and expansion valve<br>Water vapor generated in evaporator are compressed to increase pressure and temperature then condensed<br>Heat released will then be transferred to evaporator | Simple and reliable plant operation<br>Low operating temperature<br>Less power requirement | Additional compressor cost and skilled labour requirement | Buros et al. (2000) |
| 3. | Freezing | Based on the fact that when the temperature of saline water is lowered to its freezing point, ice crystals are formed of pure water<br>Opposite to distillation, in this the water changes its phase from liquid to solid | Lower theoretical energy requirement<br>Minimum corrosion and scaling problem<br>Can produce pure portable water and water for irrigation | Handling ice and water is quite challenging | Rice et al. (1997)**;** |

| Sr. No | Technology | Process | Advantages | Disadvantages | Sources |
|---|---|---|---|---|---|
| 4. | Solar Distillation | Works on two principles: evaporation and condensation<br>Salts and minerals do not evaporate with water | It requires large area, thus not suitable for large scale production | Installation cost is higher<br>Vulnerable to weather<br>Requirement of skilled labors | Shatat et al. (2014) |
| 5. | Multiple-effect Distillation | In order to produce clean distill water sea water temperature is lowered (<70ºC)<br>Stages upto 14 are used for the evaporation of sea water | This works in a lower temperature, thus reduces the potential scaling and corrosion problems<br>Pre-treatment and operational costs are low<br>Power consumption is lower than MSF<br>More efficient than MSF | | Buros et al. (2000);<br>Darwish et al. (1996) |
| 6. | Reverse Osmosis | Have the pore size of 0.0001micron<br>Removes organic matters, viruses, monovalent ions and essential minerals too | Systems are easy to plan and work<br>Have low support prerequisites and are measured in nature, making extension of the framework simple. It can considerably reduce the volume of waste streams so that these can be treated more efficiently and cost effectively by other processes. | Requirement of pretreatment and the usage of chemicals | Garud et al., (2011) |
| 7. | Electrodialysis | Under to applied electric potential, with the help of ion exchange membranes salt ions are transported from one solution to another | This is utilized for the expulsion of disintegrated solids, copper, water relaxing, recuperation of corrosive and base | Pretreatment is required<br>Organic matters, colloids etc. are not removed | Akhter et al., (2018); Caprarescu et al., (2012);<br>Oztekin et al., (2016) |
| 8. | Electro-deionization | Chemical free process, required DC, ion exchangers and resins<br>Feed water passed in between anode and cathode where ion selective membranes will allow to separate the opposite charged ions | Used in recycling of power plant boiler feed water, beverage industry etc.<br>Can be used in small space, no pollution, reliable, cost effective and provide high purity water production. | It requires pretreatment for pure water, clogging limits its operation and sometimes carbon dioxide can penetrate through system. | |

| Sr. No | Technology | Process | Advantages | Disadvantages | Sources |
|---|---|---|---|---|---|
| 9. | Nano-filteration | Contains pore size of 0.001micron<br>Removes organic molecules, most of viruses, divalent ions | It is used for the removal of hardness and no sodium ions are used<br>It do not require heating and cooling of feed water | It cannot cover the UF range efficiently<br>More costly than RO and UF | Nageswara(2014);<br>Rahimpour(2010);<br>Labban et al., (2017);<br>Mohammad(2007); |
| 10. | Forward Osmosis | Instead of using conventional hydraulic pressure as that of RO, here an osmotic pressure is being generated with the help of a concentrated draw solution, which creates a pull to water across a semipermeable membrane from the feed water.<br>The final water is produce by separating draw solutes from the diluted draw solution | Osmotic pressure is the driving force hence external hydraulic pressure is not required<br>Low fouling, brackish groundwater desalination, seawater desalination, food processing, fertilizer production etc. are the key advantages over RO | Concentration polarization and reverse salt reflux are challenges on this technique | Chun et al., (2017);<br>Philip et al., (2010);<br>Tang et al., (2010);<br>Martinetti et al., (2009);<br>Chun et al., (2015);<br>McCutcheon et al., (2006);<br>Shaffer et al., (2012);<br>Tan et al., (2010);<br>Achilli et al., (2009);<br>Kim et al., (2013a);<br>Yip et al., (2011);<br>Petrotos et al., (2001);<br>Phuntsho et al. (2013);<br>Kim et al. (2013b);<br>Subramani et al.(2015);<br>McCutcheon et al. (2006). |
| 11. | Capacitive Deionization | Feed water is passed through charged electrodes; oppositely charged ions will be adsorbed on the electrodes<br>By changing the polarity of electrodes the ions can be extracted | No applied pressure<br>More efficient for low salinity feed water<br>Reversing the polarity gives regeneration of electrodes | Small scale application<br>New technology<br>Scaling and fouling | Tang et al.(2019) |

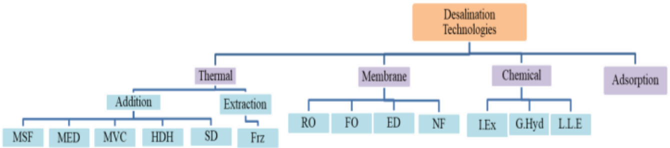


Fig. 2: Flow Chart for Desalination

Source: Youssef et al. (2014)

Depending upon the environment of desalination plant, requirement and feed water quality the energy requirement and the cost differs, which are shown in Table 2, 3 and 4.

## III. Summary

To meet the world's water demand desalination technologies are becoming very important. All these technologies have various advantages and disadvantages, depending upon the surrounding, requirement and cost we can use the suitable desalination technology. Among all these, adsorption based capacitive deionization technique occurs to be very efficient with less energy, no chemical and low cost requirement with lower impact on environment.

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TABLE 2
Installed Desalination Capacity by Country

| Country | Total Capacity ($m^3$/day) | % of Global Production | MSF | MEE | MVC | RO | ED |
|---|---|---|---|---|---|---|---|
| Saudi Arabia | 5,253,200 | 25.9 | 65.7 | 0.3 | 1.2 | 31 | 1.9 |
| United States | 3,092,500 | 15.9 | 1.7 | 1.8 | 4.5 | 78 | 11.4 |
| United Arab Emirates | 2,164,500 | 10.7 | 89.8 | 0.4 | 3.0 | 6.5 | 0.2 |
| Kuwait | 1,538,400 | 7.6 | 95.5 | 0.7 | 0.0 | 3.4 | 0.3 |
| Japan | 745,300 | 3.7 | 4.7 | 2.0 | 0.0 | 86.4 | 6.8 |
| Libya | 683,300 | 3.4 | 67.7 | 0.9 | 1.8 | 19.6 | 9.8 |
| Qatar | 566,900 | 2.8 | 94.4 | 0.6 | 3.3 | 0.0 | 0.0 |
| Spain | 529,900 | 2.6 | 10.6 | 0.9 | 8.7 | 68.9 | 10.9 |
| Italy | 518,700 | 2.6 | 43.2 | 1.9 | 15.1 | 20.4 | 19.2 |
| Bahrain | 309,200 | 1.5 | 52.0 | 0.0 | 1.5 | 41.7 | 4.5 |
| Oman | 192,000 | 0.9 | 84.1 | 2.2 | 0.0 | 11.7 | 0.0 |

TABLE 3
Energy Use for Desalination (kJ/kg)

| MSF | MEE | VC | Seawater RO | Brackish RO | Brackish ED | Source |
|---|---|---|---|---|---|---|
| 299 | | | 61 | | | Wahlgen et al. (2001) |
| 95 | | | 15-28 | | | Awerbuch et al. (1997) |
| 230 | | | 27 | | | Darwish et al. (2000) |
| 290 | | 100-120 | 23-30 | | 4 | Spiegler et al. (1994) |
| 216-288 | | | 18-22 | 11 | | Thomas et al. (1997) |
| | | 25-43 | 11 | | | Buros et al.(2000) |
| | | 29-39 | 15-28 | | | Awerbuch et al. (1997) |
| 95-252 | 107-132 | 22-29 | | | | Ettouney et al. (1993) |
| | | 14-29 | | | | Mandani et al. (2000) |
| | | 22-58 | | | | Al-Juwayhel et al. (1997) |
| | | 26 | | | | Aly et al. (1999) |
| | | 37-40 | | | | Veza et al. (1995) |
| | 95-275 | | | | | Al-Shammiri et al. (1999) |
| | 152 | | | | | Dvornikov et al. (2000) |
| | | | 14-20 | | | Wilf et al. (2001) |
| | | | 14 | 7.2 | | Glueckstern et al. (2001) |
| | | | 18-24 | | | Rautenbach et al. (2001) |

TABLE 4
Desalination Cost ($/m$^3$)

| MSF | MEE | VC | Seawater RO | Brackish RO | Brackish ED | Source |
|---|---|---|---|---|---|---|
| 1.10-1.50 | 0.46-85 | 0.87-0.92 | 0.45-0.92 | 0.20-0.35 | | Semiat et al. (2000) |
| 0.70-0.75 | | | 0.45-0.85 | 0.25-0.60 | | Buros et al. (2000) |
| | | | 1.50 | 0.37-0.70 | 0.58 | Spiegler et al. (1994) |
| 1.31-5.36 | | | 1.54-6.56 | | | Wahlgren et al. (2001) |
| 1.86 | 1.49 | | | | | Morin et al. (1993) |
| | | | 1.25 | | | Drioli et al. (1999) |
| | | 0.46 | | | | Zimerman et al. (1994) |
| | 1.17 | | | | | Dvornikov et al. (2000) |
| | | 0.99-1.21 | | | | El-Sayed et al. (1999) |
| | | | 0.55-0.80 | 0.25-0.28 | | Redondo et al. (2001) |
| | | | 0.59-1.62 | | | Leitner et al. (1995) |
| | | | 1.38-1.51 | | | Malek et al. (1996) |
| | | | 0.70-0.80 | | | Wilf et al. (2001) |
| | | | 0.52 | | | Leitner et al. (1995) |