ISSN (Online): 2456-5717

International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)

Vol.3 Issue.8 August 2017

# Design and Development of a Portable System to Desalinate Brackish Water Using Polymer Membrane

V.Benadict Bharath[1], V.Ajith Rathinam[1], S.Herald Sam Anand[1], Ashwin Nagarajan[1], Zeenathul Farida Gani[2]

[1] Undergraduate Students, [2] Professor, Department of Mechanical Engineering

Francis Xavier Engineering College, Tirunelveli- 627007

## ABSTRACT

Lack of water supply for irrigation leads to poor cultivation and in turn affects farmer's income and livelihood. The present farmer's issues and the continuing dreadful deaths of farmers all over India have raised concern to find alternate solutions to use water in a rationale manner. It has also become very much essential to have a better water management system for efficient and sustainable manner. In addition to that, undeniably there is a huge need to generate fresh water from the 70% of salt water that is available on the earth's surface. This work is an attempt to address the issues faced by the farmers due to water scarcity in India and around the globe. A thorough study to gain knowledge about water crisis, scarcity, causes, effects and potential solutions for water crisis were carried out. Various desalination techniques were learned through available literature and web sources. A portable desalination system using has been designed and developed. A few trial runs with water having different salinity level were carried out to check for the permeate flux. The results of the trial runs have shown a significant reduction in the TDS level. Though, the TDS level attained with this portable desalination system is not good for drinking purpose, it attained the level that is permissible for irrigation purpose and for process plant. The membrane module should be modified for an improved performance in the future.

## NOMENCLATURE

| Symbol | Name | Unit |
|---|---|---|
| $\pi$ | Osmotic Pressure | (Bar) |
| i | Vant Hoff Factor | No unit |
| m | Molar Concentration Of Dissolved Solids | (mol/L) |
| R | Ideal Gas Constant | (L atm $mol^{-1}$ $K^{-1}$) |
| T | Temperature Of The Water | (K) |
| $\Delta P$ | Hydraulic Pressure Differential Across The Membrane | (m) |
| $K_w$ | Membrane Permeability Co-Efficient For Water | (m/s) |
| S | Membrane Area | ($m^2$) |
| D | Membrane Thickness | (m) |
| $\Delta C$ | Salt Concentration Differential Across The Membrane | (m) |
| $K_s$ | Membrane Permeability Co Efficient For Salt | (m/s) |
| $C_p$ | Salt Concentration Of Permeate | (ppm) |
| $C_{fm}$ | Salt Concentration Of Feed Stream | (ppm) |
| $Q_p$ | Product Water Flow Rate | ($m^3$/s) |
| $Q_f$ | Feed Water Flow Rate | ($m^3$/s) |
| A | Permeability Coefficient | (m/s) |
| $(\Delta P - \Delta\pi)$ | Net Driving Pressure | (m) |
| $C_{fc}$ | Feed Concentrate Average Concentration | (ppm) |
| B | Salt Diffusion Coefficient | ($m^2$/s) |

# 1. INTRODUCTION

## 1.1 World Water Resources

The most valuable resource in the world ever is water. Water is the vital resource of all the resources available in the world. The ability of a region to flourish is indicated by the availability and distribution of purified freshwater. Around 70% of the planet is covered in water and that water returns to a useable form through natural water cycle processes [1]. However, of the total water content, only about 2.5% is freshwater and the other 97.5% is saltwater that exists in oceans, bays, seas, and saline aquifers and is not able to be used [8,9] (Figure 1).

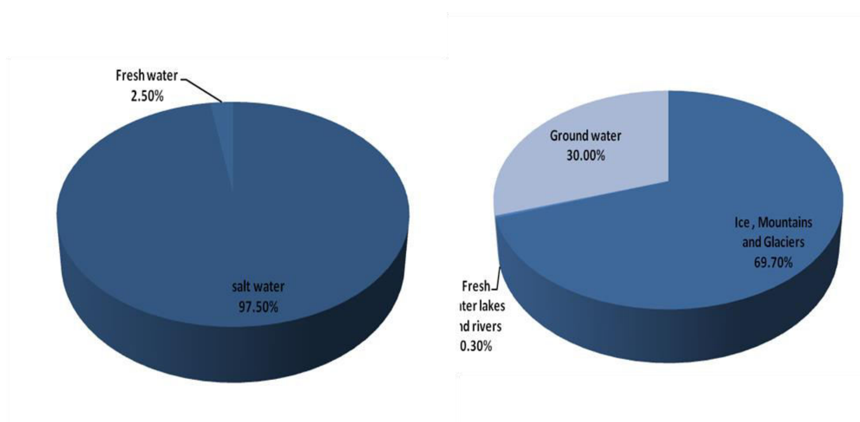


Figure 1 Breakdown of water resources & Fresh water resources

## 1.2 Water resources, utilization and crisis in India

India has about 4% of world's freshwater resources and it ranks among the top ten water rich countries. Despite this, according to the report by Intergovernmental Panel on Climate Change, India is designated a 'water stressed region' with current utilizable freshwater standing at 1122 cubic meter (cu m) per year and per capita compared to international limiting standards of 1700 cu m. In future, at the current rate it is expected that India with high demands will be termed a 'water scarce region' as utilizable freshwater falls below the international standard of 1000 cu m per year and per capita.

Drinking water is not the only end use of freshwater. Freshwater is also needed for various other sectors, including agriculture and industry. Approximately 70% of freshwater withdrawals are for irrigation purposes and about 22% are allocated for industrial uses, including process water and heating and cooling water. The fresh water withdrawal for domestic purpose is utilized for drinking, cooking, washing, taking showers, flushing toilets and others.

In India, rivers are the primary sources of fresh water for urban and rural areas, raw water for industries, and irrigation. In the course of utilization, water often gets contaminated with pesticides and industrial waste, leading to further energy consumption for water reuse. The reasons are over extraction, Deforestation, water pollution, drought.

## 2. Motivation and Objectives

The present farmer's issues and the continuing dreadful deaths of farmers all over India have raised concern to find alternate solutions to use water in a rationale manner. In addition to that, undeniably there is a huge need to produce potable water from the 70% of salt water that is available on the earth's surface. Desperation to find a solution for water crisis and a "thirst" to take a step forward in addressing the problems being faced by farmers and in saving agriculture in India has been the biggest motivation to take up this project. A strong quest to transform the inedible sea water useable is also an objective of this project. The main objective of this work is to design and develop a portable desalination system using membranes.

## 3. Proposed Theme

### 3.1 Water Types based on salinity

Salinity refers to the amount of total dissolved solids (TDS) in the water and there are three general groups in which water source can be classified based on its level of salinity and is given in Table 1. If the level of salts in the soil water is too high, the concentration of water in the soil will be low and water may flow from the plant roots back into the soil. This results in dehydration of the plant, causing yield decline or even death of the plant.

Table 1 Classification of Water Based on Salinity

| Water Class | Salt Concentration (ppm) | Types of Water |
|---|---|---|
| Non Saline | < 500 | Drinking and Irrigation Water |
| Slightly Saline | 500 – 1500 | Irrigation Water |
| Moderately Saline | 1500 - 7000 | Primary drainage water and ground water |
| Highly Saline | 7000 – 15000 | Secondary drainage water and ground water |
| Very Highly Saline | 15000 – 35000 | Very Saline ground water |
| Brine | > 45000 | Sea water |

The composition of sea water is given in Table 2.

Table 2 Composition of sea water

| Compositions | Amount in % | Amount in grams |
|---|---|---|
| Sodium | 30.69 | 10.79 |
| Chloride | 55 | 19.25 |
| Sulphate | 7.7 | 2.7 |
| Magnesium | 3.7 | 1.3 |
| Calcium | 1.2 | 0.42 |
| Potassium | 1.1 | 0.39 |
| Minor Constituents | 0.7 | 0.25 |

## 3.2 pH

pH is an abbreviation for Power of Hydrogen or Potential of Hydrogen. pH is a measure of the hydrogen ion concentration of a solution. Solutions with a high concentration of hydrogen ions have a low pH and solutions with low concentrations of H+ ions have a high pH. The equation for pH is given by the following expression $pH = -\log_{10}[H^+]$

The pH value of fresh water lies between 6 to 7 and sea water lies between 7.6 – 9. As discussed in the previous section on the effect of salinity on plant growth, the higher amount TDS causes the water to be more alkaline. Nutrient availability to plants is best when the pH of your water source is between 5.5 and 6.5. Though higher pH values generally don't harm plant growth, availability of micronutrients may decline, along with increased potential for problems related to salinity. The generally accepted pH for irrigation water is between 5.5 and 7.5. Alkaline water may contain high concentrations of bicarbonate (generally in water of pH 8 and above) and carbonates (generally pH 9 and above). This can cause calcium and magnesium to precipitate and this can affect plant growth. Some trace elements, like copper and zinc, will also be less available to the plant in this situation. A pH greater than 7.5 is likely to reduce the effectiveness of chlorine disinfection. Acidic water can also have a detrimental effect on plant growth, particularly causing nutritional problems. A pH less than 6 indicates corrosiveness, which can lead to damage to metal pipes, tanks and fittings.

## 3.3 Desalination – A potential solution

Desalination refers to the process by which pure water is recovered from saline water using different forms of energy. Saline water is classified as either brackish water or seawater depending on the salinity and water source. Desalination produces two streams - freshwater and a more concentrated stream (brine). The two main commercial desalination technologies are those based on thermal and membrane processes.

### *3.3.1 Thermal Desalination*

Thermal processes, except freezing, mimic the natural process of producing rain. Saline water is heated, producing water vapour that in turn condenses to form distilled water. These processes include multistage flash (MSF), multiple-effect distillation (MED), vapour compression (VC) and low temperature evaporation (LTE). In all these processes, condensing steam is used to supply the latent heat needed to vapourize the water[3]. Owing to their high-energy requirements, thermal processes are normally used for seawater desalination. Thermal processes are capable of producing high purity water and suited for industrial process applications. Thermal processes account for 55% of the total production and their unit capacities are higher compared to membrane processes [4]

ISSN (Online): 2456-5717
International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)
Vol.3 Issue.8 August 2017

*3.3.2 Membrane based Desalination – RO*

RO is used for both brackish water and seawater desalination as well as for waste water treatment and water recovery/reuse. A typical RO desalting plant consists of three sections, namely pretreatment section, membrane section and post treatment section. Conventional pretreatment section typically consists of particulate filtration, micron filtration and chemicals additions. Membrane section consists of membrane elements housed in pressure vessels through which pretreated saline water is passed under pressure in excess of its osmotic pressure with the help of a high pressure pump coupled with energy recovery device.

## 3.4 Present work

A desalination system using membrane is proposed to desalinate brackish water. Though the initial proposal is for brackish water, attempts will also be made to extend this work by changing the membrane configuration and membrane materials. Membrane based desalination as mentioned above works on Reverse Osmosis.

*Osmosis*

Osmosis is a naturally occurring phenomenon and one of the most important processes in nature. It is a process where a weaker saline solution will tend to migrate to a strong saline solution. (Figure 2) Examples of osmosis are when plant roots absorb water from the soil and our kidneys absorb water from our blood. A solution that is less concentrated will have a natural tendency to migrate to a solution with a higher concentration [2].

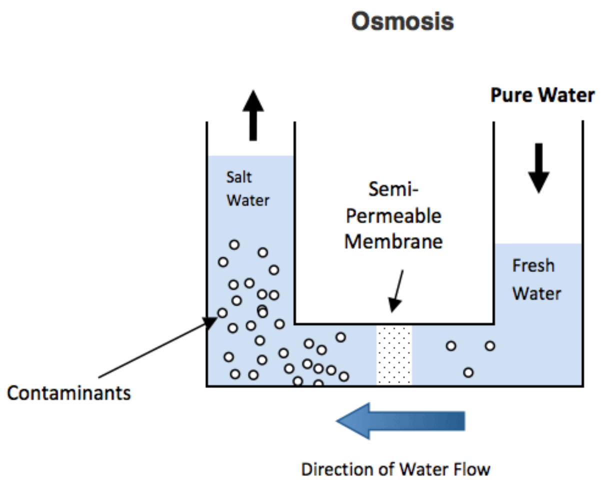


Figure 2 Schematic of Osmosis Process

*Reverse Osmosis*

Reverse Osmosis is the process of Osmosis in reverse. Whereas Osmosis occurs naturally without energy required, to reverse the process of osmosis an energy need to be applied. [2] (Figure 3). A reverse osmosis membrane is a semi---permeable membrane that allows the passage of water molecules but not the majority of dissolved salts, organics, bacteria and pathogens. However, a pressure need to be exerted to water to push it through the reverse osmosis membrane by applying pressure that is greater than the naturally occurring osmotic pressure in order to desalinate (demineralize or deionize) water in the process, allowing pure water through while holding back a majority of contaminants [6,7].

ISSN (Online): 2456-5717
International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)
Vol.3 Issue.8 August 2017

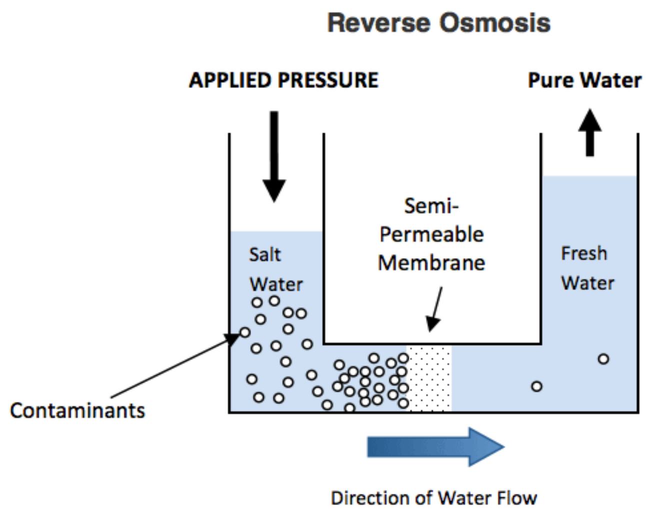


Figure 3 Schematic of Reverse Osmosis Process

Reverse osmosis works by using a high pressure pump to increase the pressure on the salt side of the RO and force the water across the semi-permeable RO membrane, leaving almost all (around 95% to 99%) of dissolved salts behind in the reject stream. The amount of pressure required depends on the salt concentration of the feed water. The more concentrated the feed water, the more pressure is required to overcome the osmotic pressure. In very simple terms, feed water is pumped into a Reverse Osmosis (RO) system and you end up with two types of water coming out of the RO system: good water and bad water. The good water that comes out of an RO system has the majority of contaminants removed and is called permeate. Another term for permeate water is product water – they mean the same thing [6,7]

# 4. Design of the present desalination system

A membrane based desalination system has been proposed. The components and design of the system is discussed in this chapter.

## 4.1 Components

*Membrane*

A membrane is a selective barrier, it allows some things to pass through but stop others. Such things may be molecules, ions or other small particles. Biological membranes include cell membranes, nuclear membranes which cover a cell nucleus. Synthetic membranes are made by human for use in labs and industries. The influent of an artificial membrane is known as the permeate and the liquid containing the retained constituents is the concentrate [5].

The polyamide membranes consist of three layers:

- Polyester nonwoven fabric act as structural support (~100µm thick),
- Microporous interlayer support of polymer like polysulfone (~ 40-50 µm thick),
- Ultra-thin polyamide barrier layer on the top surface (~0.2-0.25µm thick).

*RO Booster pump*

A booster pump is used to convert electrical energy into hydraulic energy of the fluid. This is achieved by increasing the fluid pressure. It monitors the water pressure in the storage tank. It turns the pump off and on in response to storage tank pressure. It is used to prevent chatter. i.e., humming and vibrating noises. These pumps are commonly used in one or more flow control components. The booster pump has a working pressure of 6-7 bar. It utilizes an adapter which has different sets of configuration respective to the first stage and second stage membrane. The pump is configured according to the pressure which is greater than that of the osmotic pressure of each membranes.

*RO Filter*

RO filter is used to remove large suspended particles, fungus, algae, dust, impurities. These pre-filters are used to protect the RO membranes by removing sand slit, dirt and other sediments that could clog the system additionally the carbon filters may be used to remove chlorine which can damage RO membranes. The post filter is usually a carbon filter. Nowadays the recent membranes has combined post and pre-filter along with membranes known as ultra filtration membrane. The nano-filtration system is often used as an alternative to a classical water conditioning process. Multi stage filter is used to prevent fouling of a RO system.

## 4.2 Factors affecting membrane performance

(i) Temperature

RO permeate flow is strongly dependent on the operating temperature. The higher the temperature of the water, the higher the permeate flow. This occurs because water with a higher temperature has a lower viscosity and higher diffusion rate, which makes it easier for the water to permeate the RO membrane. For elements from Dow Water and Process Solutions, a general rule of thumb is that for every 1° C increase in temperature, the permeate flow increases 3%. Most membrane manufacturers provide temperature correction tables that allow one to make more accurate conversions.

(ii) Pressure

The Net Driving Pressure (NDP) is the sum of all of the forces acting on the membrane. These may include pump or feed pressure; back pressure from line restrictions and storage tank; and osmotic pressure of the feed and permeate water.

NDP = Feed pressure – feed osmotic pressure + permeate osmotic pressure

NDP is the effective pressure the membrane feels during operation. If ones doubles the net driving pressure to an RO unit, it will double the permeate flow.

(iii) Salt Concentration

The rate of salt passage across a membrane is determined by the salt concentration gradient, which is the difference between the TDS on the feed side of the membrane versus the permeate side of the membrane. The rate of salt passage is independent of pressure. However, because more permeate water is produced as the feed pressure increases, the permeate salt concentration goes down. This occurs because the same amount of salt diffuses through the membrane, but it is dissolved in more permeate water.

Higher salt concentrations (higher TDS) will decrease the permeate flow because the osmotic pressure increases, decreasing the NDP. However, higher feed salt concentration also will increase the amount of salt passage through the membrane. Therefore, the overall water quality goes down for two reasons: first, less water is produced; and second, more salt diffuses through and is dissolved in less water.

## 4.3 Construction and Working

The proposed system consists of two stages of membranes in series. Each pump is fitted with its own casing, adapter and a pump. The feed water is placed above the set up with sufficient datum head. There is a filter to filter suspended particles, dust, and large impurities to prevent the membranes from clogging. The schematic is shown in Figure 4 and the 3D view is given in Figure 5.

The first stage membrane acquires the inlet from the pump and the process takes place. The pressure of the water is greater than that of the osmotic pressure, and hence the water starts to flow from high concentrated side to lower concentration side. The concentrate water is provided with a flow restriction which in turn yields slight more permeate water. The permeate water obtained is arable and can be used for agricultural purposes. The permeate water from the first stage membrane is collected in a separate storage tank. The obtained permeate water is then subjected to second stage purification for even more reduction in the salt content and to get potable water which can be used for human needs. Second Stage Membrane.

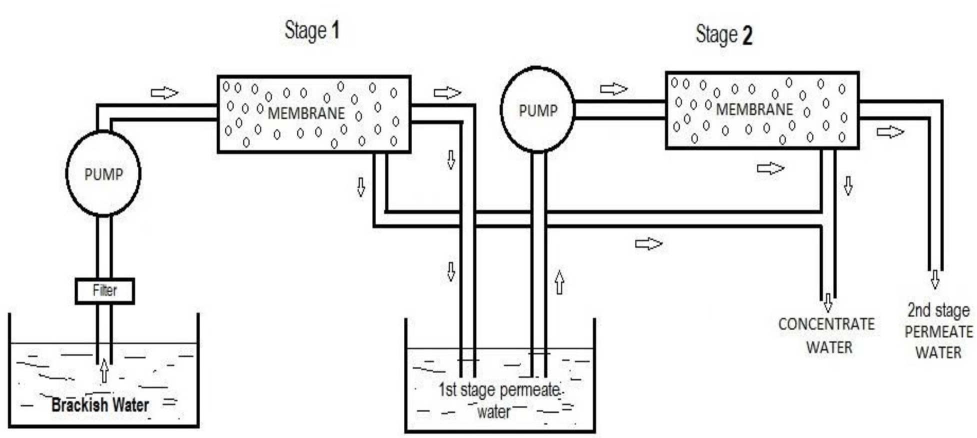


Figure 4 Schematic of the proposed system

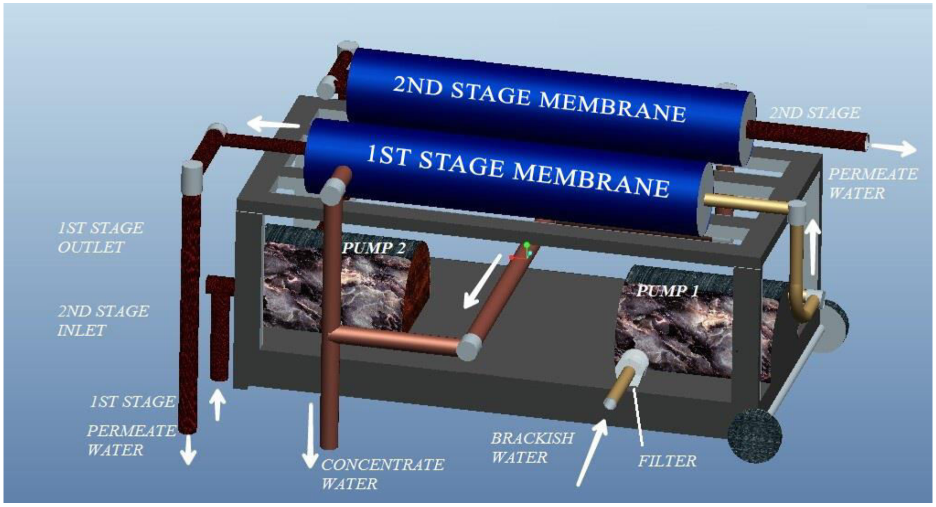


Figure 5 3D Model of the proposed system

The second stage purification is same as that of the first stage. The second stage pump sucks the water from the tank and passes it through the second stage membrane. The second stage membrane filters even more of the salt which were not removed on first stage.

## 4.4 Design Calculations

Productivity (desalinated water) depends on (1)Pump pressure (2) Osmotic pressure of the membrane($P_{pump}$ >$P_{osmatic}$) (3) Membrane solubility, permeability and porosity (4) Higher datum head provides more potential energy.

(i) Osmotic Pressure ($P_{osm}$)

It is the minimum pressure which needs to be applied to a solution to prevent the inward flow of water across a semi permeable membrane. It is also defined as the measure of the tendency of a solution to take in water by Osmosis. $\pi = iMRT$

The Van 't Hoff factor is the ratio between the actual concentration of particles produced when the substance is dissolved and the concentration of a substance as calculated from its mass. It is the relation between the ideal values of a solution's properties to the observed properties.

i= 1.8 for NaCl ; Molar mass for NaCl =58.443(g/mol); NaCl of sea water =38.855(g/l)

Molar concentration =38.855/58.443 = 0.6648(mol/l)

Osmotic pressure$\pi$ =1.8 x 0.6648 x 0.08206 x 298 = 29.264 atm ≈ 29 bar

$P_{osm}$ = *11 psi (0.76 bar) => for 1000 ppm*

(ii) Rate of water passage through a semipermeable membrane ($Q_w$)

$$Q_w = (\Delta P - \Delta P_{osm}) * K_w * S/d \quad (m^3/s)$$

(iii) Rate of salt flow, through membrane ($Q_s$)

$$Q_s = \Delta C * k_s * S/d \quad (m^3/s)$$

(iv) Salinity of the permeate($C_p$)

$$C_p = Q_s/Q_w$$

(v) Salt passage (SP)

$$SP = (C_p/C_{fm}) \times 100 \%$$

(vi) Salt Rejection (SR)

$$SR = 100 - SP (\%)$$

(vii) Permeate recovery rate (R)

$$R = (Q_p/Q_f) * 100 \%$$

(vii) Permeate flow (Q)

$$Q = A * S * (\Delta P - \Delta \pi)$$

(viii) Salt Flux ($N_A$)

$$N_A = B * (C_{fc} - C_p) \quad (ppm\ m^2/s)$$

## 5. Conclusion and Future study

A thorough study to gain knowledge about water crisis, scarcity, causes, effects and potential solutions for water crisis were carried out. Various desalination techniques were learned through available literature and web sources. A portable desalination system using has been designed and developed. A few trial runs with water having different salinity level were carried out to check for the permeate flux. The results of the trial runs have shown a significant reduction in the TDS level. Though, the TDS level attained with this portable desalination system is not good for drinking purpose, it attained the level that is permissible for irrigation purpose and for process plant.

The present project can be extended in the future to carry out a sensitivity study with different polymer membrane material to understand the effect of porosity on the output. Also, a thorough analysis for desalination technique can be carried out using appropriate software. An attempt can be made to use different pumps varying the membrane configuration.

## REFERENCES

[1] M.A. Shannon, P.W. Bohn, M. Elimelech, J.G. Georgiadis, B.J. Marinas, A.M. Mayes (2008) Science and technology for water purification in the coming decades Nature, Volume 452, pp. 301–310, ISSN 0028-0836.

[2] Zaher Al Suleimani, V.Rajendran Nair (2000) Desalination by solar-powered reverse osmosis in a remote area of the Sultanate of Oman, Applied Energy Volume 65(1–4), pp. 367-380, ISSN 03062619.

[3] Murray Thomson, David Infield (2005) Laboratory demonstration of a photovoltaic-powered seawater reverse-osmosis system without batteries, Desalination, Volume 183(1–3), pp. 105-111, ISSN 0011-9164.

[4] Agustín M. Delgado-Torres, Lourdes García-Rodríguez, Vicente J. Romero-Ternero, (2007) Preliminary design of a solar thermal-powered seawater reverse osmosis system, Desalination, Volume 216 (1–3), pp. 292-305, ISSN 0011-9164.

[5] http://www.wwdmag.com/membrane-technology/evolution-ro-desalination

[6]https://www.freedrinkingwater.com/reverse-osmosis/knowledge-base/history-of-reverse-osmosis-filtration.htm

[7]http://www.waterworld.com/articles/wwi/print/volume-23/issue-4/features/the-reverse-osmosis-membrane-evolution.html

[8] http://www.eschooltoday.com/global-water-scarcity/effects-of-water-shortage.html

[9]http://www.conserve-energy-future.com/causes-effects-solutions-of-water-scarcity.php