Desalination 268 (2011) 238–248

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Socio-economic & technical assessment of photovoltaic powered membrane desalination processes for India

Tinu Abraham *, Amit Luthra

Department of Chemical Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India, Pin No.247667

ARTICLE INFO

Article history:
Received 14 June 2010
Received in revised form 12 October 2010
Accepted 13 October 2010
Available online 12 November 2010

Keywords:
Reverse osmosis
Electrodialysis
Photovoltaic cells
Seawater
Brackish ground water

ABSTRACT

Fresh water crisis is evident in many parts of India, varying in scale and intensity at different times of the year. About seven states are underlain by brackish ground water affecting 42 million people. 25% population of India resides along the coast having easy access to seawater. Hence, these saline water resources can be exploited to meet their water requirements. Desalination technologies create new sources of fresh water from seawater or brackish water, but they do require energy. This paper addresses the socio-economic and technical feasibility of powering membrane desalination technologies with photovoltaic (PV) systems in regions which have mixed advantage of high solar potential and disadvantage of presence of saline water. A database of Indian population dependence on saline water, its regional solar potential and present state of desalination have been compiled. Technical aspects of reverse osmosis (RO) and electrodialysis (ED) membrane desalination processes powered by PV are addressed and desalinated water cost, obtained through PV-RO and PV-ED processes, are compared with diesel powered RO and ED processes respectively for a plant capacity of 50 m^3/day over a 20 year working life of the plant. The technology will augment fresh water requirements of India and contribute to its sustainable development.

1. Introduction

The need for fresh water is at the top of the international agenda of critical problems, at least as firmly as climate change. India as a country has 16% of the world's population and 4% of its fresh water resources [1]. Despite an estimated total of Rs. 1105 billion spent on providing safe drinking water since the First Five Year Plan was launched in 1951, lack of safe and secure drinking water continues to be a major hurdle and a national economic burden [1]. As a consequence of the growing scarcity of freshwater, the implementation of desalination plants is increasing on a large scale [2]. According to a report by Frost and Sullivan [3] with growing demand and more focus on desalination by the Indian states, the desalination capacity of India is expected to reach 1,449,942 m^3/day by 2015 from 291,820 m^3/day in 2008. The well established seawater and brackish ground water desalination technologies, no doubt, can be employed to produce large amounts of good quality water at a cost that as of today appears to be reasonably quite competitive, but the main drawback of all such processes still remaining to be resolved is the high energy consumption. The energy for the desalination plants is generally supplied in the form of either steam or electricity. Conventional fossil fuel-powered plants have normally been utilized as the primary sources but their intensive energy use raises increasing environmental concerns, specifically in relation to Green House Gas (GHG) emissions [4].

The process of desalination can become sustainable if dependence on fossil fuels as its energy source is eliminated. [2], [5] & [6] provide detailed analysis of desalination powered by renewable energy sources, addressing their techno-economical viability where as [7–12], focus particularly on desalination powered by solar energy. India being a tropical country is blessed with sunny days for 250 to 300 days a year with solar radiations received in the range of 4 to 7 $kWh/m^2/day$ [13]. Solar desalination systems are approaching technical and cost viability for producing fresh-water, a commodity of equal importance to energy in many arid and coastal regions worldwide [14]. Solar photovoltaics represent an ideal, clean alternative to fossil fuels, especially for remote communities such as grid-limited villages or isolated islands. Their applications for water production in remote areas are the first to be nearing cost-competitiveness due to decreasing photovoltaic (PV) prices and increasing fossil fuel prices over the last five years [15].

This paper analyses conditions of water salinity and solar potential in India and estimates the population dependent on saline water resources. It provides information on the current status of desalination efforts in India and makes an attempt to explain the photovoltaic powered membrane desalination process, in its technical perspective, and also analyses its financial, economic and social benefits in the Indian context. This paper concludes that there is immense potential

* Corresponding author. Tel.: +91 9760197699.
E-mail addresses: tinu.abraham@gmail.com (T. Abraham), luthrameister@gmail.com (A. Luthra).

0011-9164/$ – see front matter
doi:10.1016/j.desal.2010.10.035

Table 1
Classification of source water, according to quantity of dissolved solids. [17].

Water source	Total dissolved solids (ppm)
Potable water	<1000
Mildly brackish waters	1000 to 5000
Moderately brackish waters	5000 to 15,000
Heavily brackish waters	15,000 to 35,000
Average sea water	35,000

for photovoltaic powered membrane desalination process in providing drinking water for a major section of Indian population.

2. Indian perspective – water salinity, solar potential and present state of desalination

2.1. Water salinity

2.1.1. Saline water standards

Salt content in water is indicated by total dissolved solids (TDS) which is used to describe the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium, and potassium as cations and carbonate, hydrogen carbonate, chloride, sulphate, and nitrate as anions [16]. Salinity in water can occur to varying degrees and are classified into the following categories in Table 1.

According to World Health Organisation (WHO) standards [16] water containing TDS concentrations below 1000 mg/l is usually acceptable to consumers, although acceptability may vary according to circumstances. Earlier WHO had the highest desirable TDS guideline of 500 mg/l and the maximally permissible TDS guideline of 1500 mg/l. The presence of dissolved solids in water may affect its taste. Therefore the palatability of drinking water has been rated by panels of tasters based on TDS level in Table 2.

Fresh water can be obtained from two classified categories of saline water through desalination which are seawater and brackish ground water. On an average, seawater in the world's oceans has a salinity of about 35,000 ppm and because of its abundance desalination of seawater if done on a major scale in a feasible manner could answer most of the water problems in the world. Brackish ground water which is naturally available in many regions is contaminated with dissolved salts to varying degree although the TDS content is always less than in seawater. Brackish ground water is further divided into two subcategories based on their location and cause of salinity:

- Inland ground water salinity – Inland salinity in ground water is prevalent mainly in the arid and semi arid regions and is caused due to geogenic sources. Inland salinity is also caused by excess surface water irrigation in relation to ground water levels. The gradual rise of ground water levels with time has resulted in water logging and heavy evaporation in semi arid regions lead to salinity problem in command areas [18]. The ground water has mild to moderate brackishness in this case.
- Coastal ground water salinity – Problems of coastal salinity in ground water is caused by excessive exploitation of ground water. Ground water in coastal areas occurs under unconfined to confined conditions in a wide range of unconsolidated and consolidated formations. Normally, saline water bodies owe their origin to entrapped sea water (connate water), sea water ingress, leachates from navigation canals constructed along the coast, leachates from salt pans etc. In general, the following situations are encountered in coastal areas, saline water overlying fresh water aquifer, fresh water overlying saline water or alternating sequence of fresh water and saline water aquifers [18]. In this case ground water has moderate to heavy brackishness.

Table 2
Drinking water palatability rating for different TDS. [16].

Total dissolved solids (ppm)	Water palatability
<300	Excellent
300 to 600	Good
600 to 900	Fair
900 to 1200	Poor
>1200	Unacceptable

Table 3
Length of coastline of Indian states [19].

States	Total length of coastline (km)
Gujarat	1214.7
Maharashtra	652.6
Goa	151.0
Karnataka	280.0
Kerala	569.7
Tamil Nadu	906.9
Andhra Pradesh	973.7
Orissa	476.4
West Bengal	157.5

2.1.2. Population dependence on saline water in India

A geographic analysis of the presence of seawater and brackish ground water in India and the population dependence on it is discussed in detail below, which justifies the importance of salt water desalination technology for meeting the fresh water requirements in India.

- Seawater resources – India's coastline is 7517 km long and out of this 5423 km is in peninsular India with the Arabian Sea in south west, Indian Ocean in the south and the Bay of Bengal in south east, and 2094 km in Andaman, Nicobar, and Lakshadweep Islands. According to the Indian naval hydro graphic charts, the mainland coast consists of 43% sandy beaches, 11% rocky coast including cliffs, and 46% mudflats or marshy coast [19]. About 25% of the country's population lives in the coastal zone. The coastal zone is the most industrialized area in the country. Fourteen major, forty four medium and fifty five minor rivers/streams discharge into the sea through the entire length of the coast. The eastern coast is much wider than its western counterpart and the Arabian Sea water is more saline compared to the Bay of Bengal. This is due to the high evaporation combined with low river discharge along the western coast [18]. The length of the coastline of Indian States and Union Territories are given in Table 3 and 4.

  Since 9 States and 4 union territories are surrounded by seawater along one or more sides, it can play a major role in augmenting the fresh water requirements of the country if technically and economically efficient desalination technology is implemented for obtaining pure water from sea water in these regions. Three major metropolitan cities and few other smaller cities of India are located on the coast. Based on the 2001 census, 20.9 million people live in the three coastal metropolitan cities of India as per Table 5. These cities will benefit greatly from seawater desalination to meet their water requirements.

Table 4
Length of coastline of Indian union territories [19].

Union territories	Total length of coastline (km)
Daman and Diu	9.5
Pondicherry	30.6
Lakshadweep	132.0
Andaman Nicobar Island	1962.0