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Review

Desalination and sustainability – An appraisal and current perspective

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ABSTRACT

Desalination technologies have evolved and advanced rapidly along with increasing water demands around the world since 1950s. Many reviews have focused on the techno-economic and environmental and ecological issues of the desalination technologies and emphasized the feasibility of desalination industry as an alternative to meet the water demands in many water scarce regions. Despite these efforts, many perceptions about desalination processes hinder their applications for potential water supplies. This article has two specific aims: 1) provide an overview of the desalination trends around the world and discuss the sustainability components of desalination processes in comparison with other water supply alternatives; and 2) discuss case studies for desalination, and drivers and factors that influence sustainable desalination and other alternative water sources for desalination to increase our current understanding on the sensitive and futuristic issues of water supply and resource management options for drought facing regions. Although some of the facts and recent developments discussed here show that desalination can be affordable and potentially sustainable, contributions that meaningfully address socio-economic and ecological and environmental issues of desalination processes are urgently required in this critical era of severe water stress for the present context and the future development of desalination technologies.

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1. Introduction ("oil–water" relation)

Water, in general, has evolved as a social and economic commodity in many parts of the world (Rogers et al., 1998, 2005) and it has gained the socioeconomic status of energy sources such as "oil". Water, the primary basis for continued sustenance of all life, cannot be exactly matched in its quality with any other element present on the Earth. While water and oil have some common features that are critical to human civilization, a few special characteristics of water as a commodity make it even more precious for our sustainable development: 1) to handle the shortfall of oil resources, there are many alternative energy sources that can replace and fill the gap between supply and demand, however, the same is impossible for water, water cannot be replaced with other resources, 2) oil reserves are finite and non-renewable (at least in human life-cycle scale) whereas water resources are renewable and follow certain cyclic process in which it can neither be destroyed nor created and its presence varies along the regions of the world, and 3) oil shortage can be managed in many parts of the world by transporting to the place of need due to its high monetary value for economic benefit, which may not be an attractive option for water transportation and therefore water issues are local in nature and are dealt with local water and energy sources (Savenije, 2002).

The importance and value of water has been highly pronounced in recent years due to ever-growing global population, rapid industrialization and urbanization (Gude, 2015a). Over the past century, the worldwide population has tripled while the water use or water withdrawals increased more than six-fold which suggests increasing water consumption mostly driven by improved living standards and industrialization all over the world. Many regions realize the inadequacy of existing freshwater sources to meet ever growing water demands. In some cases, sufficient surface and ground water sources to even meet current demands for water supplies are not available. Therefore, the need for utilizing saline waters from the oceans and other brackish water sources and the processes that convert saltwater into freshwater have become rational and logical approaches in these regions (Gude and Nirmalakhandan, 2010). Desalination technologies have been developed over the past 50 years (Semiat, 2000). Desalination technologies initially were both cost- and energy- prohibitive. However, the impetus to install desalination plants in many coastal and metropolitan cities for providing freshwater needs stems from: i) the desperate necessity to support the water demands; ii) dramatic improvements in energy consumption by desalination technologies; and iii) reduced investment and processing costs for desalination processes.

The purpose of this paper is two fold. First, it provides an overview of the desalination water industry around the world. Then it discusses the sustainability components of desalination from the perspective of existing alternatives and current scenarios, followed by an update on the recent approaches to embrace desalination technologies in water scarce countries and the drivers and factors that influence desalination. This article attempts to provide a new perspective on the desalination systems with reference to the existing water supply options. Environmental (including energy and ecological), economic and social aspects of desalination systems have been discussed. A few case studies have been provided to elaborate the role of desalination industry in this ever water-challenging and climate changing world.

2. Worldwide desalination

While desalination of saline waters has now been accepted as a promising alternative for freshwater source, the energy demands by the existing desalination technologies for water production continue to pose challenges in their applications. In general, desalination technologies require large quantities of high grade thermal energy and/or prime quality electricity for freshwater separation which results in release of waste heat, greenhouse gas emissions and concentrates (brine) into the environment. The worldwide desalination capacity is increasing at a steadfast pace consuming equivalent amounts of fossil fuel sources with concomitant greenhouse gas emissions. In 2007, the total installed desalination capacity around the world was 47.6 million m^3/d, in 2008 it was 58 million m^3/d, and in 2011 it reached to 65.2 million m^3/d and then to 74.8 million m^3/d in 2012 which is projected to increase to 97.5 million m^3/d by the year 2015 (Bennett, 2013). While global population increased in a linear trend over the past five decades, water production by desalination technologies has taken an exponential path. The production of 1000 tons (m^3) per day of freshwater by desalination technologies requires 10,000 tons (toe) of oil per year and results in environmental degradation through greenhouse gas emissions and brine discharges (Kalogirou, 2005; Gude, 2015a). This situation can be termed as "*oil for water*" or "*water for non-renewable energy*" sources or water being named as "*the new oil*" indicating a pressing demand on the exhaustible fossil fuel reserves around the world. This situation creates social and economic impacts such as dependence on the oil rich foreign countries and economic instability for both oil-rich and water-rich countries. Since oil rich countries will experience high demands for oil supplies and similarly water rich countries for water supplies.

2.1. Desalination technologies and renewable energy sources

Well established desalination technologies can be classified as thermal (phase change) and membrane (non-phase change) processes. Thermal processes consist of an evaporator and condenser to vaporize freshwater from the feedwater (seawater or brackish water) under suitable operating temperatures and pressures and condense the same to produce freshwater while membrane processes use a physical barrier such as a membrane to separate the dissolved salts from the feed water by mechanical or chemical/electrical means using a membrane separator between the feed (seawater or brackish water) and product (potable water) (Gude et al., 2010).

Thermal desalination technologies include solar distillation (SD) such as solar stills and active and passive solar desalination