Renewable and Sustainable Energy Reviews 43 (2015) 196–206

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Low-cost low-enthalpy geothermal heat for freshwater production: Innovative applications using thermal desalination processes

Jochen Bundschuh [a,b,*], Noreddine Ghaffour [c], Hacene Mahmoudi [d], Mattheus Goosen [e], Shahbaz Mushtaq [a], Jan Hoinkis [f]

[a] University of Southern Queensland, Toowoomba, Qld, Australia
[b] Royal Institute of Technology, Stockholm, Sweden
[c] WDRC, King Abdullah University of Science and Technology (KAUST), Saudi Arabia
[d] University Hassiba Ben Bouali of Chlef, Algeria
[e] Alfaisal University, Saudi Arabia
[f] University of Applied Sciences, Karlsruhe, Germany

ARTICLE INFO

Article history:
Received 20 December 2013
Received in revised form
16 June 2014
Accepted 31 October 2014

Keywords:
Freshwater production
Geothermal water desalination/treatment
Adapting conventional technologies
Geothermal powered thermal desalination
Membrane distillation

ABSTRACT

The study is dedicated to exploring different types of low-cost low-enthalpy geothermal and their potential integration with conventional thermal-based water desalination and treatment technologies to deliver energy efficient, environmentally friendly solutions for water desalination and treatment, addressing global water crises. Our in-depth investigation through reviews of various low-enthalpy geothermal and conventional thermal-based technologies suggest that the geothermal option is superior to the solar option if low-cost geothermal heat is available because it provides a constant heat source in contrast to solar. Importantly, the stable heat source further allows up-scaling (> 1000 m^3/day), which is not currently possible with solar. Solar-geothermal hybrid constellations may also be suitable in areas where both sources are available. The review also discovers that the innovative Membrane distillation (MD) process is very promising as it can be used for many different water compositions, salinity and temperature ranges. Either the geothermal water itself can be desalinated/treated or the geothermal heat can be used to heat feed water from other sources using heat exchangers. However, there are only few economic analyses for large-scale MD units and these are based on theoretical models using often uncertain assumptions resulting in a large variety of results.

Contents

1. Introduction

Future freshwater and energy supply and global climate protection are intrinsically linked issues and must therefore be managed in integrated form. Since energy demand is forecasted

* Corresponding author at: Faculty of Health, Engineering and Science, University of Southern Queensland, Toowoomba, Qld 4350, Australia. Tel.: +61 746312694; fax: +61 746312526.
E-mail addresses: jochen.bundschuh@usq.edu.au, jochenbundschuh@yahoo.com (J. Bundschuh).

http://dx.doi.org/10.1016/j.rser.2014.10.102
1364-0321/

to double in the 2008–2035 period [1] and because the annual global freshwater withdrawal is expected to grow by about 10–12% per decade, corresponding to an increase of 38% from 1995 to 2025 [2], the securing of energy and water supply is the key challenge facing modern society. Increasing stress on the naturally limited freshwater resources [3] require massive production of freshwater from alternative sources, for example from seawater. Over 70% of the world population is living within a distance of less than 70 km from the seashore [4] or 80% within 100 km [5], suggesting desalination of seawater is a feasible option for large population groups. Other sources for freshwater production are brackish/saline groundwater, waters containing toxic elements of natural or anthropogenic origin, and municipal, industrial, and agricultural residual waters. If these options are not developed to cover the increasing water demand, there will be 9.2 billion people affected by water stress in the year 2050 as determined by the United Nations [3]. Such increased freshwater production, either by thermal-based or membrane-based technologies, demands much energy, and relates to a proportional increase of greenhouse gas emissions if energy is provided from fossil fuel resources.

In consequence, governments around the world are looking into cutting-edge energy-efficient, low-emission water desalination/treatment techniques. In particular, in the last two decades, zero-emission energy sources, especially wind and solar energy, have been developed to be used for seawater desalination (see e.g. overviews by [6–15]). In most applications, solar and wind energy are used for electricity generation and powering reverse osmosis (RO) units or solar energy is directly used for thermal-based desalination with conventional technologies. Solar stills are used for small-scale ($<10\ m^3$/day). Multi-effect distillation (MED) and multi-stage flashing (MSF) are applied for larger units. Wind and solar photovoltaic powered RO units range from small scale applications for seawater desalination in islands of the Canarias Islands and the Mediterranean region and off-grid inland areas of northern Africa to large scale seawater desalination plants as those of Perth (140,000 m^3/day) [14] and Sydney (250,000 m^3/day). Small ($<10\ m^3$/day) to middle size (lower range with 10–100 m^3/day) solar thermal desalination units were installed in the Mediterranean and the Middle East [16]. Most installed units deal with the desalination of seawater or brackish water and only very few on groundwater, contaminated water or wastewater [14]. Then there is an array of emerging technologies that are at different stages of research and development. These comprise forward osmosis (FO), membrane distillation (MD), adsorption desalination (AD), capacitance deionization (CDI), freezing, and humidification and dehumidification (H-DH).

A key problem, which often prevents the economic viability and scaling-up the solar and wind powered units, is the temporal availability of wind and solar energy. Both wind and solar energy require more complex technologies and expensive energy/electricity storage systems. This is why a renewable energy source that provides a stable energy output would be highly beneficial. Geothermal energy fulfills that demand. However, geothermal energy so far has received little interest and support for being used for desalination or water treatment [17,18]. This is in particular true for low-enthalpy geothermal resources, which are often not hot enough to generate economically electricity but still enough warm to use the heat for thermal desalination of water or remove contaminants.

In this paper, we identify different types and of low-cost low-enthalpy (50–150 °C) geothermal heat sources and evaluate their potentials and their suitability for water desalination and treatment using conventional technologies for different scales and situations (e.g. stand-alone; off-grid and on-grid areas). We analyze the principal conventional technology options that have been developed for thermal desalination using waste heat from industrial processes, heat from fossil fuel combustion, and solar heat and evaluate their suitability to use them with geothermal heat. We do not deal with systems using electricity from geothermal resources for desalination and treatment.

2. Low-cost emerging sources of low enthalpy geothermal heat

In contrast to geothermal electricity generation, industrial direct geothermal heat applications did not receive much attention in the past. This is despite that in some cases they can provide heat as a financially affordable and stable energy source. Of particular interest are thereby low-enthalpy resources (50–150 °C). If temperatures are less than about 120–130 °C, these are not of economic interest for the electricity generators; at higher temperatures, the electricity sector may compete with direct heat users. Low-enthalpy resources are found at shallower depths, their spatial availability is much larger, and their energy potentials are greater compared to hydrothermal high-enthalpy resources (>150 °C) that are limited to active tectonic plate boundaries.

Starting in the 1970s with the oil crises, in the last four decades, worldwide, geothermal resources received much attention and geothermal reconnaissance studies have been performed in many countries. In the following years, in many cases, interest decreased as fossil fuel prices decreased. In addition, research was often stopped because the encountered reservoir temperatures were not high enough (<200 °C) to produce commercially electricity using the technologies available at that time, which has been the aim of the research. This existing information can be used today, to determine the geothermal heat potentials, and suitability for freshwater production. In addition, existing boreholes can be used to access the geothermal fluids.

For many countries, the use of low-enthalpy geothermal heat is not new. Many of them, 78 countries in the year 2010, have been using these resources for the past hundreds or thousands of years for bathing, and during the last few decades, for direct use, in particular for space heating, domestic heat pumps, snow melting, heating greenhouses, aquaculture, drying of fruits, bathing, etc. [19]. Global installed geothermal power for direct use amounted 48,493 MWt by the end of the year 2009, which is an increase of about 72% referred to the 2005 data; thermal energy use was 423,830 TJ/year (117,740 GWh/year) [19]. Now, the challenge is, to properly evaluate these resources for freshwater production and water treatment according to the freshwater needs of the respective region or country.

Low-enthalpy geothermal aquifers can be accessed in many places in depths of several hundred meters. However, there are several options where the cost for geothermal heat is particularly low (Fig. 1):

(i) Hot water from hydrocarbon fields: Worldwide, millions of oil and gas wells have been sunk, many drilled to deep zones where temperatures and pressures are high, often producing hot water together with hydrocarbons. Data compiled in 1999 indicate that over 210 million barrels (33.4 million m^3) water are coproduced each day and the world average is 3 barrels of water produced per barrel of oil [20]. In the USA, 10 barrels (1.6 m^3) of water are extracted for each barrel of oil [21]. The disposal cost of this water varies between 0.10 and 2.00 US$ per barrel [22]. Using a nominal value of 0.50 US$ per barrel and above production data, then 38.3 billion US$ would be the yearly cost for water disposal/management [22].
Hydrocarbon wells have been overlooked until recently as possible geothermal energy sources [23–28] despite the fact