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Energy storage for desalination processes powered by renewable energy and waste heat sources

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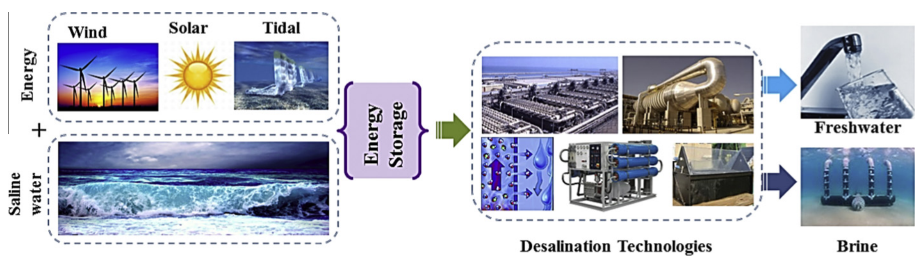
HIGHLIGHTS

- Energy storage options for various desalination processes were discussed in detail.
- Thermal/electrical energy storage options enhance desalination process performance.
- Energy storage integration provides reliable and continuous desalination operations.
- Chemical, compressed air, pumped hydrostatic energy storage need further research.
- Future research should focus on storage media, containers and thermal insulation.

GRAPHICAL ABSTRACT



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ABSTRACT

Desalination has become imperative as a drinking water source for many parts of the world. Due to the large quantities of thermal energy and high quality electricity requirements for water purification, the desalination industry depends on waste heat resources and renewable energy sources such as solar collectors, photovoltaic arrays, geothermal and wind and tidal energy sources. Considering the mismatch between the source supply and demand and intermittent nature of these energy resources, energy storage is a must for reliable and continuous operation of desalination facilities. Thermal energy storage (TES) requires a suitable medium for storage and circulation while the photovoltaic/wind generated electricity needs to be stored in batteries for later use. Desalination technologies that utilize thermal energy and thus require storage for uninterrupted process operation are multi-stage flash distillation (MSF), multi-effect evaporation (MED), low temperature desalination (LTD) and humidification–dehumidification (HD) and membrane distillation (MD). Energy accumulation, storage and supply are the key components of energy storage concept which improve process performance along with better resource economics, and minimum environmental impact. Similarly, the battery energy storage (BES) is essential to store electrical energy for electrodialysis (ED), reverse osmosis (RO) and mechanical vapor compression (MVC) technologies.

This research-review paper provides a critical review on current energy storage options for different desalination processes powered by various renewable energy and waste heat sources with focus on thermal energy storage and battery energy storage systems. Principles of energy storage (thermal and electrical energy) are discussed with details on the design, sizing, and economics for desalination process applications.

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Nomenclature

A	area (m^2)
AC	alternate current
A h	ampere hour
c_p	specific heat (kJ/kg K)
DC	direct current
I	solar insolation (kJ/h m^2)
m	mass of storage medium (kg)
MDOD	maximum depth of discharge
Q	energy or useful energy from solar collectors (kJ/h)
P	pressure (atm), power (kW)
PV	photovoltaic
S	entropy (kJ/K)
v	volume of the saline water or storage tank (m^3)
q	evaporation energy (kJ/h)
t	time (h, s)
T	temperature (K)
TCM	thermochemical reaction material
U	internal energy
V	wind speed (m/s)

Special characters

ρ	density (kg/m^3)
λ	latent heat (kJ/kg)
η	energy (first law) efficiency (%); panel efficiency
Δh	latent heat for PCM storage

Subscripts

1	TES temperature
2	evaporation chamber temperature
a	ambient
ac	alternate current
c	collector
Comb	combined
CR	chemical reaction
dc	direct current
DES	desalination
EC	evaporation chamber
h	hot stream
in	inlet, supply
e	evaporation, electrical
l, ls, L	latent, losses, load
out	energy supplied by TES
PCM	phase change material
s	solar, collectors, TES
sensible	sensible heat
STC	standard conditions
t	total
TES	thermal energy storage
th	thermal

1. Introduction

The importance and value of water has been highly pronounced recently due to exploding global population, rapid industrialization and urbanization [1,2]. It was reported that worldwide population estimates tripled while water use estimates increased more than sixfold over the 20th century, suggesting that the world not only has more water users but also a higher water consumption by these users mostly related to improved living standards all over the world [3]. It has been realized in many regions that existing freshwater resources do not have the capacity to meet the escalating demands and in some cases, there are not adequate surface and ground water sources. Therefore, the need for utilizing saline waters from the oceans and the processes to convert the salt water into freshwater have been recognized as logical approaches over past few decades [1]. Desalination technologies initially were both cost and energy prohibitive. The impetus to install desalination plants in many coastal and metropolitan cities for providing freshwater needs comes from: (1) dramatic improvements in energy consumption by many desalination technologies; and (2) reduced investment costs for desalination processes [4].

While desalination of saline waters has now been accepted as a potential alternative for freshwater supplies, the energy demands by the existing desalination technologies for water production continue to pose challenges in their applications (Fig. 1). In 2008, the worldwide installed desalination capacity was 58 million m^3/d, and in 2011 it was 65.2 million m^3/d which is projected to increase to 97.5 million m^3/d by the year 2015 [99–101]. It was estimated by Kalogirou [5] that the production of 1000 tons (m^3) per day of freshwater requires 10,000 tons (toe) of oil per year. The worldwide desalination capacity is increasing at a steadfast pace consuming equivalent amounts of fossil fuel sources and associated increase in greenhouse gas emissions. The desalination industry is projected to experience unprecedented growth concurrently with population explosion and increasing standards of living. Since the energy requirements whether thermal or electric, need to be supplied in large quantities, dependence of these technologies over finite, conventional fossil fuel sources is not a sustainable approach. Utilization of renewable energy sources such solar, wind, and geothermal sources appears to provide a sustainable alternative. Yet, the major concern with these natural and renewable energy sources is their intermittent nature and the variable intensity which limits their applications in many cases and locations. Costs associated with the renewable energy technologies is another major hurdle for successful implementation of these energy resources. Energy storage can be considered as an option to increase the performance of the renewable energy sources. Energy storage technologies help enhance utilization of these intermittent energy sources and may improve long term sustainability of the investment. Thermal desalination technologies may utilize storage units known as thermal energy storage (TES) to capture, store, and release to match the energy supply and demand trends. TES can be coupled with energy sources whether they are renewable or waste heat in nature. Photovoltaic collectors and wind turbines require batteries to store the energy to be supplied to the process for later use.

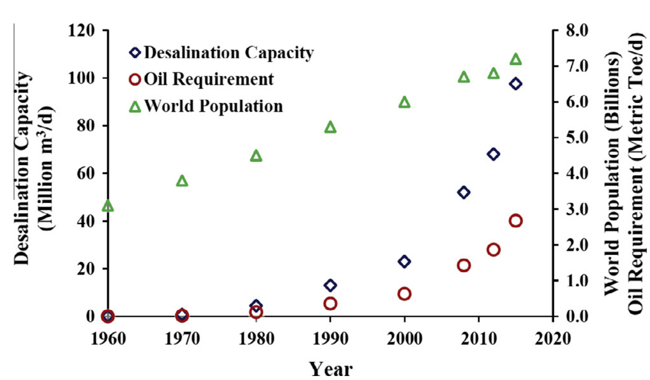

Fig. 1. Worldwide population and desalination capacity trends and the energy requirements for desalination in the form of oil.

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