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New opportunities in mass and energy consumption of the Multi-Stage Flash Distillation type of brackish water desalination process

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ABSTRACT

The scope of this article is to provide solutions for two famous bottlenecks against more popularity of Multi-Stage Flash Distillation application among the world; supply required heat specially in remote areas and high rate of feed water rejection. To overcome the first challenge, adequate combinations of technologies for the available 197 ton/h MSFD unit in a case study plant and Direct Steam Generation (DSG) as an alternative renewable energy source are considered. The retrofit study on such plants may lead to achieve solar steam. Steam is used as heat source in the brine heater of Multi-Stage Flash Distillation unit. So, as the result of this modification, 17.8 MW of fossil energy is replaced by solar energy. In the second place, returning of more than 50 percent of the treated water to the river with around 14 °C temperature rise, by using cooling tower system, is prevented. It is revealed that for each of three existing thermal desalination plants up to 53 percent of feed water, i.e.; 667 m^3/h and same amount of reject water can be conserved. Though, with this modification, the unit steam consumption has been increased up to 13 ton/h, about 50 percent of design value.

1. Introduction

Desalination systems are divided into two main types thermal and non-thermal. Thermal type desalination plants such as multi stage flash (MSF), vapor compression (VC), solar distillation and freeze desalination uses heat either direct heating for evaporation or heat removing to form water ice crystals. Other systems are classified as non-thermal system such as reverse osmosis (RO), capacitive deionization technology (CDT). Actually cost for each method depends mainly on type of physical process of salt removal (i.e. evaporation, filtration, freezing or electrostatic potential difference). The efficiency of each type depends on the total energy required to remove the salt particles which depends on some extent on the method of operation and also on the purity of the required water (Attia, 2012).

Seawater desalination is increasingly useful in several regions around the world because population is growing in places where there is not enough fresh water to support that growing. It is expected that by 2025, more than 70% of world's population will have water shortages (Li, 2012). Desalination is an energy intensive process that currently is made by means of membranes or via thermal processes. The most common desalination processes are energized directly or indirectly by fossil fuels (Hermosillo et al., 2012). On the other hand, desalination of seawater has become one of the most important commercial processes to provide fresh water for many communities and industrial sectors. Distillation processes produce about 50% of the worldwide desalination capacity, and 84% of this is produced by MSF technology (Shatat and Riffat, 2012). Currently there are more than 18,000 desalination plants in operation worldwide producing 22.9 billion gallons of water per day (IDA, 2017), 60% are located in the Middle East (Rasoul et al., 2006). The large scale MSFD plants are among the region's most important commercial processes, as they play a crucial role in providing fresh water for many communal and industrial sectors, especially in areas with a high density of population. Since they are operated with fossil fuel, they are very expensive to run and also produce harmful environmental pollutions. Moreover, such plants are not economically viable in remote areas, even near a coast where seawater is abundant. Many such areas often also experience a shortage of fossil fuels and an inadequate electricity supply. The development of proper solar harvesting systems for water desalination is imperative for the population in such areas. It plays a crucial role in socio-economic development in any country including IRAN, especially in the south area, where they suffer from a shortage of fresh water. There are extensive R&D activities, especially in the field of application of renewable energy technolo-

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Nomenclature

A	area, m^2
A_{col}	solar field area, m^2
B	brine
CP	specific heat capacity at constant pressure, kJ/kg K
CSP	concentrating solar power
D	distillate
DSG	direct steam generation
F	feed
G_b	daily average direct irradiance, W/m^2
GOR	gain output ratio = distillate mass flow rate/steam mass flow rate
h	specific enthalpy, kJ/kg
LP	low pressure
MP	medium pressure
MSFD	Multi Stage Flash Distillation
M_s	steam mass flow rate, kg/s
m	mass flow rate, kg/s
PTC	Parabolic Trough Collector
R	Recycle water
s	specific entropy, kJ/kg °C
T	temperature, °C
TBT	top brine temperature, °C
W_{col}	solar field width, m

Subscripts

b	brine
col	collector
cond	condenser
conv	convective
cw	cooling water
d	distillate product
f	feed
Inc.	incident
rad	radiative
ref	reflective
sol	solar
w	water

Greek

η	efficiency, %
η_{th}	thermal efficiency, %
η_o	optical efficiency, %

gies, to find new and feasible techniques to produce drinking water.

Thermal solar energy water desalination is known to be a viable method of producing fresh water from saline water in remote locations; conventional basin solar stills with a relatively large footprint is an example of such technology (El-bialy et al., 2016). Furthermore using a clean natural energy resource in water desalination processes reduces significantly the pollution that causes global warming. Solar powered desalination plants are one of the key technologies for the production of water from renewable energy resources. Table 1 shows some typical solar distillation plants in which indirect solar desalination systems consist of a conventional desalination unit coupled to a solar conversion system over the last decades (Rodriguez, 2007). Through different technologies, Direct Steam Generation (DSG) in the collectors is a promising alternative because it allows higher cycle temperatures and, consequently, higher system efficiencies (Vilela et al., 2013) a technique being increasingly developed by many researchers world-wide. This study presents a comprehensive methodology for a different contribution as to how a DSG system could be effectively integrated into a MSFD plant. Literature review revealed that different design aspects of CSP and DSG models with varying integration have been studied as were reported for example in the works of (Martínez and Almanza, 2007), (Feldhoff et al., 2011), (Palenzuela et al., 2015), (Elsafi, 2015), and (Valenzuela et al., 2017). They described the use of CSP technologies in general and direct steam generation in particular, mostly for supplying necessary heat to produce power, as parabolic trough solar concentrators driving steam turbines constitute around 95% of all operational solar thermal power plants (1.9 GWe) (IRENA, 2012). The proposed configuration; DSG + MSFD probably for first time is trying. A resume of the main achievements of DSG projects is reported in Table 2 (Leone et al., 2017).

In the DSG, boiler feed water can be converted to the steam in the Parabolic Trough Collector (PTC) rows as a heat transfer fluid by concentrated solar irradiation. Fig. 1 shows different parts of a solar collector assembly (Padilla, 2011). The solar energy is transferred to a water-steam cycle. Here, the produced steam provides the required heat of the brine heater. To generate solar steam, as shown in Fig. 2, there are three different process options, the once through, recirculation and injection concept (Eck and Steinmann, 2001). In once through, water passes through the absorber tube once and at the end, steam is generated. This operation mode is the simplest in terms of piping but the most complicated for the control system. In injection mode, liquid water is injected at

Table 1
Some selected solar collector-assisted MSF seawater desalination systems.

Plant location	Desalination process	M^3/d	Solar collectors
La Desired Island, French Caribbean[a]	ME-14 effects	40	Evacuated tube
Abu Dhabi, U.A.E.[b]	ME-18 effects	120	Evacuated tube
Kuwait[c]	MSF auto regulated	100	Parabolic trough
La Paz, Mejico[c]	MSF-10 Stages	10	Flat Plate + Parabolic trough
Arabian Gulf[c]	ME	6000	Parabolic trough
Al-Ain, U.A.E.[d]	ME-55 Stages MSF-75 Stages	500	Parabolic trough
Takami Island, Japan[c]	ME-16 effects	16	Flat Plate
Berken, Alemania[e]	MSF	20	–
Lampedusa Island, Italy[f]	MSF	0.3	Low concentration
PSA, Almeria, Spain[g]	ME-Heat pump	72	Parabolic trough
Gran Canaria, Spain[h]	MSF	10	Low concentration
Area of Hzag, Tunisia[i]	Distillation	0.1–0.35	Solar collector
Al Azhar University, Gaza[j]	ME-3 effects	0.2	Solar collector + PV (auxiliary energy)
Safat, Kuwait[i]	MSF	10	Solar collector

[a] Madani (1990).
[b] El Nashar (1985).
[c] Delyannis (1987).
[d] Hanafi (1991).
[e] Papadakis et al. (1996).
[f] Palma (1991).
[g] Zarza Moya (1991).
[h] Valverde Muela (1982).
[i] European Commission (1998).
[j] Abu-Jabal et al. (2001).