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ScienceDirect

Energy Procedia 139 (2017) 524–529

Energy Procedia

www.elsevier.com/locate/procedia

International Conference On Materials And Energy 2015, ICOME 15, 19-22 May 2015, Tetouan, Morocco, and the International Conference On Materials And Energy 2016, ICOME 16, 17-20 May 2016, La Rochelle, France

Design analysis of MVC desalination unit powered by a grid connected photovoltaic system

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Abstract

The use of solar energy especially for desalination of seawater is well adapted for the Saharan region where the fresh water is scarce and solar energy potential is high. This paper presents a design analysis of a single-effect mechanical vapor compression (MVC) desalination unit powered by a grid connected photovoltaic (PV) solar system. The aim of this work is to define, as function of the freshwater needs and site specificity, the embodiment of the MVC components and the PV panels' size. The proposed approach is based on MVC components models coupled with a solar energy estimation model. The results are illustrated using a case study in Dakhla city sited at the south of Morocco; they show that the embodiment of the global system depends greatly on the temperature of brine and distillate streams. A large gap between these design variables reduces the heat transfer area, but increases the size of the PV system.

Peer-review under responsibility of the scientific committee of ICOME 2015 and ICOME 2016.

Keywords: Mechanical Vapor Compression; solar irradiance; photovoltaic panels; Desalination; evaporator; South of Morocco

1. Introduction

As freshwater scarcity continues to increase with the increasing continuous of population, desalinating seawater is becoming a necessity for meeting freshwater needs especially in the North Africa and Saharan regions. The two major types of technologies that are used around the world for desalination can be broadly classified as either membrane such as reverse osmosis (RO) or thermal including single effect evaporation (SEE), multiple effect evaporation (MEE), multi-stage flash (MSF), thermal vapor compression (TVC) and mechanical vapor compression

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Peer-review under responsibility of the scientific committee of ICOME 2015 and ICOME 2016
10.1016/j.egypro.2017.11.248

(MVC) [1,2]. The MVC units have been evolved to become a mature technology over past decades. However, initial costs, system design and energy consumption remain challenging problems. Efficient use of energy in such energy-intensive operations is crucial to reduce the net energy consumption and to compete with other desalination technology. The MVC process remains to be attractive and competitive for production capacities less than 5000 m^3/day [3]. The MVC literature studies include system modeling and design as well as field data and performance evaluation [4]. An early report by Matz and Fisher [5] in 1981 showed that either the RO or MVC system has a definitive edge regarding total production cost. However, expansion of the MVC process remained limited. In 1994, only 200 MVC units with small capacity are reported by Zimmerman [6]. Several water desalination plants driven by solar energy are in operation, in Abu Dhabi, a solar desalination plant has been successfully operated since 1984 [7]. In Almeria (Spain), a Multi Effect Distillation (MED) solar seawater desalination plant of 72 m^3/day was tested and a Wind/PV/RO of around 3 m^3/day for seawater desalination in Lavrio, Greece [8]. In this study, the model is solved for a typically days in Dakhla-Morocco city, which has poor water resources, but also available great solar potential (the Sahara desert).

Nomenclature

M	Mass flow rate, kg/s
A	Area, m²
C_P	Specific heat capacity, kJ/(kg °C)
T	Temperature, °C
λ	Latent heat for evaporation, kJ/kg
U	Overall heat transfer coefficient, kW/m² °C
ΔT	The temperature difference between condensing vapor and boiling brine, °C
η	Efficiency
H	Enthalpy, kJ/kg
W	Specific power consumption, kWh/m^3
G	Direct solar irradiance, W/m²
(o,i)	(Direction, inclination) of the receiving solar collector, °
CI	The incidence coefficient
E_{Sol}	The extra-terrestrial solar radiation, W/m²

Subscripts

b	Brine
d	Distillate
e	Evaporator
s	Superheated compressed vapor
$cell$	Solar cell
PV	Photovoltaic

2. System description

The solar energy is converted into electrical energy using the photovoltaic panels to power the compressor, circulation pumps and other components. Fig. 1 shows the sequence of operations in an MVC system. The main components of the MVC unit are, the mechanical vapor compressor, evaporator/condenser heat exchanger, and a circulation pumps. The demister serves to filter the water vapor before joining the compressor. The feed preheater is a plate type heat exchanger, which recovers part of the sensible heat found in the distillate and brine stream to heat the intake seawater. The thermal energy recovered is then sprayed over the evaporator tubes of the evaporator/condenser. The feed temperature is further increased to the brine boiling temperature and subsequently evaporation commences. The produced steam is drawn through the demister to the compressor, which is powered