



Adsorption assisted double stage cooling and desalination employing silica gel + water and AQSOA-Z02 + water systems



Syed Muztuza Ali, Anutosh Chakraborty*

School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Republic of Singapore

ARTICLE INFO

Article history:

Received 6 January 2016

Accepted 2 March 2016

Keywords:

Adsorption cooling

Desalination

Heat recovery

Thermodynamic modelling

Performance ratio

SDWP

ABSTRACT

We have presented adsorption assisted cooling and desalination employing zeolites and silica gel as adsorbents and water as adsorbate for useful cooling effects at the evaporator and the desalination effects at the condenser. Since the conventional adsorption cooling system works at low evaporator pressure, only a small portion of the adsorption capacity is used for water production. To overcome these limitations, we have modelled and simulated a cooling cum desalination system, where the adsorption cooling system (stage-1) is amalgamated with the adsorption desalination system (stage-2). Therefore, the overall performance is improved by heat recovery between the condenser and the evaporators of both cycles. The simulation results are presented in terms of specific cooling power (SCP), specific daily water production (SDWP), coefficient of performance (COP), performance ratio (PR) and overall conversion ratio (OCR). These results are also compared with experimental data. It is found that the adsorption beds of cooling cycle should be housed with AQSOA-Z02 zeolites for more cooling capacity, whereas the sorption elements of desalination cycle are fabricated with silica gels for more SDWP. The proposed system produces 26% more water and 45% more cooling capacity as compared with conventional equivalent adsorption cooling and desalination systems.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

With the Agricultural, industrial and socio-economic development of many countries, the requirement of fresh water and cooling power are substantially increased over the last century. The international institute of refrigeration (IIR) reported that 15% of total global electricity production was used for air-conditioning and refrigeration applications [1]. In addition to this, for the expedition of high economic development and massive increase in population, global fresh water demand for agricultural, industrial and domestic applications are expected to be increased up to 4500, 1500 and 900 billionm³ (Bnm³) from existing demand of 3100, 800 and 600 Bnm³ by 2030. In contrast, the natural water reserve constitutes 3500 Bnm³ surface water and 700 Bnm³ groundwater [2]. Only 2.5% of the world's natural water reserve is the freshwater, remaining (96.5%) is the seawater. The largest proportion of freshwaters is frozen in ice caps and glaciers (68.7%), followed by groundwater (30.1%), lakes (0.26%), the atmosphere (0.04%), marshes (0.03%), rivers (0.006%), and biological water (0.003%) [3,4]. The World Health Organization (WHO) estimates that 884

million people do not have access to the clean and fresh water and 2.5 billion have limited access [5]. The shortage between the demand and supply of fresh water can be minimized by the desalination plants.

Among all commercially available desalination methods, reverse osmosis (RO) is mostly used (about 60%) which consumes 3–4 kW h electrical energy to operate a hydraulic pump to apply the hydrostatic pressure higher than the osmotic pressure which is about 10–15 bar for brackish water and 50–80 bar for sea water to produce 1 m³ of desalinated water [6–8]. The drawbacks of the RO systems are related to the residuals of boron, chlorides and bromides as well as the high maintenance cost of the mechanical equipment and limited membrane life span [9,10]. The burning of fossil fuels to power up the desalination plants and the cooling systems would contribute to further environmental problems. Therefore, the current situation calls for the development of thermally driven cooling and desalination system using waste heat or renewable energy sources. Examples of some thermally driven desalination system are Multistage Flash (MSF) Desalination, Multi-effect desalination (MED), solar thermal desalination etc. It should be noted here that RO, MSF distillation plants produce about 27% of all desalinated water in the world [11]. Generally the sea water is flashed through the high temperature steam at multiple stages. Since the driving heat source temperature is quite

* Corresponding author. Tel.: +65 6790 4222; fax: +65 6792 4062.

E-mail address: AChakraborty@ntu.edu.sg (A. Chakraborty).

Nomenclature

A	area (m^2)	des	desorption
c_p	specific heat capacity (J/kg K)	chw	chilled water
h_{fg}	latent heat of evaporation (J/kg)	cw	cooling water
h	enthalpy/heat transfer coefficient ($\text{J/kg, W/m}^2 \text{ K}$)	hw	hot water
M	mass (Kg)	dw	distilled water
$\dot{m}$	mass flow rate (kg/s)	$cycle$	cycle time
P	pressure (Pa)	f	fluid
T	temperature ($^{\circ}\text{C}$)	j	adsorption/desorption
t	time (S)		
U	overall heat transfer coefficient ($\text{W/m}^2 \text{ K}$)	Superscripts	
u	velocity (m/s)	sw	seawater
ρ	density (kg/m^3)	br	brine
λ	thermal conductivity (kW/m K)	Ads	adsorbents
X	salinity ($\text{gm of salt/kg of solution}$)	abe	adsorbate
V	volume (m^3)	Evp	evaporator
Q	heat/cold energy (kW)	$cond$	condenser
q	uptake (kg/kg)	bed	sorption reactor
ΔH	isosteric heat of adsorption (kJ/kg)	in	inlet
		out	outlet
Subscripts			
ads	adsorption		

high (around 120°C) at the first stage, many low temperature waste or renewable energy sources cannot be used to run a MSF desalination plant [12]. In contrary, adsorption desalination technology is a thermal compression technology that can use fairly low temperature (60°C) heat source such as industrial process waste energy; marine engines exhaust energy or solar energy etc. [13]. Sea water changes its phase to the vapor leaving the dissolved solids at the evaporator and adsorbed on to the pores of hydrophilic solid adsorbents. The driving heat repels the vapor from the porous adsorbent and transforms its phase back to liquid at condenser which is experimentally demonstrated to be comparable to deionized water quality, and can be used as potable drinking water after further pH adjustment and disinfection [14]. Apart from producing the desalinated water, the adsorption desalination cycle can produce cooling effect from the evaporator as a byproduct which is an additional benefit of using sorption method over the MSF and RO method of desalination. Although the adsorption technology is a promising alternative of conventional cooling and desalination technologies, it suffers from low specific cooling power and water production. The performances of the adsorption cooling and desalination system are dependent on the amount of water vapor uptake of the adsorbent material which is influenced by the temperature and the relative pressure of the adsorption beds [15–20]. Extensive research efforts were conducted to improve the performances in terms of COP, SCP and PR. The proposed thermodynamic modelling lies in the utilization of novel adsorbent materials with higher water vapor uptakes per adsorption–desorption cycle and faster kinetics, which ensures the optimum utilization of waste heat from heat source to heat sink [21–25]. In 2011, Wu et al. analyzed the relative performances of the adsorption desalination system, as the temperature of saline water is varied relative to the temperature of the water used to cool the adsorbent when it adsorbs the evaporated water [26]. In another study, Thu et al. proposed an advanced adsorption desalination cycle that employs internal heat recovery between the evaporator and the condenser as an encapsulated evaporator–condenser unit and found that the water production rates are improved by as much as three folds of the conventional AD cycle [27]. In 2014, Mitra et al. described a single stage adsorption cooling cum desalination system utilizing low

grade heat obtained from non-concentrating type solar collectors. The system performance is evaluated at various condenser temperatures and cycle times [28]. Ng et al. presented the performances of single stage waste heat-driven adsorption cooling cum desalination system, and reported that at 85°C hot water inlet temperatures, the cycle generates 3.6 m^3 of potable water and 23 Rton of cooling capacity per tonne of silica gel for the chilled water temperature of 10°C [29]. The summary of some relevant studies on the performances of adsorption desalination or cooling cum desalination system employing different adsorbent materials and various heat recovery schemes are presented in Table 1.

Reviewed literatures have shown that the water production and the energy consumption of adsorption cooling cum desalination system rely on the temperatures of the evaporator and the water to cool the adsorbent materials and the condenser [30–35]. It is found that more water production is achieved when the evaporator pressure is high. On the other hand, if the evaporator temperature is lower than that of cooling water, the system performance in terms of water production would be deteriorated.

These findings draw a significant research attention to study a two stage adsorption cooling cum desalination system. Mitra et al. studied a laboratory scale two stage adsorption cooling cum desalination system using silica gel – water system both theoretically and experimentally [36]. Regenerated water vapor from the desorption bed of stage-1 is delivered to the adsorption bed of stage-2 through a plenum. This study considered that due to a larger uptake difference, adsorption beds of stage-2 are smaller in size for same performances. It means that the two stage system performs better than a conventional single stage system in terms of specific cooling power and specific daily water production. Effects of cycle time and evaporator pressure on the cooling capacity and water production are reported. However, the effects of other parameters such as temperatures and flowrates of hot water and cooling water are not reported. Moreover, the operating conditions of stage-1 influence the performances of stage-2, which are not discussed in reference no. 36. In addition to this, the heat recovery from stage-1 to stage-2 is not considered. Therefore, a better design is required. The present study proposes two condensers for the two cycles instead of a plenum. The stage-1 of the system

Download English Version:

<https://daneshyari.com/en/article/7160937>

Download Persian Version:

<https://daneshyari.com/article/7160937>

[Daneshyari.com](https://daneshyari.com)