Energy 114 (2016) 10–23

Contents lists available at ScienceDirect

Energy

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

Novel process for performance enhancement of a solar continuous adsorption cooling system

Abdellah El Fadar

Laboratory of Innovating Technologies, National School of Applied Sciences, Tangier, Abdelmalek Essaadi University, Morocco

A R T I C L E I N F O

Article history:
Received 21 April 2016
Received in revised form
9 July 2016
Accepted 27 July 2016

Keywords:
Thermal energy storage
Solar parabolic trough collector
Cooling
Adsorption
Continuous cycle
Modeling

A B S T R A C T

Adsorption cooling is regarded as one of promising clean technologies since it constitutes a rational way for the use of low-grade thermal energy (industrial waste, excess production, etc.) and renewable energy sources. The current paper provides fresh ideas on the relevant issues associated with the intermittence and low performance, which are considered among the main drawbacks of solar-driven adsorption cooling systems. Its primary aim is to design and analyze a solar continuous adsorption cooling system whose design consists mainly of combining a two-tank thermal energy storage system with two adsorbent beds. The operating process is based on storage of excess thermal energy, supplied by means of a solar parabolic trough concentrator, and on its subsequent recovery for producing an additional amount of cold.

The simulation results indicate that, under the system conditions (design, working and weather), the solar coefficient of performance and daily cooling production are considerably improved when a latent heat storage unit is integrated with the system. The study reveals also that, thanks to this novel process, the number of refrigeration cycles achieved per day could be significantly increased, which means that the intermittence disadvantage could widely be overcome.

1. Introduction

Current trends in energy supply and use are patently unsustainable – economically, environmentally and socially [1]. Given this harsh reality, the policymakers and scientific community are increasingly confronted with the complex challenges of sustainable development, energy security and climate change.

Heating, ventilation and air conditioning (HVAC) are among the energy uses that consume a significant fraction of energy and release large amounts of greenhouse gas. Indeed, the IEA (International Energy Agency) reported, in 2015, that: "today, heating and cooling in buildings and industry accounts for approximately 40% of final energy consumption. With 70% of heating and cooling demand relying on fossil energy sources, these end uses are estimated to have been responsible for 30% of global carbon dioxide (CO_2) emissions in 2012" [2].

In field of refrigeration and air-conditioning, the adsorption cooling technology is more and more receiving attention and is regarded as a green technology to lessen the above energetic and environmental problems since the adsorption cooling systems use environment friendly refrigerants (water, methanol, ammonia, etc.), they could operate directly with a primary source of energy, such as solar and geothermal energies, and they could also use industrial waste heat [3]. Furthermore, they could operate at a driving temperature (52.5–82 °C) lower than that of absorption systems [4,5], and they are not noisy due to their ability to work without moving parts. In this context, the solar adsorption cooling technology appears to be promising due mainly to the cleanness and abundance of the solar energy, and because of the close coincidence between the availability of solar radiations and the peak of cooling demands. So, applications of this technology are especially interesting in sunny (i) non-electrified regions, where the preservation of foods and pharmaceutical/medical products is vital, and (ii) electrified areas in order to save energy and mitigate carbon emissions.

The adsorption refrigeration processes are carried out using a certain number of working pairs (adsorbent/refrigerant). The common physical adsorption pairs used in this field include silica gel/water, zeolite/water, activated carbon (AC)/methanol, AC/ammonia, AC/ethanol, etc. It is to mention here the shortcomings of methanol and ammonia, namely flammability and toxicity,

E-mail addresses: elfadar@ensat.ac.ma, aelfadar@yahoo.fr.

http://dx.doi.org/10.1016/j.energy.2016.07.149
0360-5442/

Nomenclature

A_c	collector aperture area (m^2)
A_{HWST}	area of hot water storage tank (m^2)
c_p	specific heat capacity (J kg^{-1} K^{-1})
h_a	latent heat of adsorption (J kg^{-1})
hr	hour (s)
I_b	direct solar irradiance on collector aperture (W m^{-2})
I_{bn}	direct normal solar irradiance (W m^{-2})
L_c	collector length (m)
L_r	reactor (adsorber) length (m)
L_{vap}	vaporization latent heat of ammonia (J kg^{-1})
m	mass (kg)
m_a	adsorbed mass on a layer of adsorbent (kg)
$\dot{m}$	mass flow rate (kg s^{-1})
N	number of cooling cycles (dimensionless)
P	pressure (Pa)
Q_c	daily cooling production (J)
q_c	cooling production during one cooling cycle (J)
r	radial coordinate (m)
T	temperature (K)
T_{g1}	temperature at the start of desorption process (K)
T_{g2}	temperature at the end of desorption process (K)
T_{suit}	suitable driving source temperature (K)
t	time (s)
t_1	time at the beginning of cooling production process without latent heat storage (s)
t_2	time at the end of cooling production process without latent heat storage (s)
t_3	time at the end of cooling production process with latent heat storage (s)
t_{cycl}	cycle time (s)
U	heat loss coefficient from hot water storage tank (W m^{-2} K^{-1})
W	width of collector aperture (m)

Greek symbols

Δx	adsorption capacity difference between adsorption and desorption phases (kg kg^{-1})
ε	porosity of adsorbent bed (dimensionless)
η	latent heat storage efficiency (dimensionless)
η_c	collector efficiency (dimensionless)
θ	volume fraction of the adsorbed phase (dimensionless)
θ_i	incidence angle (°)
λ_e	equivalent thermal conductivity of adsorbent (W m^{-1} K^{-1})
ρ	density (kg m^{-3})

Subscripts

0	without latent heat storage
1	with latent heat storage
a	adsorbate, adsorbed
ads	adsorption
amb	ambient
con	condensation, condenser
ev	evaporation, evaporator
f	fluid (water) in hot water storage tank
fin	final
g	gas
i	initial
in	inlet
l	liquid (ammonia)
m	melting
max	maximum
met	metal
me	metallic tube in adsorbent
out	outlet
rec	recovered
sat	saturation
sav	saved
sr	sunrise
ss	sunset
st0	storage in hot water storage tank without any heat removal
st1	storage in hot water storage tank with heat removal

Abbreviations

AC	activated carbon
CWST	cold water storage tank
DSCP	daily specific cooling production (J kg^{-1})
HTF	heat transfer fluid (oil)
HWST	hot water storage tank
LHS	latent heat storage
PCM	phase change material
PTC	parabolic trough collector
SCOP	solar coefficient of performance
SHS	sensible heat storage
TES	thermal energy storage

respectively. An extensive review about the selection criteria of working pairs could be found in Ref. [6]. It is worthy to note that each one of these pairs requires a driving source temperature that should be well chosen to generate a large amount of refrigerant. The choice of regeneration temperature will be discussed below in Section 2.

Although the adsorption chillers, which first appeared on the market in 1986 by the Nishiyodo Kuchouki, Co. Ltd [7], offer the above advantages, their expansion in the market remains still limited because of some technical limitations such as intermittence in operation when driven by solar energy, bulkiness, low performance and low specific cooling power due to weak heat and mass transfer in adsorbents. To improve the performance of the adsorption bed, efforts should be focused on reducing the inter-particle thermal resistances as well as the interior mass transfer resistances of the particle [8,9]. Comparatively, the inter-particle mass transfer resistance is less important [9].

On the other hand, the parabolic trough collectors (PTCs) have been used in numerous applications, such as electricity generation, desalination, heating [10], whereas very few works have been devoted to cooling purposes in spite of their benefits, namely they can achieve higher tracking accuracy than dish-engine collectors [11], they are lighter than flat plate and evacuated tube collectors; moreover, their high efficiency may offer the possibilities to produce high amounts of thermal energy that could be stored and subsequently used in an effective way depending on the application. These advantages could be a satisfactory solution to overcome the low performance, bulkiness and intermittence drawbacks of the solar adsorption cooling systems.

In fact, continuous solar adsorption cooling systems, based upon two or more adsorbers, are more interesting due to the timely coincidence that offer between needs and production of cold, and