Applied Thermal Engineering 58 (2013) 656–663

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

New solid desiccant solar air conditioning unit in Tunisia: Design and simulation study

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HIGHLIGHTS

- A new design of solid desiccant solar air conditioning unit is presented.
- Three modes of the functioning for this unit are developed.
- The modelling study is based on thermal and mass balances.
- A simulation study of the functioning of the unit is presented.

ARTICLE INFO

Article history:
Received 15 August 2012
Accepted 5 May 2013
Available online 13 May 2013

Keywords:
Air conditioning
Desiccant cooling
Solar energy
Design
Modelling
Simulation

ABSTRACT

Solar air conditioning units present a promising solution for air conditioning, especially desiccant units, in terms of environmental protection and energy saving. In this context, the aim of this paper is a presentation of a new solid desiccant solar air conditioning unit for office spaces in Tunisia and a simulation study of its functioning. Thus, mathematical models for each component are developed which are based mainly on thermal and mass balances. Three mode of functioning are simulated for three climate cases: relatively cold and humid for Bizerte, hot and dry for Remada and finally moderate for Djerba. The results show that the conditioned air obtained in each mode of functioning can ensure comfortable conditions for the office space occupants.

1. Introduction

Conditioned air becomes a vital necessity at office spaces. However conventional units of air conditioning have some environmental problems. In addition, conventional units consume a large quantity of electricity [1,2] which is an expensive energy obtained often by means of oil resources [3]. So more and more CO_2 emissions. Furthermore, with conventional units of air conditioning, the dehumidification of the air is done through a cooling operation under dew point temperature [4]. Thus, the air is very cold to be pulsed in the conditioned space. This operation can be characterized as an energy consuming procedure [5] and in some cases it cannot ensure the achievement of temperature and humidity levels required by the user [6].

So due to the lack of oil resources in the planet and the pollution of the environment, many countries are encouraging the use of renewable energies [3] for air conditioning.

In Tunisia, the sector of energy confronts many problems owed essentially to the exhaustion of the reserves of hydrocarbons, and also to the steady increase of the rhythm of the consumption. Consequently the replacement of the conventional electric air conditioning by another alternative becomes a necessity. So limiting the need of the electrical energy for the air conditioning and satisfying needs in air conditioning are the main objectives to be achieved in our country. These objectives should be realized without breaking the international commitments relative to the environmental protection. Indeed, these commitments mainly intend to reduce CO_2 emissions, avoid the use of harmful gases to the ozone layer and to the greenhouse effect used in the conventional air conditioners.

Given the drawbacks mentioned above, many researches many investigations have been performed to solve these problems especially on the design of solar air conditioning unit.

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http://dx.doi.org/10.1016/j.applthermaleng.2013.05.005

Nomenclature

A	cross section of the air flow for one channel of the hygroscopic wheel (m^2)
$A_{1,2}$	areas of the coils in the storage tank (m^2)
A_{lat}	lateral area of one channel of the hygroscopic wheel (m^2)
A_d	desiccant cross section for one channel of the hygroscopic wheel (m^2)
C_p	specific heat (J/(kg K))
C_c	specific heat of the absorber J/(kg°C))
C_f	specific heat of water (J/(kg°C))
f	specific function (°C)
H	enthalpy ($kJ/kg_{dry\ air}$)
h	convective heat transfer coefficient between absorber/water ($W/(m^2 {}^\circ C)$)
h_{wh}	heat transfer coefficient between desiccant/air (W/m^2 K)
h_m	mass transfer coefficient between desiccant/air (kg/m^2 s)
I	solar radiation (W/m^2)
L_{wh}	length of the hygroscopic wheel (m)
L_{ab}	length of the absorber (m)
L	mass flow of distributed water per unit of area (kg/m^2 s)
M	mass of the water in the storage tank (kg)
M_c	mass of the absorber (kg)
M_f	mass of the water (kg)
m_f	mass flow of the water produced by solar collector (kg/s)
$\dot{m}$	mass flow (kg/s)
p	pressure (Pa)
Q_{ad}	adsorption heat (J/kg)
S	area of the flat plate solar collector (m^2)
T	temperature (°C, K)
T_a	ambient air temperature (°C)
T_c	absorber temperature (°C)
T_f	water temperature (°C)
T_s	temperature of the water in the storage tank (K)
$T_{f2/1}$	inlet/outlet water temperature, feeding side (K)
$T_{l1,2}$	inlet/outlet water temperature, distribution side (K)
t	time (s)
$U_{1,2}$	overall heat transfer coefficient of the coil in the storage tank (W/m^2 K)
U'	global exchange coefficient between absorber/external environment ($W/(m^2 {}^\circ C)$)
V	velocity of the air flow (m/s)
v	water velocity (m/s)
W	water content in the desiccant ($kg_{water}/kg_{desiccant}$)
x	axial direction (m)
Y	specific humidity ($kg_{water}/kg_{dry\ air}$)

Greek letter

β	optical coefficient
α	absorption coefficient of the absorber
τ	transmission coefficient of the glass
η	water–air heat exchanger efficiency
ε	efficiency
ρ	density (kg/m^3)
ω	specific humidity of the air ($kg_{water}/kg_{dry\ air}$)
ω_p	specific humidity of the air at the desiccant coating ($kg_{water}/kg_{dry\ air}$)
φ_p	relative humidity of the air at the desiccant coating

Subscripts

a	air
acc	accumulation
atm	atmospheric
c	cold
catu	cold air to use
cv	convection
d	desiccant
Ech	air–air heat exchanger
h	hot
hatc	hot air to cool
Hum	humidifier
in	inlet
out	outlet
p	desiccant coating
t	treated
tc	to cool
tca	treated cold air
tu	to use
u	used
uha	used hot air
w	water
w	wet
ws	saturation

In this context, solid desiccant units present a promising solution for air conditioning, in terms of environmental protection and energy saves. Indeed, desiccant units do not use harmful refrigerants to the environment. In addition, desiccant dehumidification is advantageous in handling latent heat, easy to be regenerated using low-grade energy, such as solar energy [7].

The standard desiccant unit which is mostly applied today uses standard components which have been used in air conditioning applications for buildings or factories since many years. These components are (i) a desiccant wheel to dehumidify the air, (ii) a heat exchanger to cool the supply air and to heat the return air, (iii) a humidifier to treat the supply air, (iv) a humidifier to cool the return air using evaporative cooling close to the saturation line and (v) a solar thermal collector system to produce hot air for the regeneration of the desiccant wheel [8].

H.M. Henning et al. [8] presented the results of the desiccant cooling cycle for climatic conditions with high ambient air humidity values. In this case, there is an enthalpy exchanger wheel in addition to the components used in standards configurations. Thus, the air is pre-cooled and pre-dehumidified before it's entering the standard desiccant cycle using the return air from the conditioned space. However, high regeneration temperature (100 °C) is needed to ensure the regeneration of the desiccant wheel.

Furthermore, H.M. Henning et al. [8] presented also a desiccant cycle combined with two cooling coils. Thus, the air is pre-cooled under its dew point temperature by passing through the first cooling coil. This operation ensures the pre-dehumidification of the pre-cooled air. Furthermore, the air is finally cooled to the desired temperature before it's entering the conditioned space by use of the second cooling coil. However, if a compression machine is used for providing cold water, the unit will be more complex and more expensive. Not only this, but it is possible to front the risk of going back to the disadvantages of conventional machines already quoted. On the other hand, if an absorption or adsorption machine is used to produce cold water, the unit will be more complex and more expensive.