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An overview of solid desiccant dehumidification and air conditioning systems

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ABSTRACT

To address the importance of desiccant air-conditioning (DAC) systems, this paper discusses the comparison between DAC and conventional vapor compression air-conditioning (VAC). Performance and economic feasibility (PEF) of the system is conferred with reference literature to correlate the types of DAC system from the perspective of energy saving and system payback period. The present study provides three examples of existing desiccant cooling systems namely (i) standalone DAC system, (ii) single-stage hybrid DAC system, and (iii) two-stage hybrid DAC system, which highlight their importance under different environmental conditions. This study provides scientific and experimental supports on how the standalone or hybrid desiccant cooling can be a supplement to the exiting VAC system.

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Nomenclature

AC	air-conditioning
AH	absolute humidity (kg/kg dry air)
AHP	adsorption heat pump
CFCs	chlorofluoro-carbons
COP	coefficient of performance (dimensionless)
DAC	desiccant air-conditioning
DBT	dry bulb temperature (K)
DEC	direct evaporative cooling
DHCs	desiccant humidity conditioners
DW	desiccant wheel
EER	energy efficiency ratio
GWP	global warming potential
HCFCs	hydrochlorofluoro-carbons
HFCs	hydro-fluorocarbons
HVACs	heating, ventilation and air-conditioning systems
IEC	indirect evaporative cooling
IRR	rate of return
M-Cycle	Maisotsenko cycle cooling
ODP	ozone depletion potential
PEF	performance and economic feasibility
RH	relative humidity (%)
RPH	revolution per hour
SEM	scanning electron microscope
SHR	sensible to latent heat ratio
T	dry bulb temperature (K)
TSDC	two-stage desiccant cooling
UK	United Kingdom
UAE	United Arab Emirates
VAC	vapor compression air-conditioning

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1. Introduction

The humidity and temperature control is essential for human's thermal comfort. The water adsorption affinity of desiccants make them able to be used in the applications where the main objective is to remove the moisture [1,2]. Desiccant is a hygroscopic substance that attracts the moisture due to vapor pressure difference. The desiccant air-conditioning (DAC) involves desiccant dehumidification for humidity control and evaporative cooling for temperature control. The DAC is an attractive technology because it is free from CFCs/HCFCs/HFCs and can be regenerated by low grade thermal energy. Apart from the conventional room air-conditioning (AC), the potential applications of DAC are the industrial processes, hospitals, museums, marine ships, greenhouses, drying grains, product preservation and storage etc. The conventional vapor compression air-conditioning (VAC) systems are in practice to obtain the desired conditions. It uses environmentally harmful refrigerants and consumes primary energy in an inefficient way [3]. On the other hand the energy consumption can be reduced up to 5% for heating and 30% for cooling by the use of desiccant in the cooling systems [4]. In desiccant systems the latent load of AC is achieved by desiccant itself whereas the sensible load is accomplished by direct and/or indirect evaporative cooling [5–7]. The ability to deal the sensible and latent load independently makes the DAC system more versatile and flexible. The desiccant carries the latent load of AC efficiently which reduces the energy consumption and increases the system COP [8].

From the above prospective the present study gives an overview of desiccant dehumidification and air-conditioning. The study focuses on solid desiccants which are compact, having less chance of corrosion and carryover, and commonly used as compared to other desiccants [9]. Different kinds of desiccants are discussed as a potential candidate for DAC system. Principles and features of DAC are discussed and their importance over VAC is highlighted. The factors affecting the performance and economic feasibility (PEF) of the system are also highlighted. Three different kinds of existing DAC systems are reviewed comprehensively in order to determine the applicability of DAC designs for the maximum PEF, which distinguish the present study from the earlier review papers in this field.

1.1. *Background of the study*

Nowadays AC became a necessary part of everyday life. The conventional vapor compression type ACs use the HCFC or HFC based refrigerants thus contaminating the globe continuously [10]. In European market nearly 1.6 million units of room ACs were sold in 1996 [11] and 3.5 million units were sold in 2005 [12]. As of Italy and Spain the annual additional cooling capacity is about 12.6 GW i.e. nearly 5 GW increase in electric peak demand [12] and due to heavy growth in cooling demand the degradation of environment is also large [13]. However, the DAC is an environment friendly AC technology which can be operated by thermal energy rather than electricity. Development of desiccant technology was started by Shelpuk and Hooker in 1979 under the scheme of US solar heating and cooling program [14]. Until now many developments have been made in the solid, liquid and hybrid DAC system through experiments and simulations [5]. The applications of desiccant system are also expanding widely and showed higher potential as compared to VAC system [15].

1.2. *Desiccant materials*

A desiccant material that can adsorb large amount of water vapors and can also desorb easily at low regeneration temperature is required for the DAC system [5]. Desiccant may be classified into many ways e.g. solid or liquid desiccants, physisorption or chemisorption desiccants, natural or artificial desiccants, bio or rock based desiccants, composite and polymer based desiccants etc. The term physisorption or chemisorption reflects the strength of the bond between the adsorbate and adsorbent. The removal of water vapors from the air is normally considered as physisorption because of low bond strength between adsorbate and adsorbent. In DAC system the bond strength is kept optimally low for an efficient regeneration