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Research Paper

Experimental evaluation of a solid desiccant system integrated with cross flow Maisotsenko cycle evaporative cooler

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HIGHLIGHTS

- Solid desiccant dehumidifier was integrated with cross flow Maisotsenko cooler.
- Performance of MC-DAC was experimentally investigated over a wide range of operating conditions.
- MC-DAC can provide comfort conditions at low regeneration temperatures of 70 °C in subtropical climatic conditions than DAC.
- MC-DAC system is 60–65% more efficient than conventional DAC in terms of COP.

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ABSTRACT

This paper presents the performance investigation of a solid desiccant dehumidifier integrated with Maisotsenko cycle (M-Cycle) based cross flow heat and mass exchanger (MC-DAC). The experimental test rig consisting of a silica gel based desiccant wheel and a heat recovery wheel is coupled with M-Cycle indirect evaporative cooler. The effect of wide range of inlet air parameters such as ambient temperature, humidity ratio, and regeneration temperature on the performance of integrated system was analyzed and compared with the conventional desiccant air conditioning (DAC) system. Set of experiments were carried out for both systems at constant process as well as return air mass flow rates under different operating conditions. MC-DAC system was observed to be around 60–65% more efficient than the other system in terms of COP_{th} providing same supply air conditions at low regeneration temperatures.

1. Introduction

The world's energy consumption is rising at an exceptional rate and is being estimated that it will rise about 35% from 2010 to 2035 [1]. The total energy consumption by the building sector is about 30–40% and about 50% of this is being consumed by the air-conditioning appliances to provide human comfort [2]. It is obvious from the facts that the significant portion of energy is being consumed to maintain the indoor conditions comfortable for the humans. Moreover, this increasing consumption of energy is causing global warming rise throughout the world due to higher emission of greenhouse gases in the environment. So, the need for alternative means of energy generation and efficient appliances is undeniable, especially from the context of energy starved countries, to accommodate the changing face of energy provision.

Traditional air conditioning systems relying on vapor compression cycle, usually operate in two processes. First, the air is cooled below the dew point by condensing moisture which leads to low evaporating temperature and poor system performance. This cooled air is then dehumidified to the desire humidity level in the second process and is reheated to the desired indoor temperature, which results as overall higher energy consumption. One of the most promising solutions to all of the aforementioned problems is to replace these traditional systems with the desiccant air-conditioning [3]. These systems combine the desiccant device with direct evaporative coolers for the moisture removal and then subsequent cooling. Two different technologies are being used for dehumidification purpose: liquid and solid desiccants. Liquid desiccant systems consist of an absorber and regenerator. These are better dehumidifiers and require low regeneration heat than solids

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Nomenclature

CC	system cooling capacity, kW
COP	co-efficient of performance
DAC	desiccant air conditioning system
DEC	direct evaporative cooler
H	enthalpy content in the air stream, kJ/kg k
HMX	heat and mass exchanger
$\dot{m}$	air mass flow rate, kg/s
MC-DAC	integrated Maisotsenko cycle and desiccant air conditioning system
M-Cycle, MC	Maisotsenko cycle
N	rotational speed, rev/hour
Q	heat transfer rate, kW
T	temperature, °C
ω	humidity ratio, g/kg
Subscripts	
DW	desiccant wheel
HW	heat wheel
in	inlet or intake air
sup	supply air
Reg	regeneration air
P	process air
R	return air
Th	thermal

but there are drawbacks too e.g. higher initial installation cost, corrosion factor in heat exchanger and proper monitoring of saline concentration [4]. On the other hand, solid desiccants which also functions due to partial pressure difference between the air flow and its surface. Alumina silicate, silica gel and zeolite are most commonly used adsorbents in the form of fixed blades, as rotary wheels or cross flow beds [5]. Rotary wheels are more appropriate for air conditioning applications as they can operate easily without any disruption.

A traditional ventilation cycle based desiccant evaporative cooling system is shown in Fig. 1, which comprises a desiccant wheel, rotary heat exchanger and direct evaporative coolers. Rotary heat exchanger pre-cools the dehumidified air which is further processed through direct evaporative cooler for cooling [6,7]. The main drawback of these systems is that there is moisture addition to the dehumidified air, in the direct evaporative cooling, resulting in poor system performance and uncomfortable provision of indoor conditions. This poor system performance is due to the fact that direct evaporative cooler's thermal effectiveness is limited to the wet-bulb point of inlet air stream. Moreover, regeneration heat requirement of such systems increases in hot and humid climates, where high regeneration temperatures (90–120) °C are not easily achievable.

In view of above mentioned drawbacks, new technologies and methods are being simulated, experimented and studied to enhance the effectiveness of desiccant air conditioning systems. Montazeri et al. [8] performed CFD based simulations to evaluate evaporative cooler's performance. It was observed that system's sensible cooling capacity for the inlet water of 35.2 °C can be enhanced to 40%. Moreover, the temperature gradient between inlet water and inlet air was increased from 0 °C to 8 °C. Chen et al. [9] analyzed a desiccant material made from the mixture silica gel, sodium polyacrylate and polyacrylic acid to determine best mixing ratio. This analysis resulted that such desiccant material has 41% more sorption capacity than silica gel as sorptive material. She et al. [10] studied a hybrid refrigeration system with liquid desiccant based evaporative cooling system for subsequent air cooling. The liquid desiccant based system used thermal energy from the condenser to derive it and the obtained results determined the optimal proportions used for liquid desiccant under different operating conditions. Later on, Jani et al. [11] analyzed a hybrid system using mechanical compression and solid desiccant through TRNSYS. The system was simulated under cooling load of 1.8 kW and the obtained results indicated that system is more effective in hot and humid climates. Kim et al. [12] experimentally evaluated a liquid desiccant based evaporative air-conditioning system using outdoor air conditions. System used water side free cooling arrangement with desiccant solution to increase system effectiveness. The results highlighted that the water temperature required for cooling is higher for desiccant solutions than the conventional cooling water. Moreover, the system was good from economic point of view expecting that energy savings might compensate the initial cost.

It is clear from all of the aforementioned studies that several studies have been done on the desiccant systems using direct evaporative cooling mainly. However, one prominent issue with this system is the high regeneration temperature requirement apart from its limitation to work in hot and humid climates. Therefore, researchers focused on different techniques to solve the problem by integrating indirect evaporative coolers with desiccant systems. Elgendy et al. [13] performed a simulation study on the desiccant air-conditioning system with direct/indirect evaporative coolers using TRNSYS and EES. The study concluded that the desiccant systems with indirect evaporative coolers have more COP than traditional systems. Gao et al. [3] studied numerically a desiccant system integrated with counter flow indirect evaporative cooler by using low grade heat source for regeneration purpose. The effectiveness of desiccant wheel and counter flow heat and mass exchanger was assessed based on the number of heat transfer units (NTUs) and the operating parameters. This study indicated that for

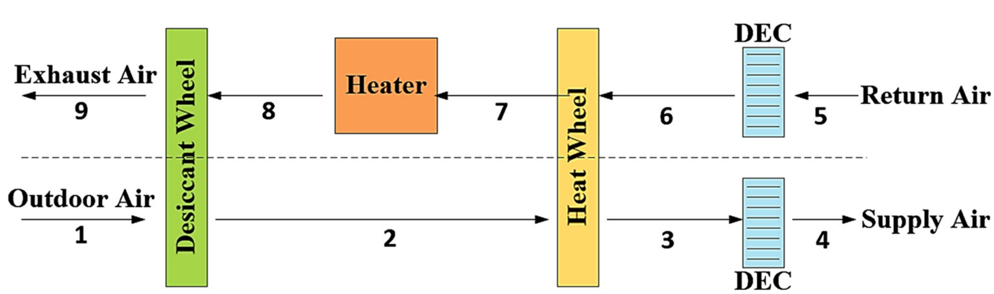

Fig. 1. Schematic of a typical Desiccant Air Conditioning (DAC) System.