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Effect of ambient conditions on the first and second law performance of an open desiccant cooling process

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Abstract

An open desiccant cooling process is presented and applied to ventilation and recirculation modes of the system operation. The cooling system consists of a desiccant wheel, a rotary regenerator, two evaporative coolers, and a heating unit. Certain ideal operating characteristics based primarily on the first law of thermodynamics are assumed for each component. The system with indoor and outdoor ARI conditions has a thermal coefficient of performance (COP) of 1.17 in ventilation mode and 1.28 in recirculation mode. A second law analysis is also performed and at ARI conditions, the reversible COP of the system is determined to be 2.63 in ventilation mode and 3.04 in recirculation mode. Variation of the first and second law based COP terms and cooling load with respect to ambient temperature and relative humidity are investigated in both modes of the system operation. The results of the analysis provide an upper limit for the system performance at various ambient conditions and may serve as a model to which actual desiccant cooling systems may be compared. As an additional study, a non-ideal system operation is considered and it is determined that both the COP and cooling load decrease with increasing ambient temperature and relative humidity, and they approach zero at high values of ambient temperature and humidity.

Keywords: Desiccant; Cooling; Refrigeration; Air-conditioning; Second-law analysis

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Nomenclature

COP	thermal coefficient of performance the desiccant cooling system
$\mathrm{COP_C}$	Carnot COP of a closed cycle heat-driven cooling system
$\mathrm{COP_{R,C}}$	COP of a Carnot refrigerator
$\mathrm{COP_{rev}}$	reversible COP of the ideal desiccant cooling system based on equivalent Carnot temperatures
h	enthalpy of moist air ($\mathrm{kJ\,kg^{-1}}$ dry air)
h_{fg}	enthalpy of vaporization of water ($\mathrm{kJ\,kg^{-1}}$)
h_{w}	enthalpy of liquid water at ambient state ($\mathrm{kJ\,kg^{-1}}$)
q_{in}	heat input to Carnot heat engine ($\mathrm{kJ\,kg^{-1}}$)
q_{regen}	regeneration heat input to desiccant cooling system ($\mathrm{kJ\,kg^{-1}}$ dry air)
q_{cool}	cooling load of desiccant cooling system ($\mathrm{kJ\,kg^{-1}}$ dry air)
s_{w}	entropy of liquid water at ambient state ($\mathrm{kJ\,K^{-1}\,kg^{-1}}$ dry air)
T	dry-bulb temperature (°C)
T_{wb}	wet-bulb temperature (°C)
T_{c}	Carnot equivalent temperature of condenser (K)
T_{e}	Carnot equivalent temperature of evaporator (K)
T_{s}	Carnot equivalent temperature of heat source (K)
T_{ambient}	ambient temperature (K)
T_{source}	heat source temperature (K)
T_{space}	temperature of cooled space (K)
w_{out}	work output from Carnot heat engine ($\mathrm{kJ\,kg^{-1}}$)

Greek letters

ω	specific humidity or humidity ratio (kg water kg dry $\mathrm{air^{-1}}$)
$\Delta\omega_1$	specific humidity increase of air across the evaporative cooler in process line, (kg water kg dry $\mathrm{air^{-1}}$)
$\Delta\omega_2$	specific humidity increase of air across the evaporative cooler in regeneration line (kg water kg dry $\mathrm{air^{-1}}$)
$\Delta\omega_3$	specific humidity increase of air in the cooled room (kg water kg dry $\mathrm{air^{-1}}$)
$\Delta\omega_4$	specific humidity exchange in the desiccant wheel (kg water kg dry $\mathrm{air^{-1}}$)
ϕ	relative humidity
$\eta_{\mathrm{th,C}}$	thermal efficiency of Carnot heat engine

1. Introduction

Desiccant cooling systems are heat-driven cooling units. Their operation is based on the use of a desiccant wheel (DW) in which air is dehumidified. The resulting dry air is somewhat cooled in a heat exchanger and then further cooled by an evaporative cooler (EC). The resulting cool air is directed into the room. The system may be operated in a closed cycle or more commonly in an open cycle in ventilation or in recirculation modes. A heat supply is needed in the system to regenerate the desiccant and a low-grade heat at a