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Thermodynamic performance assessment of a novel air cooling cycle: Maisotsenko cycle

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ABSTRACT

This study presents energy and exergy analyses and sustainability assessment of the novel evaporative air cooling system based on Maisotsenko cycle which allows the product fluid to be cooled in to a dew point temperature of the incoming air. In the energy analysis, Maisotsenko cycle's wet-bulb and dew point effectiveness, COP and primary energy ratio rates are calculated. Exergy analysis of the system is then carried out for six reference temperatures ranging from 0 °C to 23.88 °C as the incoming air (surrounding) temperature. The specific flow exergy, exergy input, exergy output, exergy destruction, exergy loss, exergy efficiency, exergetic COP, primary exergy ratio and entropy generation rates are determined for various cases. Furthermore, sustainability assessment is obtained using sustainability index method. As a result, maximum exergy efficiency is found to be 19.14% for a reference temperature of 23.88 °C where the optimum operation takes place.

Evaluation de la performance thermodynamique d'un nouveau cycle de refroidissement : le cycle de Maisotsenko

Mots clés : Énergie ; Exergie ; Refroidissement ; Refroidisseur d'air ; Système évaporatif ; Cycle de Maisotsenko

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Nomenclature

e	specific exergy (kJ kg^{-1} or kJ kg$_w^{-1}$)
$\dot{E}x$	exergy rate (kW)
c_p	specific heat (kJ kg^{-1} K^{-1})
h	specific enthalpy (kJ kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1} or kg$_w$ s^{-1})
P	pressure (kPa)
$\dot{Q}$	cooling capacity rate (kW)
R	ideal gas constant (kJ kg^{-1} K^{-1})
$\dot{S}$	entropy generation rate (kW K^{-1})
T	temperature (°C or K)
$\dot{W}$	blower power (kW)

Greek symbols

ϵ	effectiveness (–)
η	efficiency (%)
Φ	pressure ratio (–)
Ψ	exergy efficiency (%)
ω	humidity ratio (kg$_w$ kg$_{da}^{-1}$ or kg$_w$ kg^{-1})
$\overline{\omega}$	mole fraction ratio (–)

Subscripts

0	reference (dead state)
da	dry air
dest	destruction
dp	dew point
ex	exergy, exergetic
in	input
loss	losses
out	output
pd	power distribution
SI	supply inlet
SO	supply outlet
t	total
w	water
wb	wet bulb
wv	water vapor

Abbreviations

COP	coefficient of the performance
DEC	direct evaporative cooling
EER	energy efficiency ratio
HMX	heat and mass exchanger
ID	indirect/direct
IEC	indirect evaporative cooling
M	membrane
MVC	mechanical vapor compression
NREL	national renewable energy laboratory

1. Introduction

During the past decade there has been increasing attention to living standards and their improvement. So, comfortable air conditions must be created for better living environment. In this regard, air condition systems have become more popular to supply comfortable environment. Especially, indirect evaporative air cooling systems can widely be used to obtain this condition due to their high efficiencies and low costs (Chen et al., 2010). Indirect evaporative air cooling systems can lower air temperature and avoid adding moisture to the air. Furthermore, it can limit the supply air temperature above the wet-bulb temperature of the outdoor air (Zhao et al., 2009; Idalex Technologies Inc., 2010a). In this context, there is a kind of novel indirect evaporative cooling system which is the so-called "Maisotsenko cycle" or "M-Cycle".

Atmospheric air can be employed in many cycles for various applications, e.g., the Maisotsenko cycle which uses the wet side and dry side of a plate like indirect evaporative coolers, but with a much different airflow creating a new thermodynamic cycle. This cycle as developed based on Russian patents N571669, 979796, 2046257 and U.S. patents N4350570, 4842052, 4971245, 4976113, 4977753, and 5453223 is considered a potential system (Gillan, 2008; Rexresearch, 2010).

The Maisotsenko cycle combines with the thermodynamic processes of heat exchange and evaporative air cooling in an indirect evaporative air cooler resulting in product temperatures which approach the "dew point temperature" of the air. This cycle uses the enthalpy difference of the air at dew point temperature and the air saturated at a higher temperature to reject the heat from the product. Also, the Maisotsenko cycle allows the product fluid to be cooled in to the dew point temperature of the incoming air ideally. The air is then precooled before passing into the heat rejection stream where the water is evaporated. This novel cycle is realized in a single device and it allows high heat flux and low-pressure drop (Maisotsenko and Gillan, 2003).

To better understand the Maisotsenko cycle, exergy analysis method can be applied with energy analysis and sustainability assessment methods. Exergy analysis method uses both conservation of mass and energy principles. This method is based on second law of thermodynamics for analysis, design and improvement of energy systems. Exergy is always evaluated with respect to a reference environment (i.e., dead state) and it can be destroyed when the irreversibility process occurs. If an exergy analysis performed on a system, thermodynamic imperfections can be quantified as exergy destruction, which represent losses in energy quality or usefulness (Dincer and Rosen, 2007). Furthermore, when the thermodynamic system is in equilibrium with the environment, the state of the system is called as to be "dead state", and temperature of this situation is called "dead state temperature" (or reference temperature).

No studies about thermodynamic analysis based on energy and exergy analyses and sustainability assessment of the Maisotsenko cycle have appeared in the open literature to the best of the authors' knowledge, although there are some studies related to "energy analysis" and "Maisotsenko cycle" or "indirect evaporative cooling". In this regard, as to be the first step, there are only just four studies about "Maisotsenko cycle" without exergy analysis and sustainability assessment which are as follows. Maisotsenko and Gillan (2003) presented the Maisotsenko open perforated cycle which combines with the thermodynamic processes of evaporative cooling and heat exchange. It was found that at no time water was evaporated