INTERNATIONAL JOURNAL OF REFRIGERATION 52 (2015) 66–82

Available online at www.sciencedirect.com

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A theoretical study on a novel solar based integrated system for simultaneous production of cooling and heating

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ARTICLE INFO

Article history:
Received 24 May 2014
Received in revised form
17 December 2014
Accepted 18 December 2014
Available online 30 December 2014

Keywords:
Solar based
Integrated system
Cooling
Heating
Exergy

ABSTRACT

An integrated system for simultaneous production of triple-effect cooling and single stage heating is proposed in this paper to harness low grade solar energy. The proposed system combines the heliostat field with a central receiver and the ejector-absorption cycle with the shaft power driven transcritical CO_2 cycle. A parametric study based on first and second laws of thermodynamics is carried out to ascertain the effect of varying the exit temperature of duratherm oil, turbine inlet pressure, and evaporators temperature on the energy and exergy output as well as on the energy and exergy efficiencies of the system. The results obtained indicate that major source of exergy destruction is the central receiver where 52.5% of the inlet solar heat exergy is lost followed by the heliostat where 25% of the inlet exergy is destroyed. The energy and exergy efficiencies of the integrated system vary from 32% to 39% and 2.5%–4.0%, respectively, with a rise in the hot oil outlet temperature from 160 °C–180 °C. It is further shown that increase in evaporator temperature of transcritical CO_2 cycle from −20 °C to 0 °C increases the energy efficiency from 27.45% to 43.27% and exergy efficiency from 2.51% to 2.97%, respectively. The results clearly show how the variation in the values of hot oil outlet temperature, turbine inlet pressure, and the evaporator temperature of transcritical CO2 cycle strongly influences the attainable performance of the integrated system.

Une étude théorique sur un nouveau système intégré à base d'énergie solaire pour la production simultanée de refroidissement et de chauffage

Mots clés : A base solaire ; Système intégré ; Refroidissement ; Chauffage ; Exergie

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http://dx.doi.org/10.1016/j.ijrefrig.2014.12.013
0140-7007/

Nomenclature

A_{ap}	aperture area [m^2]
A_{field}	area of heliostat field [m^2]
ARC	absorption refrigeration cycle
Comp	compressor
C	concentration ratio
C2	condenser of the absorption refrigeration cycle
COP	coefficient of performance
CO_2	carbon dioxide
$\Delta\dot{E}$	exergy change [kJ s^{-1}]
EJE	ejector
E3	evaporator of the transcritical CO2 cycle
$\dot{E}$	exergy rate [kJ s^{-1}]
E	evaporator
ERC	ejector refrigeration cycle
GEN	generator
h	specific enthalpy [kJ kg^{-1}]
LiBr–H_2O	lithium bromide–water
$\dot{m}$	mass flow rate [kg s^{-1}]
ORC	organic Rankine cycle
P	pressure [Pa]
$\dot{Q}$	energy rate [kJ s^{-1}]
q	solar radiations received per unit area or DNI [Wm^{-2}]
R-123	2,2-Dichloro-1,1,1-trifluoroethane
s	specific entropy [kJ kg^{-1} K^{-1}]
TC	transcritical CO_2 cycle
T	absolute temperature [K]
U	velocity [ms^{-1}]
$\dot{W}$	rate of work done [kJ s^{-1}]

Greek symbols

μ	entrainment ratio
η	efficiency [%]

Subscript

A	absorber
Ap	aperture
C1, C2, C3	condensers
comp	compressor
CR	central receiver
D	destruction
d	diffuser
E1, E2, E3	evaporators
EJE	ejector
f	refrigerant fluid
GC	gas cooler
GEN	generator
H	heating
HRVG	heat recovery vapor generator
is	isentropic process across the turbine/compressor
IHX	internal heat exchanger
mf	mixed stream flow
m	mixing chamber
n1	inlet of nozzle
n2	outlet of nozzle
n	nozzle
oil	hot oil (Duratherm600)
P	pump
pf	primary flow
r	water refrigerant
sf	secondary flow
SHX	solution heat exchanger
s	solution mixture of LiBr–H_2O
s'	state at the end of isentropic process across the nozzle/diffuser of the ejector
th	thermal
T	turbine
TV	throttling valve
1, 2, 3..........a, b, c	state points in Fig. 1

1. Introduction

During the last few decades, an increasing interest, based on research and development, has been concentrated on utilization of solar energy more aggressively to address the world energy and environmental situation. The possibility of utilizing solar energy for the production of cooling and heating has attracted Man's attention since the early development of solar technology (Grossman (2002), Petela (2009)). Solar powered cooling is regarded as a promising technology due to the close coincidence of very high air-conditioning and refrigeration demands in peak summers when there is maximum available solar energy. This offers an excellent opportunity to meet out the increasing energy demand for cooling of various countries of the gulf region where more than 60% of the power produced is used for refrigeration and air-conditioning purposes (Ratlamwala et al. (2013)). Recently, rapid development occurred worldwide in the basic technology and market strategy for the concentrating solar power (CSP) technologies, including parabolic trough, power tower, and dish/engine (Yao et al. (2009), Larbi et al. (2010), Montes et al. (2011)).

The superiority of second law analysis over the traditional first law methods for energy conversion processes in general and solar thermal technology in particular has been widely recognized due to the fact that latter does not distinguishes the quantity and quality of energy and simply provides the overall performance of the system. On the other hand, combined first and second law analysis which is called the exergy analysis gives a clearer assessment of various losses occurring in energy systems both quantitatively and qualitatively and the irreversibilities in the system and thereby shows the possibilities where improvements in efficiency could be made (Bejan (2002), Dincer and Rosen (2007), Hepbasli (2008)).

In this context, throughout the literature, there are numerous studies reporting the second law performance of solar driven absorption refrigeration cycle, ejector refrigeration cycle, and combined ejector-absorption refrigeration cycle. Chua et al. (2002) modeled and developed an irreversible