Energy Conversion and Management 51 (2010) 434–445

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Numerical simulation of a Linear Fresnel Reflector Concentrator used as direct generator in a Solar-GAX cycle

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ARTICLE INFO

Article history:
Received 23 May 2008
Received in revised form 9 March 2009
Accepted 10 October 2009
Available online 18 November 2009

Keywords:
Ammonia–water
Direct vapor generation
Absorption refrigeration
Solar energy
Fresnel

ABSTRACT

In this work a methodological analysis to design and evaluate the technical feasibility of use a Linear Fresnel Reflector Concentrator (LFRC) as generator in an advanced absorption refrigeration system (Solar-GAX cycle) has been carried out. For this purpose, a detailed one-dimensional numerical simulation of the thermal and fluid-dynamic behavior of a LFRC that solves, in a segregated manner, four subroutines: (a) fluid flow inside the receptor tube, (b) heat transfer in the receptor tube wall, (c) heat transfer in cover tube wall, and (d) solar thermal analysis in the solar concentrator has been developed. The LFRC numerical model has been validated with experimental data obtained from the technical literature; after that, a parametric study for different configurations of design has been carried out in order to obtain the highest solar concentration with the lowest thermal losses, keeping in mind both specific weather conditions and construction restrictions.

The numerical result obtained demonstrates that using a LFRC as a direct generator in a Solar-GAX cycle satisfy not only the quantity and quality of the energy demanded by the advanced cooling system, it also allows to obtain higher global efficiencies of the system due to it can be operated in conditions where the maximum performance of the Solar-GAX cycle is obtained without affecting in any significant way the solar collector efficiency.

1. Introduction

In recent times, more attention is being set on solar refrigeration system as a consequence of rising electricity rates and increasing power demand caused by conventional air conditioning and refrigeration systems. There are alternative technologies for cooling that contribute to decrease power demand, the conventional high Global Warming Potential (GWP) and the Ozone Depletion Potential (ODD). In addition, developed countries need new refrigeration technologies instead of conventional compression refrigeration to meet air conditioning and cooling demand without greenhouse emissions. Solar energy has the evident advantage that cooling is generally required when solar radiation is available; this allows to use an integral system consisting in a solar thermal collector arrangement coupled to a refrigeration system driven thermally. Some experimental and theoretical studies has been developed in order to take advantages of solar energy in refrigeration and air conditioning systems [1]. Li and Sumathy [2] developed a simulation of a solar absorption refrigeration system coupled with flat collectors and a storage tank with two sections, the results shown that using this type of storage tank benefits the system due to the refrigeration effect is quicker and the coefficient of performance (COP) is also higher than a system with a storage tank with normal stratification. Zyed et al. [3] reported an experimental research of a solar refrigeration system with a solar array with 49 m^2 of flat collectors, the absorption system is a water cooled single effect cycle with a capacity of 35 kW and a storage tank of 2 m^3. The array of collector is coupled indirectly to the absorption cycle using water to transport the solar energy gain. Mazloumi et al. [4] proposed with a simulation study a single effect $LiBr/H_2O$ refrigeration system with a capacity of 17.6 kW (5 tons refrigeration) activated with solar energy obtained with parabolic trough solar collectors. In this study a thermal efficiency of 0.69 is reported in the solar system and a COP in the cycle of 0.7 that results in a global efficiency of 0.48. The systems proposed above has as its principal disadvantage the thermal losses due to the indirect coupling between the solar array and the refrigeration cycle and the systems also required a higher initial inversion due to more components are needed. Ortega et al. [5] in order to reduce the thermal losses and the number of components proposed a compound parabolic concentrator (CPC) coupled directly with a single effect solar absorption system with a capacity of 3.8 kW. The system reported a theoretical CPC efficiency of 0.46 and a COP in the cycle of 0.45 that results in a global efficiency of 0.21; this global efficiency is low due to a low efficiency single effect

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doi:10.1016/j.enconman.2009.10.005

Nomenclature

A_a	reflector aperture area (m^2)
A_r	receptor tube heat transfer area (m^2)
A_t	fluid flow cross section area (m^2)
$A_{t,c}$	cover tube cross section area (m^2)
$A_{t,r}$	receptor tube cross section area (m^2)
C	concentration ratio (dimensionless)
C_p	specific heat at constant pressure (J/(kg K))
d	mirror position (m)
D	diameter (m)
e	specific energy ($H + v^2/2 + gz\sin\theta$) (J/kg)
f	focal distance (m)
fr	friction factor (dimensionless)
F_r	Froude number (dimensionless)
F_{rc}	view factor between receptor and cover (dimensionless)
g	gravitational constant (m/s^2)
G	distance between consecutive mirrors (m)
G_v	mass velocity (kg/m^2 s)
h	heat transfer coefficient ($W/(m^2 K)$)
H	enthalpy (J/kg)
I	solar irradiance (W/m^2)
k	thermal conductivity (W/(m K))
k_{eff}	effective thermal conductivity (W/(m K))
L	length (m)
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
n	number of control volumes
p	pressure (bar)
P	perimeter (m)
Pr	Prandtl number (dimensionless)
$\dot{q}$	heat flow per unit area (W/m^2)
$\dot{q}_u$	useful energy gain per receptor unit area (W/m^2)
$\dot{q}_{wall}$	heat flux from wall to fluid per receptor unit area (W/m^2)
$\dot{Q}_u$	energy gain (W)
rug	absolute tube roughness (m)
Ra	Rayleigh number (dimensionless)
Re	Reynolds number (dimensionless)
S	solar absorbed energy per unit area (W/m^2)
t	time (s)
T	temperature (K)
v	velocity (m/s)
W	mirror width (m)
W_e	Weber number (dimensionless)
x_g	vapor quality (dimensionless)
z	axial coordinate

Greek letters

α	absorbance (dimensionless)
β	inclination angle of the receptor tube (rad)
ε	emittance (dimensionless)
ε_g	void fraction (dimensionless)
ϕ	generic dependent variable
γ	shape factor due to inexact concentrator orientation (dimensionless)
η	efficiency (dimensionless)
θ	inclination angle of the mirror (rad)
ρ	density (kg/m^3)
ρ_o	surface reflectivity (dimensionless)
σ	Stefan–Boltzmann constant (5.6697×10^{-8} $W/(m^2 K^4)$)
τ	transmissivity (dimensionless)
τ_w	wall shear stress (N/m^2)
μ	dynamic viscosity (kg/(ms))
ξ	solar sub tense angle (rad) ($\xi = 32'$; design consideration)
Δz	spatial discretization step (m)
Ψ	surface tension (N/m)
Δt	temporal discretization step (s)
Φ	two-phase frictional multiplier (dimensionless)

Subscripts

amb	ambient
b	beam
c	cover
conv	convective
ext	external
f	fluid
g	gas phase
go	only gas
int	internal
l	liquid phase
lo	only liquid
N	number of mirrors
r	receptor
rad	radiative
tp	two-phase

Superscripts

–	arithmetical average over a *CV*
∼	integral average over a *CV*
o	value of previous instant

cycle is used and it is not exploited the potential of advanced absorption cycles with interchange of heat between the generator and absorber (GAX cycles).

The GAX cycle provides the highest COP of any single effect absorption cycle due to possibility of internal heat recovery at the highest temperature zone of the absorber and transferred to the lowest temperature zone of the generator [6]. In order to reach this performance, high temperature in the generator is required. This can be reached coupling concentrator solar collector with this type of cycles. Until now, only works with this type of cycles activated with direct fire and residual heat has been reported. Kang et al. [7] proposed an advanced GAX cycle activated with residual heat and they reported that the generation temperature can be reduced until 172 °C solving the corrosion problems produced with temperatures higher than 200 °C. Velázquez and Best [6] studied a GAX cycle of 10.56 kW of refrigeration capacity activated with natural gas and solar energy; they proposed a methodology to evaluate the thermodynamic behavior of these systems, a refrigeration COP of 0.86 and a heating COP of 1.86 are reported with an internal energy integration of 15.6 kW. Kang et al. [8] developed four configurations of hybrid-GAX cycles that combined the characteristics of advanced absorption cycles and vapor compression ones; they reported that when a compressor is put between the evaporator and the absorber a COP 24% higher than a conventional GAX cycle can be reached. This configuration with different pressure levels can reach temperatures until −80 °C in the evaporator and can reduced the generator temperatures to 164 °C if a compressor is collocated between the generator and the condenser.

In the other hand, solar thermal collectors are now more efficient. In fact, some systems developed in the past have reappeared; this is the case of the LFRC developed in 1968 by Francia [9] for steam generation at 101.32 bar and 450 °C. The interest in LFRC