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Impact of different internal convection control strategies in a non-evacuated CPC collector performance

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Abstract

Over the last decade the technological advances observed in solar collector materials, namely better spectrally selective absorber coatings and ultra clear glass covers, contribute to performance improvements and translate into higher operational temperature ranges with higher efficiency values.

While the use of Evacuated Tube Collectors (ETCs) is becoming widespread in the thermal conversion of solar energy, non-evacuated solar collectors still hold advantages at manufacturing, reliability and/or cost levels, making them interesting and competitive for a large range of applications, in particularly, in temperature ranges up to 80 °C. However, these advantages have not prevented the major drawback of these collectors when compared to ETCs: thermal losses due to internal convection which prevent their general use in the range of operating temperatures up to 150 °C.

Insulation, double glazing or selective coatings can be used in non-evacuated collectors to reduce heat losses. To prevent internal convection losses in these solar collectors, different control strategies have been studied, such as the adoption of different inert gases within the collector cavity, physical barriers reducing air flow velocities over the absorber or cover surfaces or the use of concentration.

In the present article, an assessment of adopting such internal convection control strategies in a CPC collector is presented. Each of the presented strategies is assessed in terms of the resulting collector optical and thermal characterization parameters and yearly collector yield. For this purpose, an integrated tool allowing the design, optical and thermal characterization of CPC collectors was developed. The results obtained provide valuable guidelines for anyone wishing to implement any of these strategies in a new collector design.

Keywords: CPC collector; Convection losses; Medium temperature

1. Introduction

The energy balance in a solar collector results from: the radiative flux effectively transferred into the absorber surface and other internal exposed surfaces; the useful heat removed to the heat transfer fluid; and all thermal losses to the surrounding environment (Rabl, 1985; Duffie and Beckman, 2006). Since most non-evacuated collectors possess insulation and a glazed absorber enclosure, internal convection must be carefully handled if collector heat losses are to be reduced. That is clearly shown by ETCs, when compared to non-evacuated collectors: after elimination of internal convection, due to the vacuum created between absorber and cover surfaces. As a result, ETCs present a much reduced heat loss coefficient and may operate at higher temperatures. However, non-evacuated collectors have some advantages in manufacturing, reliability,

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Nomenclature

Romans

a_1	global heat loss coefficient (W/(m^2 K))
a_2	temperature dependent heat loss (W/(m^2 K^2))
A_a	collector aperture area (m^2)
C	concentration factor
C_{eff}	effective concentration factor
C_p	specific heat at constant pressure (J/(kg K))
C_{trunc}	truncation concentration factor
D	diffuse irradiance incident on the horizontal plane (W/m^2)
D_{col}	diffuse irradiance incident on the collector aperture plane (W/m^2)
e	thickness (m)
$\dot{E}$	specific collector yearly yield (kW h/(m^2 year))
$\tilde{f}_{ij}$	nodal shape factor of surface associated with node i to the surface associated with node j
$\tilde{F}_{mk}$	shape factor of edge surface m to edge surface k
F'	irrigation factor
G	global irradiance incident on the horizontal plane (W/m^2)
G_{col}	global irradiance incident on the collector aperture plane (W/m^2)
$h_{\mathrm{conv,ext}}$	external convection coefficient (W/(m^2 K))
k	thermal conductivity (W/(m K))
k_m	thermal conductivity of material m (W/(m K))
k_{surf}	cavity surface thermal conductivity (W/(m K))
K	incidence angle modifier
$K_{\mathrm{dif,d}}$	diffuse radiation weighted average incidence angle modifier
$K_{\mathrm{dif,h}}$	hemispherical diffuse radiation weighted average incidence angle modifier
$K_{\mathrm{dif,r}}$	reflected radiation weighted average incidence angle modifier
K_l	longitudinal incidence angle modifier
K_t	transversal incidence angle modifier
l_m	thickness of material m (m)/perimeter of edge surface m (m)
l_{surf}	cavity surface perimeter (m)
L	characteristic length (m)
L_a	aperture (transversal) length (m)
$L_{\mathrm{a,trunc}}$	truncation aperture (transversal) length (m)
L_{trunc}	truncation height (m)
$n_{\mathrm{hits},k}$	number of rays hitting edge surface k
$n_{\mathrm{rays},m}$	number of rays emitted from edge surface m
$\dot{q}$	heat flux (W/m^2)
$\dot{q}_{\mathrm{cond}}$	conduction heat flux (W/m^2)
$\dot{q}_{\mathrm{conv,ext}}$	external convection heat flux (W/m^2)
$\dot{q}_{\mathrm{conv,int}}$	internal convection heat flux (W/m^2)
$\dot{q}_{\mathrm{rad}}$	internal long-wave radiation heat exchange heat flux (W/m^2)
$\dot{q}_{\mathrm{RT}}$	absorption of direct external irradiation (W/m^2)
$\dot{q}_{\mathrm{RTdif}}$	absorption of diffuse external irradiation (W/m^2)
$\dot{q}_u$	collector usefull heat removal (W/m^2)
Q_{beam}	beam power (W)
Q_i	power absorbed at node i (W)
Q_{ray}	ray power (W)
t	time (s)
T	temperature (K)
T^*	collector reduced temperature difference
T_0	characteristic temperature (K)
$\overline{T}_{\mathrm{abs}}$	average absorber temperature (K)
T_{amb}	ambient air temperature (K)
T_f	average heat transfer fluid temperature (K)
T_i	temperature value on node i (K)
T_{in}	collector inlet temperature (K)
T_{out}	collector outlet temperature (K)
T_{surf}	perimeter averaged surface temperature (K)
ΔT	characteristic temperature difference (K)
U_{amb}	ambient air velocity (m/s)
(x,y)	co-ordinates on the Cartesian referential (m)

Greek symbols

α	absorptivity
α_m	absorptivity of edge surface m
β	tilt angle (°)
ϵ	emissivity
η	collector instantaneous efficiency
η_O	optical efficiency
$\eta_{\mathrm{O,sim}}$	simulated optical efficiency
ν	kinematic viscosity (m^2/s)
θ	dimensionless temperature/incidence angle (°)
θ_a	aperture angle (°)
θ_l	incidence angle on the longitudinal plane (°)
θ_t	incidence angle on the transversal plane (°)
ϱ	mass density (kg/m^3)/reflectivity
σ	Stefan–Boltzmann constant (5.6704×10^{-8} W/(m^2 K^4))
ω	vorticity
ψ	stream function

durability and cost level in general, making them still competitive for a wide range of applications, in particular in the range of operating temperatures going up to, say, 80 °C.

The increasing number of new applications at temperature levels up to 150 °C, including process heat in industry (Vannoni et al., 2008), solar cooling (IEA Solar Heating and Cooling Programme Task, 2004; SOLAIR, 2008), desalination or even power generation based on Organic Rankine cycles (Delgado-Torres and Garcia-Rodriguez, 2007; Delgado-Torres et al., 2007; Horta et al., 2008), creates a new interest in extending the efficiency of non-evacuated collectors to those higher operation temperatures.