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A parabolic-trough collector for cleaner industrial process heat

Aránzazu Fernández-García [a], Esther Rojas [a], Manuel Pérez [b], Ricardo Silva [b], Quetzalcoatl Hernández-Escobedo [d], Francisco Manzano-Agugliaro [c, *]

[a] CIEMAT-Plataforma Solar de Almería, Ctra. Senés, km 4, E04200 Tabernas, Almería, Spain
[b] CIESOL Research Center on Solar Energy, UAL – CIEMAT Joint Center, University of Almería, Ctra. Sacramento s/n, E04120 Almería, Spain
[c] Dept. Engineering, CEIA3, University of Almería, Ctra. Sacramento s/n, E04120 Almería, Spain
[d] Facultad de Ingeniería, Universidad Veracruzana, Campus Coatzacoalcos, Avda. Universidad Veracruzana km. 7.5, 96536, Col. Santa Isabel, Coatzacoalcos, Veracruz, Mexico

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ABSTRACT

Despite its huge potential for increasing sustainability, the use of solar energy in industry is still scarce. Many industrial thermal demands range from 120 to 250 °C, which are difficult to supply using solar energy because of the lack of specific solar thermal conversion devices. Parabolic-trough collectors (PTCs) suitable for these applications should be small due to space constraints. This study addressed the specific design of a small-sized industrial PTC with a flat transparent cover in the aperture plane. The cover is critical to the success of this technology in industrial environments, because it ensures protection of the rest of the collector components, which may have very poor durability. The cover also increases rigidity and makes cleaning easier. Three different PTCs with the same basic geometry were analysed by numerical simulation. Two of them had glass receiver tube covers, one with an additional flat cover in the aperture plane and the other one without it. The third one had an uncovered receiver but a flat cover in the aperture plane. Simulations showed that the collector design with a flat glass aperture cover only has the highest thermal losses. The design with both flat glass aperture and tube covers has lower thermal losses than the one with a glass tube cover only. However, optical-geometric efficiency is inferior and, as a result, overall efficiency is slightly lower. In addition, thermal insulation on the reflector back is not recommended.

1. Introduction

According to the latest International Energy Agency (IEA) statistics (for 2011), industry is one of the main consumers of energy worldwide, around 30%, slightly more than transport (IEA, 2013). A large share of the industrial energy demand is direct thermal energy, called industrial process heat (IPH). Processes like drying, evaporation, pasteurization, boiling, freezing and cooling, for instance, consume around 75% of the energy in the food industry (Do et al., 2014).

The main sectors are food and beverages including wine, textile, transport equipment, metal and plastic treatment, and chemicals, and the most suitable processes are cleaning, drying, evaporation and distillation, blanching, pasteurisation, sterilisation, cooking, melting, painting and surface treatment (Vannoni et al., 2008). Specifically, industrial sectors and processes with thermal demands ranging from 120 to 250 °C are food and beverages (drying, evaporation, pasteurisation and sterilisation), wood treatment (compressed and drying), paper (blanching, boiling and drying), chemicals (distillation), metal and plastic treatment (drying) and automotive industry (painting) (Kalogirou, 2003). The ECO-HEATCOOL study done in 32 countries,[1] reveals that 57% of the IPH demand is below 400 °C (Werner and Constantinesku, 2006).

Renewable resources are those which are constantly renewed, continuously supplying materials (Karana and Nijkamp, 2014; Zea Escamilla and Habert, 2014), food (Sánchez-Muros et al., 2014) and energy (Glavic and Lukman, 2007). Solar energy is an inherently renewable resource that represents an attractive option for supplying the industrial thermal demand in an environmentally–friendly manner, and thereby contributing to the implementation of industrial ecology. This concept informs

* Corresponding author.
E-mail address: fmanzano@ual.es (F. Manzano-Agugliaro).

[1] EU25 + Bulgaria, Romania, Turkey, Croatia, Iceland, Norway and Switzerland.

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Nomenclature

A_c	net aperture area (m^2)
C_c, C_d, C_e	coefficients for Zhukauskas correlation (–)
C_{geo}	geometric concentration ratio (–)
C_p	specific heat (J kg^{-1} K^{-1})
d	diameter (m)
e	thickness (m)
E_b	direct solar irradiance (Wm^{-2})
f	focal length (m)
f_{flu}	friction factor (–)
h	(convective) heat transfer coefficient (Wm^{-2} K^{-1})
$K(\varphi)$	incidence angle modifier (–)
k	thermal conductivity (Wm^{-1} K^{-1})
l	collector total length (m)
l_a	aperture width (m)
l_c	characteristic length (m)
Nu	Nusselt Number (–)
P_{gai}	heat power gain on the absorber tube in the two-dimension study (Wm^{-1})
P_{los}	heat losses to ambient in the two-dimensions study (Wm^{-1})
P_{sol}	solar radiation power incident on the collector in the two-dimensions study (Wm^{-1})
P_{use}	useful thermal power transferred to the working fluid in the two-dimension study (Wm^{-1})
Pr	Prandtl number (–)
Re	Reynolds number (–)
T	temperature (°C)
v	velocity (m s^{-1})

Greek symbols

α	solar absorptance (–)
β	acceptance angle (°)
γ	intercept factor (–)
ΔT	temperature difference (°C)
ε	thermal emittance (–)
ε_{gr}	grain height (μm)
η	efficiency (%)
ρ	density (kg m^{-3})
ρ_s	solar specular reflectance (–)
τ	solar hemispherical transmittance (–)
φ	incidence angle (°)
ψ	rim angle (°)
ϑ	dynamic viscosity (Pa·s)

Subscripts

abs	absorber
air	air
amb	ambient
ann	annular space
car	carbon
cav	cavity collector space
cov	cover
cr	Chrome
fla	flat
flu	heat transfer fluid
geo	geometric
inn	inner
opt	optical
out	outer
ove	overall
ref	reflector
sky	sky
ste	steel
tub	tubular
win	wind

Acronyms

CFD	computational fluid dynamics
CPC	compound parabolic concentrator
IEA	International Energy Agency
IPH	industrial process heat
PTC	parabolic-trough collector
S2S	surface to surface

decision-makers about the environmental impact of industrial processes by tracking and analysing resource use and flows of industrial and consumer products and waste (Duchin and Levine, 2008). According to Korhonen et al. (2004a), industrial ecology is based on using nature's model of recycling material, cascading energy and solar energy-based sustainable ecosystems to make wasteful, unsustainable, fossil fuel-based industrial systems more ecological. Industrial ecology is also related to the system development principles of natural ecosystems. Perhaps, the most commonly used such principle is "roundput", i.e., closed loops and reuse of waste by industrial actors who learn from natural ecosystem processes, where material cycles and energy cascades are the foundation of system operation, and solar energy is the only external input to this materially closed system which emits only waste energy or heat (Korhonen, 2004). Therefore, solar energy is one of the pillars of this concept, and has been included as an important theme in previous research (Lowe and Evans, 1995; Korhonen et al., 2004b). The use of solar energy systems (such as those proposed in this paper) to supply the energy required by industry permits clean manufacturing (because solar energy is a clean energy source), which, according to Despeisse et al. (2012), has a major role in the move towards a more sustainable society.

In 2007, there were about 90 solar IPH plants in operation worldwide, with a total capacity of about 25 MW_{th} (35,000 m^2)[2] (Vannoni et al., 2008). According to a study done by the IEA Solar Heating and Cooling Implementing Agreement, solar collectors for low-temperature IPH (<120 °C) could reach an installed capacity of 3.2 TW_{th}, producing around 7.2 EJ solar heat per year by 2050 (Frankl, 2012). Another study, performed by the United Nations Industrial Development Organization, predicts that solar thermal energy could contribute 5.6 EJ per year to industry by 2050 (UNIDO, 2012). It is also important to mention that the use of solar systems in the food industry could contribute to stabilizing food prices, reducing its strong dependency on fuel prices (Venegas-Reyes et al., 2012). Solar thermal energy plants require some maintenance, however, such tasks can easily be executed by the maintenance crew available at any industrial facility, hence ensuring operation of the system at peak efficiency (Kutscher et al., 1982).

The temperature requirements of solar IPH applications range from 60 °C to 260 °C (Kalogirou, 2003). Small-sized PTCs are an appropriate solar technology for covering the thermal energy

[2] China and Japan not included.