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Optimization of a combined solar chimney for desalination and power generation

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ABSTRACT

Large footprint and very low efficiency are main disadvantages of solar chimneys. To resolve this, solar desalination system has been added under the collector of a solar chimney power plant. Generally the collector ground is completely covered by the desalination pond but here it is shown that more benefit can be achieved by partial occupation of the collector area. This is performed by implementing the particle swarm optimization (PSO) algorithm in conjunction with a one dimensional simulation code. The code is first validated using data of a laboratory scale solar chimney. Then, optimization results show that for a collector diameter of 250 m and tower height of 200 m, a solar pond located between radii 85 and 125 m of the collector can maximize the outcome of the combined system. Generally, dimensions of the desalination system depend on local cost of building the system and price of electricity and fresh water produced.

1. Introduction

By approaching the end of fossil fuels era, researches about new sources of energy have attracted more and more attention. Solar radiation can be considered as a reliable source in countries having hot climates such that radiation intensities in the order of 1000 W/m^2 are common. Several technologies have been developed during the last century for harvesting this source such as photovoltaic, concentrators, desalinators and solar chimneys.

The concept of solar chimneys was first presented by Gunther in 1931 [1]. Several years after, the first pilot plant was built in Manzanares, Spain which had great impact on academic studies of solar chimneys. Based on experimental data published from this plant, several studies have been performed such as the works of Haaf [2,3]. Kasaeian et al. [4] have built a laboratory scale solar chimney in Zanjan, Iran. Their solar chimney did not have any turbine but accurate data about the temperature and velocity of air in the collector and tower section at different times were reported. Other experimental studies are also performed on small scale devices by Maia [5], Pasumarthi et al. [6] and Ghalamchi et al. [7]. These measurements are available and may be used for validation.

Theoretical study of solar chimneys is well reported in the literature. First thermodynamic analyses could be found in the work of Mullet [8] and Padki [9]. In these works, friction in the chimney is neglected and the velocity of air inside it is approximated very roughly. No distribution of state variable can be obtained with their method. A detailed mathematical model was developed by Pasumarthi et al. [10]. In their model, the collector is considered as a whole and some approximations have been used to estimate the average amount of heat transferred to the air. Gannon and Backstrom [11] performed a theoretical analysis considering different loss mechanisms and proposed a simple model for the collector. Their work includes chimney friction, system, turbine and exit kinetic energy losses at different sections. Similar results have been presented by Bernandes et al. [12]. The large footprint of a solar chimney and very low efficiency are major disadvantages of this system. Studies are performed to alleviate this problem by finding new applications for the solar chimney. To this end, agriculture was proposed and implemented in the Manzanares plant. With this idea, usable land could be saved and economic benefits could be added. Another concept includes implementing heat storing materials on the collector ground. By this method, the heat is absorbed during the day and released during nigh time. So, the availability of the chimney is extended at the cost of introducing a lag in its performance. Further details could be found in the work of Zhou et al. [13] and Rufuss et al. [14].

A new concept using solar chimney system to drive both power generation and seawater desalination systems was proposed by Wang et al. [15]. In this system, seawater supplied from the sea is exposed to air in the collector and thus producing warm and saturated air for the chimney. The vapor contained in the warm air is condensed to water

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Nomenclature

A	area
C	heat capacity
c	constant
d	diameter
eps	emissivity
F	force
f	friction factor
Fa	aspect factor
g	gravity
H	section height
h	convection factor
I	irradiation
k	conduction factor
L	latent heat of evaporation
m	mass flow rate
n	number
P	pressure
Pr	Prandtl number
q	heat transfer rate
Re	Reynolds number
r	radius
T	temperature
t	time
v	velocity
w	weight
x	particle position vector
y	local best value
$\hat{y}$	global best value
z	height/depth

Subscripts

a	ambient
bw	bracing wheel
c	glass cover
ct	cover temperature
ew	water evaporation
g	ground
gr	ground to roof
h	heat
hb	beam heat
hd	diffusive heat
p	at constant pressure
r	roof
ra	roof to ambient
rh	roof convection
rs	roof to sky
t	tower
wt	water temperature
w	water
g	ground

Greek letters

α	absorbtivity
β	transmissivity
θ	angle
ε	roughness
ρ	density
σ	Stefan-Boltzmann coefficient
τ	shear stress
μ	viscosity

using a condenser installed at the chimney top. The resulting freshwater having high gravitational potential energy is used for driving power turbines at the bottom of the tower. The performance of this combined system was compared with a classical one by Zhou et al. [16].

Another concept was presented by Zuo et al. [17] in which the collector ground is covered with solar distillation ponds. In this system the solar energy is first absorbed by the insulated desalinator ground and thus heating the water layer above it. The resulting vapor is condensed on the desalinator glass roof and collected with predefined tubes. The desalinator roof is then cooled by the air moving through the collector and thus providing warm updraft air for the chimney. So the idea is to integrate a solar distillation system under the collector of a solar chimney. With a simplified model, they have shown that the efficiency of a solar chimney can be improved from 0.74% to 55.35%. Zuo et al. [18] built a small experimental setup for the combined solar chimney system and found that the efficiency of this system was not more than 25% which is notably lower than his prediction.

In the latter concept, the collector area is fully occupied by the desalination system while no obligation exists for this. Here, it is proposed that the desalination system may only be installed in some

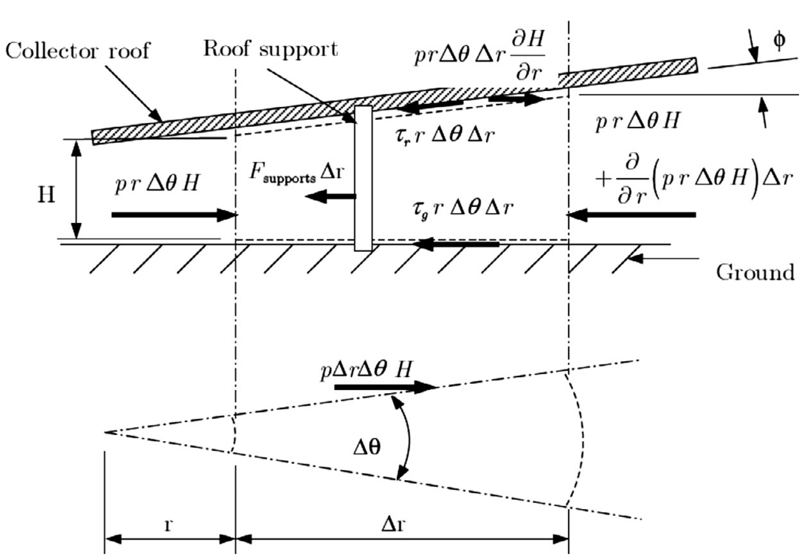

Fig. 1. Forces applied on a sample C.V.