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Hybrid transpired solar collector updraft tower

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ABSTRACT

A novel hybrid solar updraft tower prototype, which consists of photovoltaic panels and transpired solar collector, is studied, its function principle is described and its experimental performance is presented for the first time. A test unit of transpired solar collector updraft tower was installed at the campus of Trakya University Engineering Faculty in Edirne-Turkey in 2015. PV modules cover 42% of transpired solar collector area. PV and turbine power output, solar radiation, ambient temperature, temperature rise, collector cavity temperatures, and chimney velocities were monitored during 18 months. The results showed that hybrid solar updraft tower efficiency increased by about 2% in average compared to stand-alone PV system. The temperature rise in hybrid solar updraft tower is found to be 12–14 °C on the typical sunny day. Energy was produced continuously for 24 h. The results showed that solar utilization ranges from 60% to 80% during daytime.

1. Introduction

Climate changing and rising demand for energy accelerate usage of renewable energy technologies; particularly the use of solar power plants has become more attractive in recent years among all renewable energy systems. However, high investment costs, relatively low energy conversion efficiencies and longer payback periods of investment in solar power production prevent these systems' wide use, especially in developing countries. On the other hand, low energy yields of solar power systems increase the amount of required land for specific energy production target. Also, monotype technologies lead to inefficient land management in terms of solar power production. In general, main problems in solar power production are as follows: low efficiency, high amount of land in use, monotype technology, low energy production, high investment costs and longer payback periods. Considering current solar power systems, one of the methods to overcome these problems can be a hybridization of different solar power technologies. With this purpose in mind, in this study, two different solar power technologies, photovoltaic and solar updraft tower, are combined to find a potential solution for the aforementioned problems.

Modern solar updraft towers (SUT) are relatively new, attractive topic for scientists because it includes multi-disciplinary physics, but less known for end-users because it is not used in commercial systems and not available in the market, as described in relevant literature (Bennett, 1896; Cabanyes, 1903; Günther, 1931; Ley, 1954; Schlaich et al., 1980). One of the main reasons for non-commercial-experimental level of SUT is very low energy conversion efficiency, compared to other solar power technologies, and large construction requirements (Zhou and Xu, 2016; Haaf et al., 1983; Haaf, 1984). However, it can be stated that SUT research and development works are in the beginning phase at the moment, and there are big opportunities to develop SUT systems. Recent works showed that SUT performance can be increased significantly by using some new methods and different configurations. Some recent and important works on the performance of SUT can be lined up as follows. Hollick and Eryener (2015, 2016) invented a new method to produce hot air for SUT systems and offered a transpired solar collector updraft tower. Experimental test of transpired solar collector updraft tower showed that thermal efficiency is increased 3 times and land requirements can be reduced by more than 50% (Eryener et al., 2017). Koonsrisuk and Chitsomboon (2013) showed that convergent-divergent solar updraft tower configuration chimney can produce several hundred times more power than a conventional solar updraft power plant. Hu et al. (2017) studied a divergent tower configurations theoretically for SUT and found that a divergent tower could produce power output of 680 kW instead of obtained output of 48 kW for the first modern SUT in Manzanares in the 90s. Okada et al. (2015) studied diffuser tower experimentally and showed that power output can be increased by 3 times compared to conventional tower. Cottam et al. (2016) showed that canopy design has a big effect on SUT performance and proposed a new collector profile to increase power output. Moreover, double collector configurations are proposed by several researchers to improve performance (Pretorius, 2007; Pretorius and Kröger, 2006). All these studies show that solar updraft tower research and development can be considered relatively new and there is a

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Nomenclature

Abbreviations

A	surface (m^2)
c_p	specific heat capacity ($J\,kg^{-1}\,°C^{-1}$)
F	view factor (–)
G	solar irradiation ($W\,m^{-2}$)
h	heat transfer coefficient ($W/m^2\,°C$)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
T	temperature (°C)
$\dot{Q}$	heat (W)

Subscripts and abbreviations

cav	cavity
cg	collector-ground
coll	collector
con	convection
cs	collector-sky
gr	ground
in	inlet
out	outlet
HYB	hybrid
r	reference
rad	radiation
therm	thermal
TSC	transpired solar collector
TSCUT	transpired solar collector updraft tower
turb	turbine
SUT	solar updraft tower
sur	surroundings
PV	photovoltaic panel
PVT	photovoltaic thermal

Greek letters

ε	emissivity
σ_{SB}	Stefan-Boltzmann constant
βp	PV module temperature coefficient for efficiency
η_p	PV module efficiency
η_p	reference PV module efficiency at standard conditions

big potential to increase SUT performance by applying new methods.

In order to produce more power from the large area of solar collector in SUT, some hybridization was proposed by various researchers for the use of geothermal sources and compost waste heat (Anderson et al., 2016; Cao et al., 2014). Some mountain-SUT arrangements are studied to increase power naturally (Bilgen and Rheault, 2005; Zhou and Yang, 2009). Some of these proposals also include photovoltaic panels, namely multiple technologies are combined theoretically such as Geothermal/PV/SUT or Compost Waste/PV/SUT (Anderson et al., 2016; Chen et al., 2014; Zhou et al., 2009). All these studies show another aspect of SUT systems: SUT systems can be combined with any kind of heat source, however, none of them were realized as either commercial or experimental projects.

The present study provides experimental performance of a hybrid solar updraft tower test unit which was installed at the campus of Trakya University Engineering Faculty in Edirne-Turkey in 2015. Solar radiation, PV power output, chimney turbine power output, ambient temperature, collector cavity temperatures, and chimney velocity data were monitored for two years. Total efficiency was determined and potential power of SUT system was analyzed.

2. Experimental setup

In order to see performance of photovoltaic integrated transpired solar collector updraft tower, a pilot experimental prototype was built at the campus of Trakya University Engineering Faculty, Edirne, Turkey in 2015. The roof is composed of transpired solar collector, photovoltaic and glazed polycarbonate panels. Photovoltaic panels are integrated into transpired solar collectors, and glazed polycarbonate panels were installed to provide daylight to facilitate plant growth and to

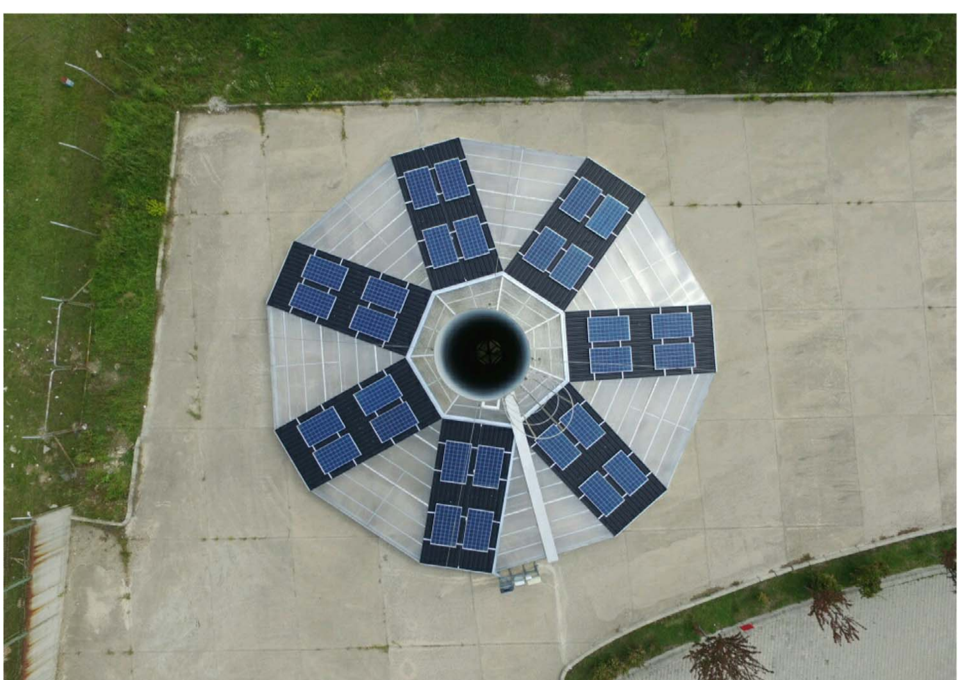

Fig. 1. Top view of hybrid SUT.