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Effect of Divergent Chimneys on the Performance of a Solar Chimney Power Plant

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Abstract

This paper numerically examined the performance of divergent chimneys in solar chimney power plants with two shape-controlling parameters, that is, the area ratio of the chimney exit over the entrance and the divergent angle. Compared with the conventional cylindrical chimneys, a higher power output in the divergent-chimney system could be achieved. This enhancement effect, however, increased first and then declined with increasing the area ratio or the divergent angle. Furthermore, subsequent parametric studies indicated that the area ratio and the divergent angle have different impacts on this enhancement effect: the area ratio may dominate the strength of the enhancement effect while the divergent angle may dominate the change rate of the enhancement effect along the varying shape-controlling parameters.

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Keywords: Solar chimney power plant; Divergent chimney; Area ratio; Divergent angle; CFD.

1. Introduction

A solar chimney power plant (SCPP) utilizes the air heated by sunlight to generate a buoyancy-driven updraft inside a gigantic chimney which can drive one or more wind turbines for power generation (as shown in Fig. 1). The chimney works as a thermal engine converting the internal energy of the air into mechanical energy, which is known as the stack (or chimney) effect. Hence, it is easy to understand that the chimney is one of the critical components in a SCPP. Earlier theoretical analysis revealed that both the height and the radius of the chimney have a critical role in determining the power output of SCPPs [1-2]. Furthermore, an optimal height-to-radius ratio of the chimney was claimed based on a 10MW SCPP with an 800m-high chimney [3]. At the same time, for commercial application of SCPPs of MW size, several designs of the chimney with heights varying from 500 to 1500 m were proposed in previous studies [4].

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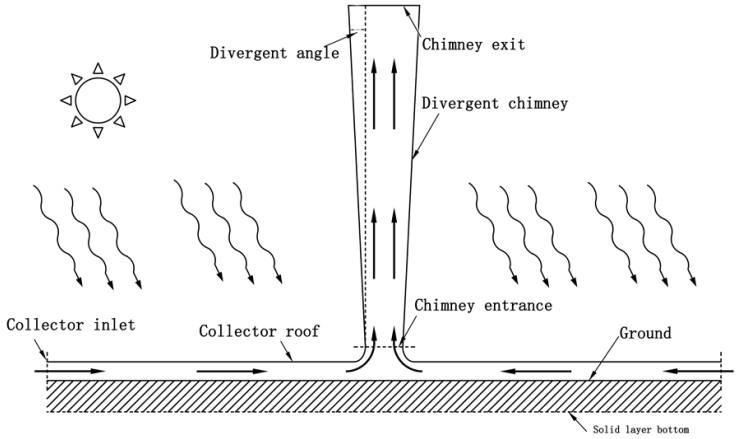

Fig. 1. A schematic of divergent solar chimney power plant.

In recent years, the chimney shape has been discussed from the perspective of system performance. Table 1 summarizes publications in which the cylindrical-chimney SCPPs was compared with the divergent-chimney SCPPs. Obviously, the divergent chimneys showed a better performance compared with the cylindrical chimneys in the numerical and the experimental outcomes. Besides, the numerical simulation indicated that the performance of the divergent solar chimney was governed by some shape-controlling parameters, that is, the Divergent Angle (DA) [6, 7] and the Area Ratio (AR) of the divergent chimney exit over its entrance [1, 5]. Notably, the power output of the divergent chimneys in Table 1 varied very much in different studies, which may be attributed to two issues: (1) authors used different dimensions of SCPPs for testing the divergent chimneys; and (2) different shape-controlling parameters were adopted for defining the shape of the chimneys. Nevertheless, based on the results of previous studies, the better performance of the divergent chimneys should be distinctly stated.

Table 1. Publications on the chimney shape impact on the performance of SCPPs.

Paper	System dimension	Chimney shape	Power output*
Koonsrisuk *et al.* (2013) [5]	Collector dia.: 200 m; chimney height: 100 m	Area ratio: 0.25 to 16.0	0.06 to 179.16
Ming *et al.* (2013) [3]	Collector dia.: 2000 m; chimney height: 800 m	Area ratio: 0.25 to 2.25	0.80 to 1.07
Patel *et al.* (2014) [6]	Collector dia.: 0.6 m; chimney height: 10 m	Divergent angle: 0° to 3°	1.0 to 9.8
Okada *et al.* (2015) [7]	Collector dia.: 0.66 m; chimney height: 0.40 m	Divergent angle: 4°	~3.0

* Normalized by the power output in the cylindrical-chimney SCPPs

The aim of this study is to numerically investigate the enhancement in the SCPP performance of using divergent chimneys through a serial of parametric studies. The discussed parameters included the dimensions of the SCPPs and two shape-controlling parameters, namely the Divergent Angle (DA) and the Area Ratio (AR). Three chimney heights were considered in the numerical study. For each chimney height, the shape of the divergent chimneys was further defined with the AR and the DA, respectively. By this, we supposed to discuss whether the variation in the performance of the divergent chimney along the two shape-controlling parameters would be independent of the chimney heights or not. On the other hand,