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# Comprehensive study of wind supercharged solar chimney power plant combined with seawater desalination

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ABSTRACT

In this study, a model of wind supercharged solar chimney power plant combined with seawater desalination (WSSCPPCSD) was proposed. The integrated system was divided into wind pressure ventilator and solar chimney power generation system for numerical simulation. Three-dimensional unsteady state numerical investigation on wind pressure ventilator was carried out as well as steady state numerical study on the solar chimney power generation system. The flow field characteristics and performance parameters of the two subsystems were analyzed. Subsequently, the comparison between solar chimney power plant (SCPP), solar chimney power plant combined with seawater desalination (SCPPCSD) and WSSCPPCSD was conducted. The results show that, although SCPPCSD can greatly improve the solar energy comprehensive utilization, the power generation is reduced. The wind pressure ventilator proposed in this paper could not only significantly increase the power generation but also increase the freshwater production by providing a negative pressure of 64.5 Pa at the chimney outlet. It was found that at 800 W/m$^2$, an increase in power output of about 14.7 kW and increase in hourly freshwater production of 30 g/h were obtained.

## 1. Introduction

Solar chimney technology is one of the feasible ways to achieve large-scale utilization of solar energy, which integrates collector technology, chimney technology and wind turbine technology. The concept of solar chimney on power generation technology was first described by Spanish Artillery Colonel, Isidoro Cabanyes (1903)which was later employed in the design and construction of the first practical solar chimney power plant in Manzanares pioneered by Prof. Schlaich and his colleagues (Robert 1981). This prototype plant of 50 kW operated from 1982 to 1989 until being destroyed by a storm, which verified the technical feasibility of solar chimney power plant (SCPP). The experimental results of Spanish prototype were reported in Haaf (1984), which also involved analysis of energy balance, collector efficiency, pressure losses in the turbine section, along with the power generation cost.

This attempt has greatly stimulated the research in this field. In order to evaluate the impact of various factors on the performance o

f the solar chimney power plant, an ideal air standard cycle analysis with the main losses and the collector model was carried out by Gannon and von Backström (2000). Dai et al. (2003) proposed a simple model of SCPP to analyze the influence of geometric sizes, environment condition and some relevant coefficients on the output power. Ming et al. (2008a) did a numerical simulation of solar chimney power plant coupled with turbine, and studied the effect of turbine rotational speed on system performance. Afterwards, the heat storage was included in the simulation to analyze the system flow and heat transfer characteristics, together with the heat storage performance under different irradiance (Ming et al. 2008b). Effects of heat storage thermal properties and soil compactness were analyzed by Hurtado et al. (2012) and Bernardes (2013). The effect of external crosswind on system was studied by Ming et al. (2012) through numerical simulation, and they reported that, the crosswind could be positive for the system when its velocity is above 15 m/s. This factor was also analyzed by Zhou et al. (2012), and the variation of enlargement degree on inflow with the chimney height and collector size was included. Considering the radiation heat transfer in the collector, Guo et al. (2014) did a numerical simulation which coupled with radiation, solar load and the fan model, then in Guo et al. (2015), they replaced the previous fan model with a real turbine model, and carried out a comparison between results of these two methods. Recently, the effects of blade number, rotational speed, collector diameter, and chimney height were reported in a numerical study by Kasaeian et al. (2017).

In order to make it possible and economic for the commercial application of large-scale Solar Chimney Power Plant, great efforts have been devoted to finding a new design structure or to improving the

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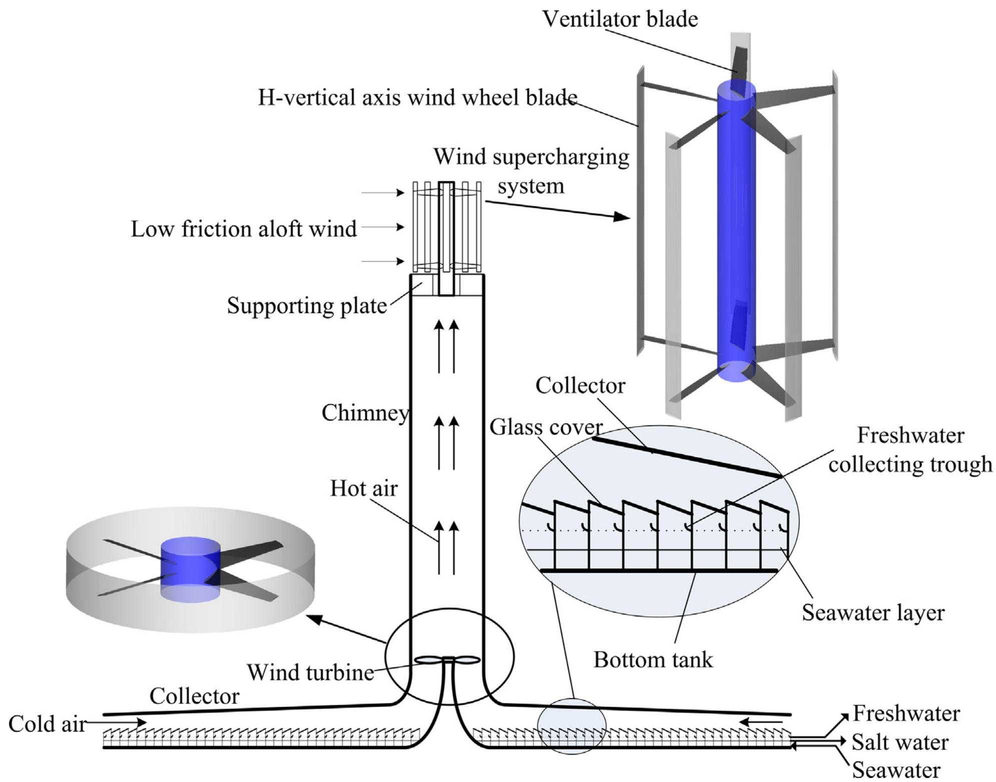


**Fig. 1.** Schematic diagram of WSSCPPCSD system structure.

efficiency with a constant even reduced chimney height. Papageorgiou (2004) firstly proposed the concept of floating solar chimney technology, and it was proved to be more cost competitive compared with other renewable technology by Papageorgiou (2007) and Zhou et al. (2008). Bilgen and Rheault (2005) proposed the design of sloped solar updraft power plant with the collector built on sloped surface or suitable hills, which is applicable for mountainous region. They reported that the chimney height might be reduced by almost 90% and the thermal performance is slightly improved. Li et al., 2012 proposed a solar and wind energy extraction system, which combined a tornado-type wind tower with SCPP. They found that, the pressure deficit generated by tornado-type wind tower could greatly improve the power generation capacity with the utilization of high-elevation wind energy, which means that the height can be greatly reduced compared with the same rated conventional SCPP.

In addition, limited by the relatively low overall efficiency of conventional SCPP, the coupling of solar chimney technology and other renewable technologies becomes a new competitive option, which can improve the comprehensive utilization of solar energy and achieve multiple objectives simultaneously. Wang et al. (2006) proposed an integrated system for output of electricity and freshwater, the climbing saturated moist air got condensed in the heat exchanger installed at the chimney outlet, and then the freshwater was used to drive the hydraulic turbine to obtain power output. Based on this structure, some improvements were made by Zhou et al. (2010), and then a comparison between conventional SCPP and combined solar chimney system for power generation and seawater desalination (CSCSPD) was conducted. The research reported that the temperature, air velocity and power generation in CSCSPD were both lower compared with conventional SCPP. Zuo et al. (2011) proposed a new solar chimney power system with integration of sea water desalination (SCPPCSD), in which closed seawater desalination zone (disk solar distiller) was adopted to replace the heat storage layer, then the mathematical model was developed and benefit analysis was conducted. In addition, Zuo et al. (2012) built up an experimental system to verify the feasibility of this integrated system, and the results showed that the solar energy utilization efficiency was significantly improved in SCPPCSD. Niroomand and Amidpour (2013) proposed a new combination of solar chimney and Humidification-Dehumidification desalination process, and discussed the effects of tube number, humidifier inlet water temperature and its mass flow rate on the performance of this process, the results also reported that with the increase of freshwater output, the power output would decrease.

Obviously, the reduction in electricity generated by the coupled system constitutes challenge to the commercialization of Solar Chimney Power Plant. This is because the pressure difference in the integrated system is affected as part of the energy gained at the collector was used for desalination, thus leading to slight decrease in system average temperature and consequently reduction in the pressure difference between the system air and the ambient air. This results in reduction to the power generation capacity of the coupled system in comparison to the operation of conventional SCPP.

Considering the performance challenges associated with SCPPCSD, a novel Wind Supercharged Solar Chimney Power Plant Combined with Seawater Desalination (WSSCPPCSD) was proposed. The model has an integration of supercharged wind pressure ventilator installed at the chimney exit of SCPPCSD aimed at improving the performance. The numerical study on the proposed system was divided into two components to study the operations of the solar chimney power generation system and the wind pressure ventilator. The study of the flow field characteristics and performance parameters of the system involves unsteady state numerical simulation of the wind pressure ventilator and steady state numerical simulation of solar chimney power generation system. Besides, a comparison between SCPP, SCPPCSD and WSSCPPCSD was conducted to analyze the effects of the coupling of wind pressure ventilator.