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Numerical study of a solar chimney power generation system coupled with turbine

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***Abstract*— Numerical simulations have been performed to analyze a solar chimney power generating plant which consists of four components, collector, chimney, turbine and soil. The turbine is an important component of the plant as it extracts the energy from the air and transmits it to the generator. It has significant influence on the plant as its pressure drop and plant mass flow rate are coupled. Firstly, a comparison between the numerical results and experimental data was carried out to verify the validity of the numerical method in this study. The effect of solar radiation and pressure drop on the output power has been analyzed. The numerical simulation results show that: (1) the output power increases firstly and then decreases with the pressure drop increasing from to 250 Pa; (2) the flow rate decrease with the increase of pressure drop; (3) the updraft velocity increases significantly inside the system with the increase of solar radiation and pressure drop. In addition the output power depends strongly on solar radiation and the position of the turbine inside the chimney.**

***Keywords*— Simulation, CFD, turbine, output power, pressure drop.**

I. INTRODUCTION

Being the most abundant and well distributed form of renewable energy, solar energy constitutes a big asset for arid and semi-arid regions. A range of solar technologies are used throughout the world to harvest the sun‘s energy. In the last years, an exciting innovation has been introduced by researchers called solar chimney. It is a solar thermal driven electrical power generation plant which converts the solar thermal energy into electrical power in a complex heat transfer process. The implementation of this project is of great significance for the development of new energy resources and the commercialization of power generating systems of this type and will help developing countries to promote the rapid development of the solar hot air-flows power generation [Chen et al., (2010)]. In order to predict solar chimney conversion unit performance various mathematical models have been developed. The following literature survey focuses on the solar chimney turbines. Many studies were conducted to evaluate the performance of a solar chimney coupled to a turbine. 3-D Numerical simulation of the solar chimney power plant couple with turbine conducted by [Ming et al., (2008)] indicated that it is a little difficult to simulate the turbine region and much more meshes are needed to accurately describe flow, heat transfer and output power performances of the system. It was concluded that it is impossible to realize the simulation procedure simultaneously including regions of the solar chimney power plant system, the ambience and the 3-D turbine due to the limitation of grids number. The research work conducted by [Pastohr et al., (2004)] indicated years ago that it is also an efficient way to realize the object by simplifying the 3-D turbine to be a 2-D reversed fan with pressure drop across it being pre-set. This method was also verified by [Xu et al., (2011)] and [Ming et al., (2011)] and was proven to be effective to alleviate the mesh pressure by 3-D turbine region without significantly total performance of solar chimney power plant. Ming et al. conducted a study considering the turbine as a reversed fan with pressure drop across it being pre-set although 3-D model for the solar chimney power plant and the ambience is selected. Conversion of fluid energy to electrical power depends primarily on the operation of the turbine.

In this study, a simulation is carried out to study numerically a solar chimney power generation system coupled to a turbine using the Spanish prototype as a practical example. The main focus of the present paper is the evaluation of the power output. The solar radiation, the pressure drop as well as the position of the turbine were all being taken into consideration in the analysis.

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II. WORKING PRINCIPLE

Solar chimney power plant is a sustainable source of power production. The system has three main components: Collector, chimney and turbine. The collector absorbs heat energy from solar radiations, the air inside the collector moves due to buoyancy effects and finally reaches the center of the chimney with a certain velocity. The turbine located there rotates by extracting the kinetic energy of the air. Finally this kinetic energy is converted to electric power (see figure 1).

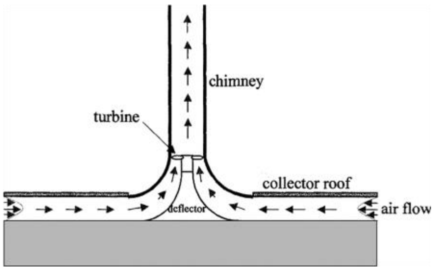

Fig. 1 Solar chimney power plant scheme

III. NUMERICAL METHOD

A physical model for a solar chimney power plant was built based on the geometrical dimensions of the prototype Manzanares. The governing equations were numerically solved with the help of the commercial simulation program FLUENT (version 6.3). The basic equations were simplified to axisymmetric and steady state. The turbulence model chosen for the description of the turbulent flow conditions was the standard k–ε model. The standard wall mode was selected. To obtain a more accurate performance prediction of the solar chimney power plant, the discrete ordinates (DO) radiation model was adopted in this numerical simulation. The plant was divided into four parts: the collector, the chimney, the turbine and the soil. The main boundary conditions are illustrated in figure 2 and Table 1.

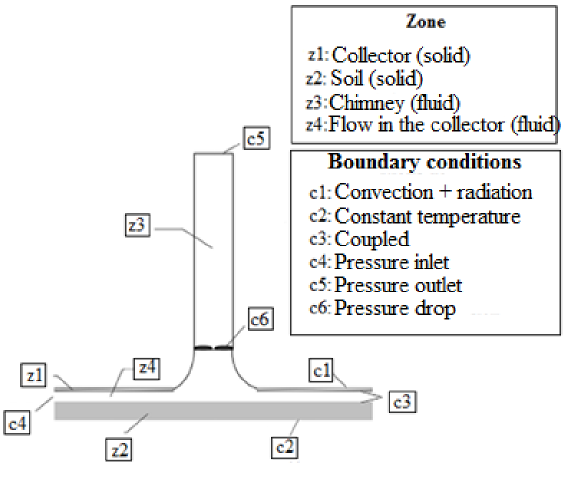

Fig. 2 Boundary conditions

The main dimensions for the Spanish prototype are: the chimney is 194.6 m high and 10.16 m in diameter; the collector is 1.85 m high and 244 m in diameter. The turbine of the solar chimney is an important component of the plant as it extracts the energy from the air and transmits it to the generator. It has significant influence on the plant. In this work, the turbine is regarded as a reversed fan with pressure drop across it being pre-set.

TABLE I
BOUNDARY CONDITIONS

Position	Type	Value
Collector inlet	Pressure inlet	T_0=293 K, ΔP=0 Pa
Chimney outlet	Pressure outlet	ΔP=0 Pa
Cover	Convection+radiation	h=8 W/m^2.K, T_0=293 K
Ground	Constant temperature	T=$T_{ambiant}$
Chimney wall	wall	0 W/m^2
bend	wall	0 W/m^2
Soil-face	wall	0 W/m^2
Air-soil	wall	Coupled
Turbine	Reverse fan	$\Delta P_{turbine}$

IV. RESULTS AND DISCUSSIONS

A. Validation Results

The numerical method was validated using the experimental data of the Spanish prototype obtained from the literature [(Schlaich et al., (2005)]. Comparison between the numerical results and experimental data was carried out to verify the validity of the numerical method in this study. As shown in Figs. 3 and 4, the simulation results were quite consistent with the experimental data.

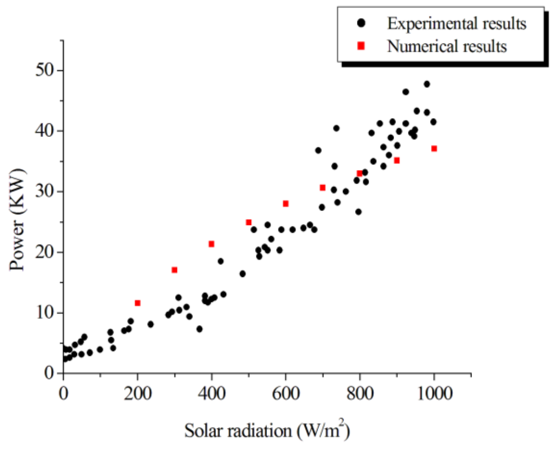

Fig. 3 Comparison of output power between simulation results and experimental data

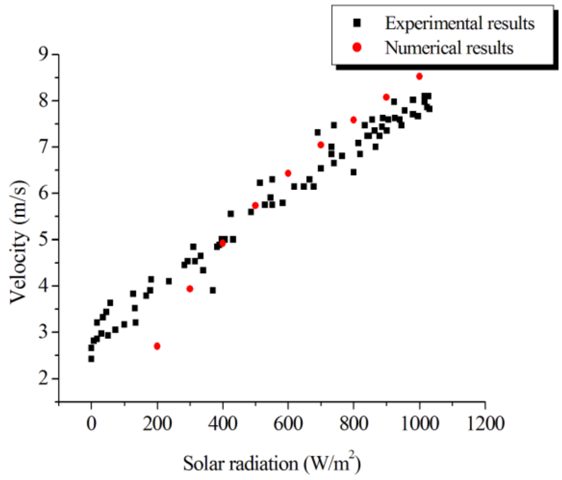

Fig. 4 Comparison of updraft velocity between simulation results and experimental data

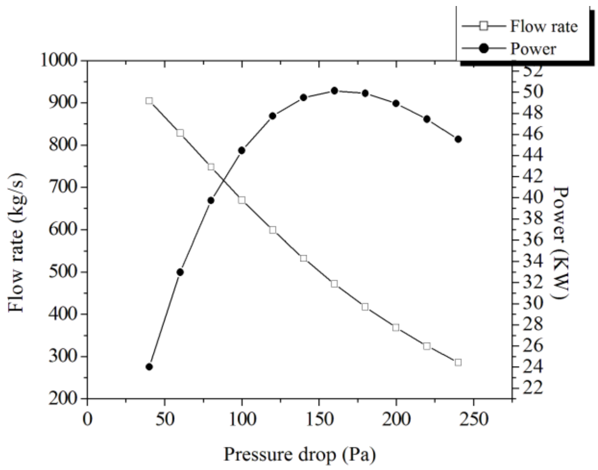

Fig. 5 Effect of pressure drop on mass flow rate and output power distributions

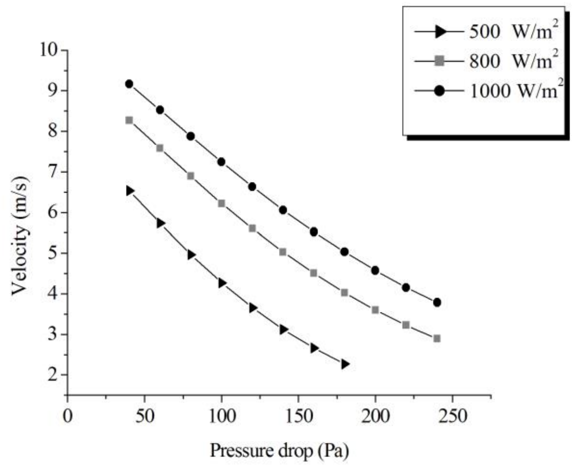

Fig. 6 Variation of updraft velocity versus solar radiation and pressure drop

B. Study of a Chimney Coupled to a Turbine

To study the effect of pressure drop on output power of the turbine and mass flow rate, we assign the pressure drop a group of values ranging from 0 to 250 Pa at an interval of 20 Pa. the output power of this model was calculated according to the following equation:

$$P = \eta \Delta p \dot{m} \qquad (1)$$

Fig. 5 shows the influence of the pressure drop (ΔP) on the power and mass flow rate profiles for a constant solar radiation (800 W/m^2). It implies that, when the pressure drop increases, the mass flow rate decreases. This figure also demonstrates that increasing pressure drop results in an increase in the output power. When the pressure drop exceeds 150 Pa the output power gradually decreases.

Fig. 6 illustrates the updraft velocity distribution in the solar chimney power plant for three different solar radiations. Numerical simulations were carried out for the Spanish prototype by setting the solar radiation at 500 W/m^2, 800 W/m^2 and 1000 W/m^2 and the updraft velocity in the chimney was calculated by adjusting the values of pressure drop across the turbine.

As shown in this figure, when the turbine pressure drop remains constant, the air velocity of the system increases with the increase of solar radiation. It indicates also that the updraft velocity decreases notably with increasing turbine pressure drop. From fig.5 and 6, it can be concluded that the turbine pressure drop is a key factor that influence the performance of the solar chimney power plant.

C. Effect of the Turbine Position

For a given solar chimney power plant system, the position of the turbine installed inside the system might be an important problem requiring further discussion. In this work, we have studied the effect of the position of the turbine inside the chimney on the output power produced by the system. Figure 7 displays how the output power, which represents the ability of the solar chimney to convert the solar and wind energy into electric energy, can be influenced by the position of the turbine and solar radiation. As we can see from the fig. 7, as the turbine is positioned at a higher position the velocity will develop more so the power output does. But as the turbine is positioned at a higher position inside the chimney it will complicate the maintenance of the system so this means more investment cost which is uneconomical. For this reason turbine should be placed near the bottom of the tower, for ease of access for maintenance and easy connection to the generating equipment [Pasumarthi et al., (1998)].

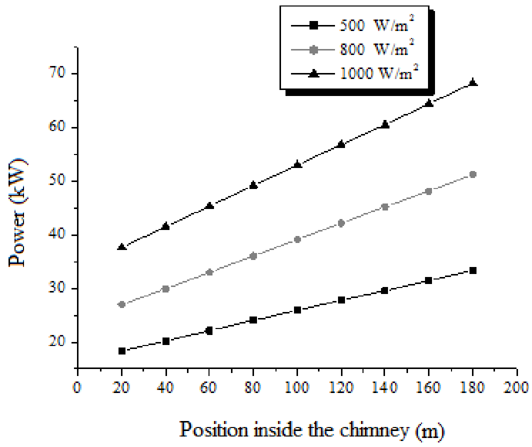

Fig. 7 Effect of varying the position of the turbine

Figs.7 illustrates the output power distribution in the solar chimney power plant for three different solar radiations (500,800 and 1000 W/m^2). It shows that for a fixed position of the turbine, the power depends strongly on the solar radiation variation.

V. CONCLUSIONS

In this work a numerical model of a solar chimney power plant coupled to a turbine was developed. The numerical results for velocity at the chimney inlet and electrical power output were in close agreement with experimental data of the Manzanares prototype power plant. Through the detailed numerical simulations, this paper has investigated the influences of various parameters on solar chimney output power performances such as the solar radiation, the pressure drop and the position of the turbine inside the system. The numerical simulation results revealed that the turbine pressure drop has a great influence on the distribution of the mass flow rate and updraft velocity. It was found also that the output power mainly varied with a change in solar radiation and position of the turbine inside the chimney. It indicated also that for economic, obvious engineering and practical reasons, the turbine should be always placed at the base of the chimney.

REFERENCES

[1] Y.Chen, Y.Yang, Y.Wei, Y. Jing-Hui and Y. Tian , "沙漠太阳能热风发电技术及其应用", Energy Research and Information, vol. 26, N°2, pp. 117-121, 2010.

[2] T.Z. Ming, W. Liu, G.L. Xu, Y.B. Xiong, X.H. Guan, and Y. Pan, "Numerical simulation of the solar chimney power plant systems coupled with turbine", Renewable Energy, vol. 33, pp.897–905, 2008..

[3] H. Pastohr, O. Kornadt, and K. Gürlebeck, "Numerical and analytical calculations of the temperature and flow field in the upwind power plant", International Journal of Energy Research, vol. 28, N°6, pp. 495–510, 2004.

[4] H.Pastohr, Thermodynamische Modellierung eines Aufwindkraftwerkes. PhD thesis, der Bauhaus-Universität Weimar, Germany, 2004.

[5] G. Xu, T. Ming, Y.Pan, F. Meng, and C. Zhou, "Numerical analysis on the performance of solar chimney power plant system", Energy Conversion and Management, vol. 52, N° 2, pp. 876-883, 2011.

[6] T.Z. Ming, R.K. de Richter, F.L. Meng, Y. Pan, and W. Liu, "Chimney shape numerical study for solar chimney power generating systems", International Journal of Energy Research, 2011.

[7] J. Schlaich, R. Bergermann, W. Schiel, and G. Weinrebe, "Design of Commercial Solar Updraft Tower Systems-Utilization of Solar Induced Convective Flows for Power Generation", Journal of solar energy engineering, vol. **127, N° 1**, pp. 117-124, 2005.

[8] N. Pasumarthi, S.A. Sherif, "Experimental and theoretical performance of a demonstration solar chimney model Part I: mathematical model development", International Journal of Energy Research; vol. 22, N° 3, pp. 277-288, 1998.

[9] Fluent Inc., 2005. Fluent 6.3 User Guide.