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Fluid mechanics analysis and realization of electric and program for solar chimney power generation project—a case in China

Abstract. *Utilization of solar chimney power generation project has proved to be a promising approach for future applications. This paper gives the fluid mechanics analysis and electric and program realize for a solar chimney power generation project located in Taiyuan. Three groups geometric parameters of project is assumed such as chimney diameter, outer limit height of collector, and tilted angle of collector, and the output characteristics at different parameters is discussed to gain the optimal designed structure. Then the overall structure of system is designed to achieve the real-time data acquisition and system control. Finally, the control software and test hardware is designed based on the proposed overall structure of system, and the experimental and simulation results prove the correctness and effectiveness of designed solar chimney power generation system.*

Streszczenie. *W artykule analizuje się mechanikę przepływu strumienia ciepła z systemie elektrowni słonecznej z kominem solarnym. Układ analizuje się na przykładzie takich elektrowni usytuowanych w prowincji Taiyan w Chinach. Przedstawiono projekt elektrowni, badania właściwości oraz oprogramowanie. (**Analiza mechaniki strumienia ciepła w projekcie elektrowni słonecznych z kominem solarnym na przykładzie systemu zrealizowanego w Chinach**)*

Keywords: solar chimney power; fluid mechanics analysis; experimental measurements.
Słowa kluczowe: elektrownie słoneczne, komina solarny, mechanika strumieni ciepła.

Introduction

At present, the annual consumption of fossil resources in the whole world is more than billions of tons such as coal, oil, and natural gas, which belongs to the non-renewable resources, and the large scale fossil resources consumption has bring a serious of environmental issues, such as air pollution, water pollution, and global warming, etc. The renewable and sustainable energy is used to alternative the conventional fossil resource such as solar energy, wind energy, tidal energy, and biomass energy, etc. The exploration and exploitation of renewable resources has been considered by the whole world, no matter developed country or developing country. It is well known that China is the largest developing country in the world, and the Gross Domestic Product (GDP) in 2011 is about 7,400 billion dollars, which ranks the second in the whole world, just behind of USA, and the total energy consumption is approximately equal to America. For example, the total consumption amount of coal and oil are more than 2.74 and 0.36 billion tons in 2008, respectively, and natural gas is about 80.7 billion m^3 [1]. The coal in the total energy structure has a large share of 70% in the past 30 years, which has brought a series of environmental problem such as greenhouse air emissions, acid rain, soil pollution, and so on. The total pollution loss accounts for 10% of Chinese Gross Domestic Product over the past 10 years [2]. The inappropriate energy supply structure in China must be changed to realize the sustainable development of country and society in future [3-5]. Chinese central government and local governments have realized the serious question, and the application of renewable resources has come into the rapid development stage to improve current inappropriate energy structure. For example, some photovoltaic (PV) power stations have been established in western area of China, and the averagely installed capability is more than 100MW. And the accumulative installed capability of wind power system in 2010 is more than 41,827MW and ranks the first in the world [6].

The solar energy is the most abundant renewable resource as compare with other renewable energy. And the solar energy resource in China is abundant. Especially, the western area has the best solar radiation, which is more than Japan, Russia, and Korea, and so on. At present, some application examples are used to improve the inappropriate energy structure of China, such as PV power station, solar water heater, and solar greenhouse, etc [4]. But there are little researcher consider the application of Solar Chimney. The surface of western area in China is covered largely by desert and gobi, and natural condition is very bad, but there are the best solar resource. So the solar Chimney technology is gradually considered by Chinese government and enterprises. The solar chimney system consists of three parts: the collector, turbines and the chimney, which is suggested by Professor Schlaich of Stuttgart University in 1978. As shown in Fig.1, a circular transparent canopy or roof raised a certain height from the ground, with a chimney or circular tower at its centre, and there are more than one turbine generators located at its base. The solar radiation penetrates the roof of collector and strikes the ground surface beneath it, and the air is heated, which flows toward and up into the central chimney to drive the generator [7]. Here, d_c and d_G is the diameter of chimney and collector, respectively. And H_c, H_1 and H_2 is the height of chimney, the lowest height and highest height of collector, respectively. Many literatures have described the technologies of solar chimney such as modeling, elementary theory of stationary vortex columns, thermal analyses, and numerical analysis, etc [8-16]. But the actual example of solar chimney in China is a little, and the only testing project is established by Huazhong University of Science and Technology. Fortunately, some Chinese enterprises have realized the question, and some basic research of solar chimney power system began in a few years ago.

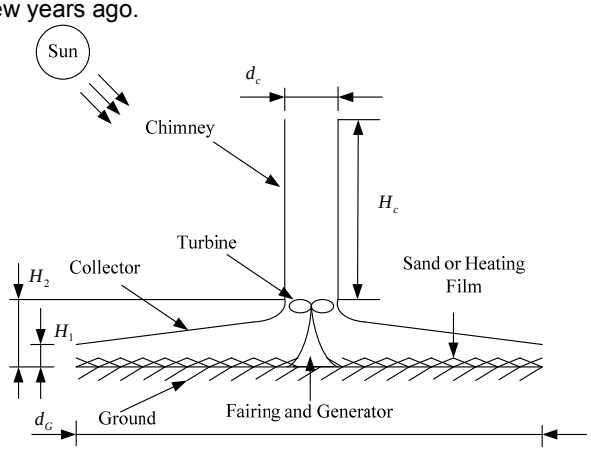

Fig.1. Schematic diagram of a solar chimney power plant

A Chinese project is introduced in this paper, which will be established Taiyuan University of science & technology located in Taiyuan, the capital of Shanxi province, and the thermodynamic analysis, detection circuitry and electrical equipment is discussed and designed in the follow section, respectively. The purpose is to cause the attention of solar chimney application of Chinese experts.

Project introduce

Taiyuan is the capital of Shanxi province, which located in the central area of China. The solar chimney project is cooperative researched by Taiyuan University of science & technology and Shanxi international electric PV power Co., LTD. The related techniques of this test items is used in the early study of later large project. The design goals of the project include that:

◆The maximum output power is 10W.

◆The height and diameter of chimney can be adjusted.

◆The proper heat storage device to ensure a full-time job system.

◆Efficient power generation device.

◆ Each type of data acquisition sensors, such as temperature, wind speed, rotate speed, voltage, current, and solar radiation, etc.

◆Visualization control system.

Certainly, the project scale is strictly limited, because of the limited fund and space. Part structure size is determined as follows: the chimney height is nine meters which is given by Shanxi power Co., LTD, and the diameter of collector is 12 meters which is decided by the site conditions. Then based on the climate conditions in Taiyuan and site conditions of project , the computational fluid dynamics method is used to analyze the effect of chimney diameter, collector openings height, collector gradient for the system performance. the auxiliary data acquisition and remote transmission system is designed, which is required to reach the following functions: I) many information of multiple sensor from the experiment device is collected such as multipoint temperature, multipoint pressure, multipoint wind speed, turbine rotate speed, turbine torque, output power, output voltage, and output current, etc. II) the real-time work information is transmitted to the laboratory and storage. III) preservation and processing of real-time data.

Fluid mechanics analysis

The modeling software and the analysis software use the Gambit 2.4.6 and ANSYS Fluent 13.0, respectively. Based on the analysis result of report, the recommended structure size is given. The supposed temperature of soil and collector is $50^{o}C$ and $37^{o}C$, respectively. The assumed geometric parameters of three groups are given as can be seen form Table.1. The output characteristics of project at different assumed geometric parameters are discussed in follow sections.

Firstly, as shown in Table.1, the group I includes four diameters of chimney, and the output efficiency of four different chimney's diameters of system is compared to achieve the optimal chimney diameter. As can be seen from Fig.2, with the increasing of the chimney diameter, the wind speed in chimney is gradually reduced, but the output power of turbine is gradually increases. Certainly, with the increasing of diameter, the price and weight of chimney is gradually increases. The diameter of 0.8 meter is recommended in this project. Fig.3 shows that the gas velocity distribution in chimney at one meter diameter. Fig.4 is the partial enlarged detail of Fig.3. The air velocity in internal road of chimney is different based on different height and site as shown in Fig.3 and Fig.4. Certainly, the air pressure is different, and the lowest pressure located in turbine district which has been discussed in many literatures. Normally, an axial pressure turbine is installed in the district by using the pressure difference between turbine district and high altitude atmospheric pressure. So the chimney effect can drive the turbine rotation and output power by using the air thermal energy. The chimney exit has the highest air velocity as shown in Fig.3, and with the increasing of chimney height, the velocity is gradually increase. But there is not a wind turbine in the site, and the air kinetic energy is wasted. The thermal energy and kinetic energy of solar chimney power plant should be applied in future construction project.

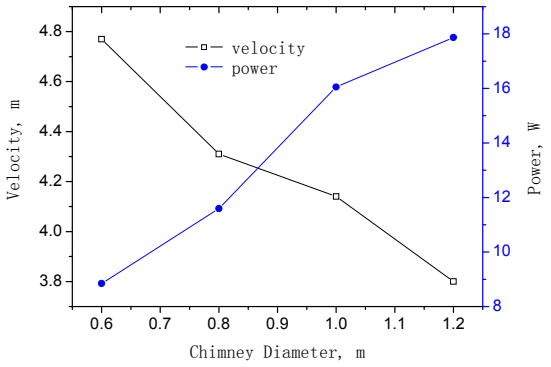

Fig.2. The influence of chimney diameter for solar chimney power plant

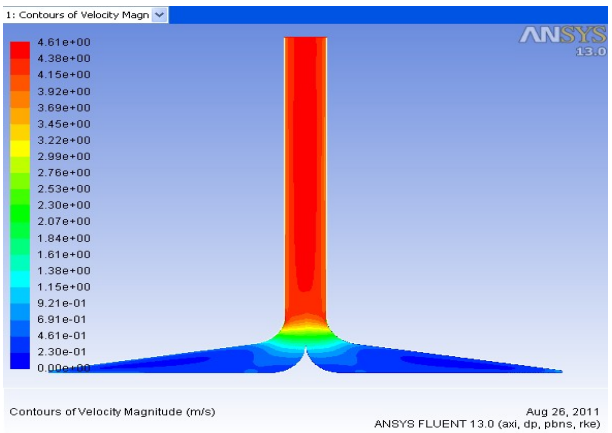

Fig.3. Gas velocity distribution map for the chimney diameter of one meter

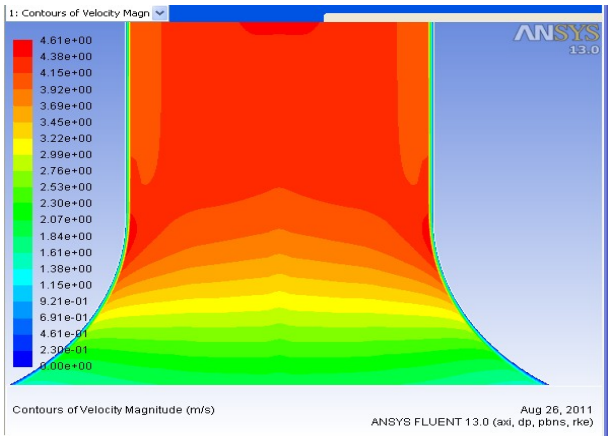

Fig.4. Partial enlarged detail of Fig.3

Secondly, four outer limit heights of collector are assumed in group II, and the output efficiency of four outer limit height of collector is compared to achieve the optimal

outer limits height. As can be seen from Fig.5, with the increase of the outer limits height, the output power of system is increase, but the increase is very small. And the higher outer limit height will increase the construction cost and influence the test accuracy, the proposed height in this project is from 0.1 to 0.2 meter.

Table.1 Assumed geometric parameters（unit: meter）

	d_c	H_c	H_1	H_2	d_G		d_c	H_c	H_1	H_2	d_G		d_c	H_c	H_1	H_2	d_G
	0.6	9	0.1	1	12		1	9	0.1	1	12		1	9	0.1	1	12
I	0.8	9	0.1	1	12	II	1	9	0.2	1	12	III	1	8.8	0.1	1.2	12
	1	9	0.1	1	12		1	9	0.3	1	12		1	9.2	0.1	0.8	12
	1.2	9	0.1	1	12		1	9	0.4	1	12		1	9.4	0.1	0.6	12

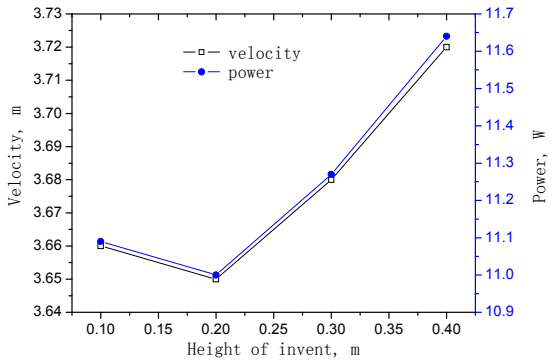

Fig.5. The influence of outer limits height for solar chimney power plant

Thirdly, four tilted angles of collector are assumed in group III, and the output efficiency is compared to achieve the optimal tilted angle of collector. As shown in Fig.6, the air velocity is increased with the increasing of tilted angle of collector, and the output power is increase. But the air thermal energy accounts for the most part of output energy and the air kinetic energy accounts for a little part, and the higher tilted angle of collector increases the construction cost. So the proposed tilted angle in this project is from 1^o to 2^o.

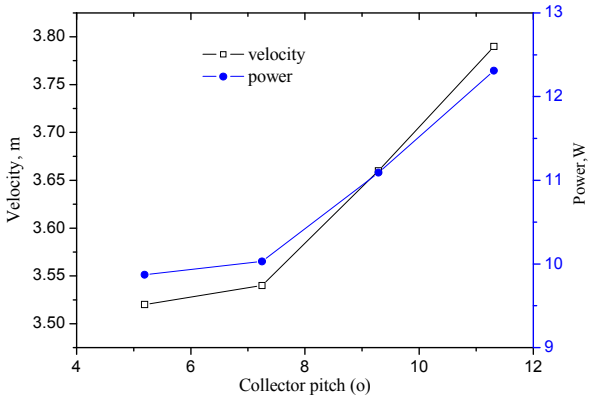

Fig.6. The influence of tilted angle of collector for solar chimney power plant

Electric and program realize

In order to gain the real-time data of solar chimney power plant, the overall structure of system is designed based on the user's need. Fig.7 shows the proposed structure. The designed structure includes three parts: I) project site; II) information transmission path; III) laboratory.

Generator and luminous power monitoring core consists of the generator monitoring core board, single chip power supply board, multipathsimulator output board, voltage measurement, and current measurement board. The measurement system distribution box consists of the ADAM remote IO group, wireless router, generator and luminous power monitoring core, chip power supply, and industrial power supply. Project site consists of the major structure of solar chimney power plant, measurement system distribution box, sensor group, and axial flow wind turbine. Then the acquisition of test data is transmitted by using wireless router. Finally, the wireless router located in laboratory receives the data from the project site. The experiment device control program of solar chimney power plant is used to manage and control the system running. Then the experimental data is extracted by using the Matlab, and the historical data is saved in computer by using SQL server 2008 software. Here, ADAM remote IO group uses the ADAM-6017-BE, and the wireless router uses Tenda W309R, and the luminous power uses TES—1333R.

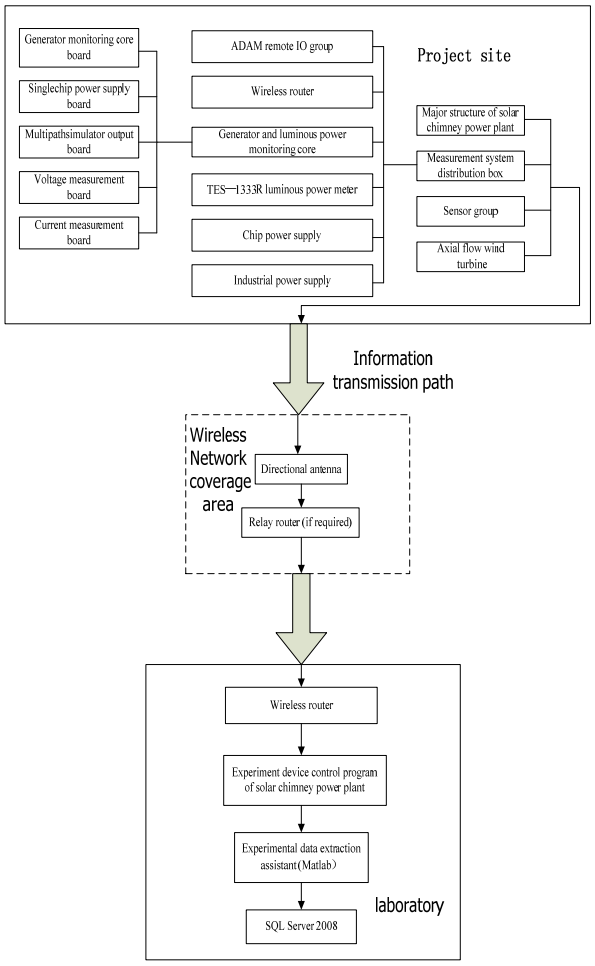

Fig.7. The designed structure of solar chimney power plant

According to the designed structure as shown in Fig.7, the designed circuit board of solar chimney power plant, and the circuit board consists of chip power supply, industrial power supply, ADAM remote IO group, voltage and current measurement board, single chip power supply board, generator and luminous power monitoring core board, and multipathsimulator output board. The circuit board forms the measurement system distribution box, which can meet the power supply, data measurement of sensor group, A/D conversion, long-distance transmission, and other functions. With the increasing of sensor group number, the number of ADAM6017 can gradually increase. According to need changing, the voltage and current measurement board can add or detract.

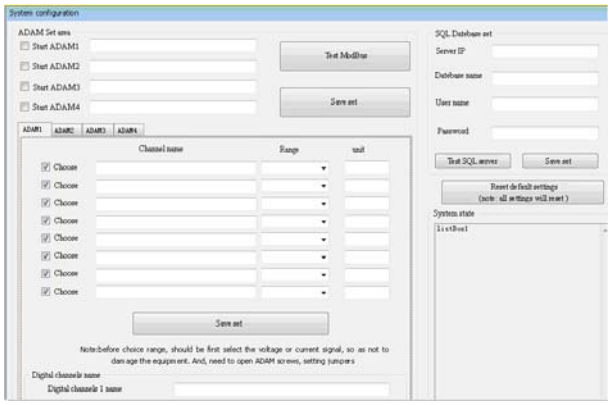

Fig.9. System configuration schematic diagram

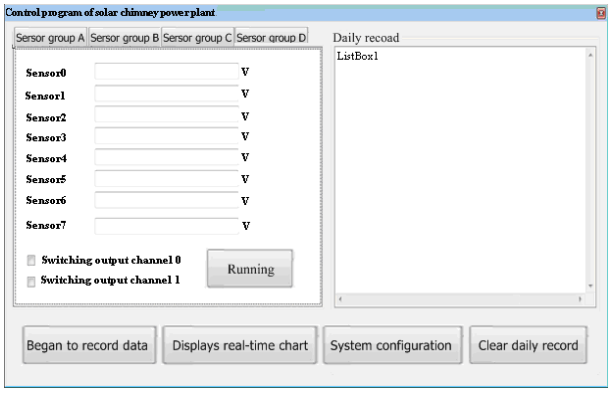

Fig.10. Control program of solar chimney power plant

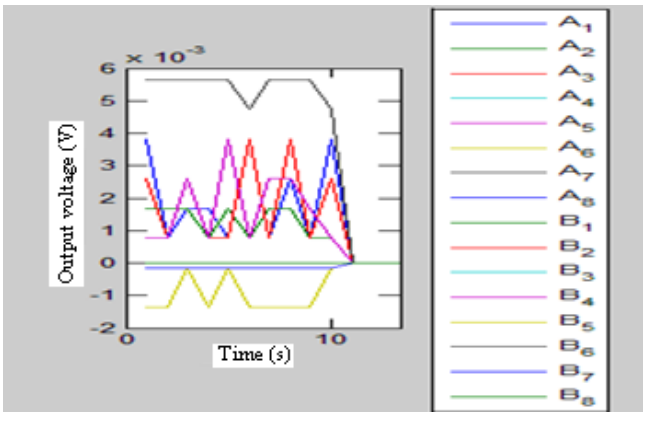

Fig.11. Drawing module schematic diagram of control procedures

The designed control program uses the Visual Studio 2010 software, and system configuration schematic diagram can be seen from Fig.9. And the control program of solar chimney power plant can be seen in Fig.10. The drawing module of control procedures uses the dot net builder toolbox of Matlab 2011b, which can be seen in Fig.11, and the user data extraction procedure uses the Database tool box of Matlab 2011b. The collection data is saved by using the SQL 2008, which can be seen from Fig.12. The program design of singlechip uses the AVR Studio 5.0, and the debugging uses AVR Studio 4.0. The PCB design uses the Altium Designer Release 10.

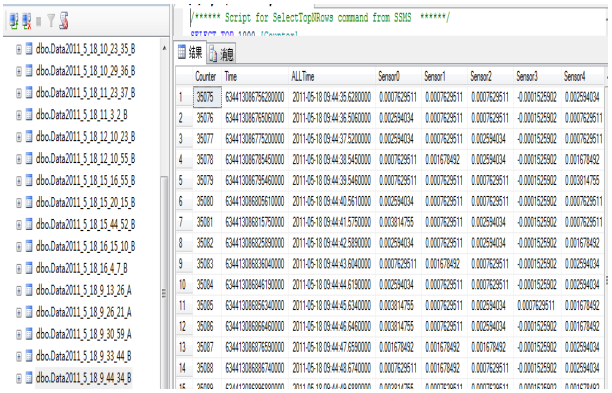

Fig.12. Save the collection data

The management and control system of solar chimney power generation project is designed to gain real-time data and control the running of system based on above mention method and circuit board, and the experimental circuits and hardware board have been tested in the actual conditions. The experimental and simulation results demonstrate that the designed control software and test circuit can achieve the safety running under different weather conditions.

Conclusions

A solar chimney power plant is designed to research the output characteristic under different weather conditions, and the project is used in the early research of later large project. The fluid mechanics analysis and electric and program realize is discussed in this paper, and which bases on the user need and weather conditions of project site. The designed circuits and programs have been tested in real experiment, and the correlation designed structure can be used in future large project.

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