A Review of the Air Vortex Formation to Generate Energy in Solar Chimney*

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***Abstract*— The solar chimney power plant has a great potential for power generation if it is utilised. A complete solar chimney system contains of a solar collector, a chimney and a turbine. Many studies have been done in order to increase the efficiency of the solar chimney power plant. This included the solar chimney applications, hybrid system possibilities, experimental and simulation studies and structural design of the solar chimney. Even though many types of hybrid systems have been built and analysed, the potential of applying air vortex still an area to be discovered. Hence, this paper is focus in analysing the possibility of creating air vortex in solar chimney power plant for power generation. The concept of air vortex formation is discussed. Besides, the type of air vortex and its characteristics are also listed down and analysed.**

Keywords— Air Vortex, Solar Chimney, Hybrid System

I. Introduction

The energy consumption had gradually increased over the last century due to the change of lifestyle as well as industrialisation (Cheng, 2010). All over the world, energy supply was mainly depended on the efficiency of energy production, levels of energy conversion and the standard of living of their expectation (Kreith, Kreider, & Krumdieck, 2010). The world population growth and standard of living in developing or developed countries caused the global energy consumption averagely raised 2% every year (Ngô & Natowitz, 2009). It is estimated that in 2025 about 8.4 billion people living in the Earth and needed a huge amount of energy (Golušin, Dodić, & Popov, 2013). This energy is harvested from the renewable and non-renewable sources of energy. In Malaysia, the growth of energy demand is very significant. In 1991, the primary energy supply was 20,611 kilotonnes of oil equivalent (ktoe), increased to 50,658 ktoe in 2000 and 54,194 ktoe in 2013. On the same time, the electricity desire was rose, from 22,273 gigawatts hour (GWh) in 1991 to 60,299 GWh in 2000 and further raised to 71,159 GWh in 2003. In this few years, the obvious growth of economic and industries in Malaysia, able to prove that there is an inseparable relation between GDP with the GWh (Jafar et al., 2008). Besides, harmful greenhouse gases produced through burning fossil fuels are the cause of global warming (Prasad et al., 2017). The study showed that the Earth temperature is increasing annually and the Arctic sea ice is melting due to the climate changes (Matishov et al., 2016). This is a warning sign from our mother Earth. Unfortunately, the renewable energy is still unable to contribute much towards the world energy supply. In a nutshell, the clean and sustainable renewable energy is the key of future. One of the promising renewable energy source is turning solar energy to electrical (Zhou, Wang, & Ochieng, 2010).

The history of a chimney was started from European when they used fire to warm the house and roof hole to evacuate those smoke and dust out from their house. On 17th century, the industrial started to build chimney to remove unwanted gases out from the boiler, or other fireplaces to maintain clean surrounding atmosphere inside the industry (Patil, 2013). In 1903, Cabanyes¬ came up with an idea of locating the wind blade to generate electricity inside the house. This was the origin of the hybrid system, which utilise the usage of chimney, besides heating air. Lastly, the very first idea of solar chimney power plant (SCPP) was proposed by Schlaich in 1968. The prototype of SCPP was created in Manzanres, between the year 1981 and 1982 (Haaf, 1984). Since then, the possibility of the solar chimney power plant is catching the researches attention. The concept of the SCPP to generate electricity is using the natural convection with the support of the thermodynamics theory. In this paper, the application, description and possibilities of hybrid SCPP system are discussed.

II. Application of SCPP

After the introduction of solar chimney from Cabanyes, there were a few patents came up on this in Australia, Canada, Israel, the USA (Lucier, 1979). The beginning of the SCPP was started with the prototype presented by Schlaich and his team, which has the high of 194.6 m, a collector of 122 m in radius and a single vertical axis single-rotor turbine configuration with four blades installed on its base (Pasumarthi & Sherif, 1998). Throughout the eight years, this prototype able to contribute 50 kW of peak power (Schlaich, 1995). This is the first movement to prove that the contribution of the SCPP as sustainable renewable energy is possible. In Australia, the project of building 1000 m high with a 7000 m diameter collector SCPP was proposed and supported by the government. This plant was predicted to produce 200 MW of power, which able to support over 200,000 households and a reduction of CO_2 gas emission by approximately 1,000,000 tonnes (“EnviroMission Limited,” 2018). In the Northwestern regions of China, there was a pilot SCPP set, which 200 m high with 500 m diameter solar collector, had the ability to produce 110 to 190 kW electric power on a monthly average (Dai et al., 2003). In 2008, a proposal was written and the predicted result was analysed in Mediterranean region. In this proposal, the size of the SCPP suggested to be 550 m high and 1250 m diameter of solar collector to produce about 2.8 to 6.2 MW of power (Nizetic et al., 2008). An analysis research had completed in Arabian Gulf area, which showed that with the 500 m high and 1000 m diameter collector, the SCPP could produce about 8 MW of power in that region (Hamdan, 2011). Another performance prediction research done in Adrar site estimated that area capable to generate about 140 to 200 kW of power with the size 200 m high and 500 m diameter collector of SCPP (Larbi et al., 2010).

III. Description

A. Natural Convection

Convection is a mode of transfer heat through fluid. Convection could be categories to two types, natural and forced. Natural convection happens when the buoyancy forces occur after the fluid absorbs heat. When the gap of the temperature is huge, the density of the air particles is changing. This is the moment where buoyancy force produced. According to Archimedes’ principle, the buoyancy force is proportional to the density of the object (Rathore & Kapuno, 2011). As we know, the cold air is denser than hot air. In other way round, the hot air particles have higher kinetic energy than the cold one. Hence, the hot air particle tense to vibrate and escape to the surrounding. The air particles close to the heat source will have the most of the energy. Hence, the energy pushes the other air particles, which contain lower energy, to another direction. This causes the air circulation due to the natural phenomenon. The cold air particles, which are denser, will pushes down the air particles with moderate energy level because of the gravitational forces. By using the idea and apply on the SCPP, the increased heat through the solar collector will attract the air surrounding flow into the system through the base and out through the other end of the chimney. As the result, the wind turbine, which located in the middle of the plant, will turn and generate electrical energy for consumers (Cao et al., 2018).

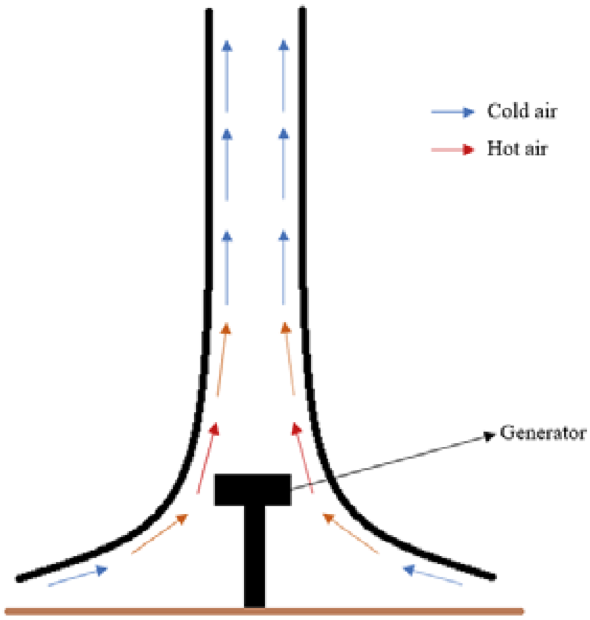

Figure 1: Air flow inside solar chimney by using natural convection concept

B. Solid Wall Chimney

Solid wall chimney act as an insulator to prevent hot air loss to the surrounding too quickly. In order to obtain sufficient buoyancy force, the current design of the solar chimney is often tall. There are quite a few researches done to indicate the relation of natural convection with the solid wall chimney. In 1942, Elenbaas proposed natural convection problem occur in between of parallel vertical plates. Elenbaas analysed the natural convection between isothermal parallel plates and optimised the design according to the maximum heat transfer rate. Then, in 1962, Bodoia & Osterle did the numerical solution for the relation of the flow between plates with the temperature by using finite difference method. After that, in 1988, Sparrow, Ruiz, and Azevedo presented another numerical analysis by considering both natural convection and solid wall conduction.

C. Cold Inflow

Cold inflow is the most common problem happen in the solid wall chimney. This is due to the unstable wind flow and downdraft occur (Zhai & Fu, 2006). Bouchair et al. (1988) conducted an experiment proved that the reversal flow appeared at the chimney outlet. Kihm et al. (2003) also identified the reversal flow of the air through vertical isothermal channel walls. Those researches showed the appearance of cold inflow or reversal flow. However, the flow does not last until the base of the solar chimney. There were several researches conducted on this matter in order to increase the efficiency of SCPP.

IV. HYBRID SCPP SYSTEM

Zuo et al. (2011) built a small scale solar chimney power plant together with sea water desalinization system. The efficiency of this hybrid SCPP increased by 21.13%. However, this plant also involved with the fossil fuel system, it was still not a fully green plant. According to Zhou et al. (2010), the power output from the hybrid system of water desalinization with SCPP was slightly less productive as the tradition SCPP system. Maia et al. (2009) used photovoltaics cell in their SCPP to conduct the performance analysis on agricultural crop drying. Cao et al. (2014) came out with a hybrid system of geothermal into SCPP. This study was conducted at Xi'an and the performance of this plant was 26.3% larger than the classic SCPP. From all of the researches, it could conclude that hybrid SCPP system is a possible idea which increased the purpose of the SCPP system other than electric generation.

Vorticity is a measure of rotation of a fluid particle, which is also means the tendency of the fluid particles to "spin" (Yu, 2011). There are two main categories of vortices, rotational and irrotational. When the fluid particles are rotating the flow at non-zero vorticity flow field, it is rotational; else, it is irrotational (Kundu et al., 2016). Tornado is a fast speed rotating column of air where contact the surface of the Earth with the cumulonimbus cloud, often named as cyclone. The average wind speed of the tornadoes is about 180 km/h. It is a type of vortex (Wikipedia, n.d.). There are two types of tornadoes, supercell and non-supercell thunderstorms. Supercell thunderstorms are the most dangerous type of tornado which rotate horizontally in an organized scale; while, non-supercell thunderstorms formed from a vertically spinning parcel of air which has less energy, as gustnado, landspout and waterspouts (101, n.d.). This natural phenomenon has provided an idea of implementation of air vortex into the SCPP system. There is still not much of studies regarding to this combination.

Ninic & Nizetic (2009) did a theoretical analysis on the design of stationary vortex columns of SCPP. They analysed and used the concept of Gravitational Vortex Column (GVC) in their design. The work efficiency from their calculation was positive. However, as the realistic cycle is more complex than the Brayton cycle and the atmospheric air state is not always standard as used in the calculation, there are more analysis needed to be carried out. There is another research conducted by Al-Kayiem et al. (2018) which is about solar vortex engine. They used solar air collector and vortex generation engine to create the vortex. The vortex was generated and extending vertically towards the atmosphere with the pattern just alike with the natural tornado. In 2009, Michaud proposed to involve atmospheric vortex engine (AVE) to create artificial anchored tornado like vortex tangentially into the base of a circular wall. His concept was using the same thermodynamics basic as solar chimney, just that AVE do not consists physical vertical tube and the transparent solar collector. In short, create an artificial tornado like vortex and make use it into SCPP system is a potential way to increase the performance efficiency.

CONCLUSION

The SCPP is believed to be the future of the renewable energy to reduce the dependent on fossil fuel and air pollution. The experimental and theoretical studies in this field should be increased. The performance of the SCPP system is depend on its location. The thermal difference in the solar chimney is the key of success to produce more power. However, for the area that has limited period of solar radiation, the hybrid system should be considered to be added into the plant. Air vortex could be the way as mechanical energy, which is the centrifugal force produced, will provide a sustainable platform in order to turn the wind turbine in the middle of the plant. When the turbine able to turn continuously, the generator could generate more electricity to the community. Besides its main purpose to generate electricity, the space of the solar collector can be a dryer for the agriculture crops or sea water desalination.

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