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A Brief Review on Solar Updraft Power Plant

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Abstract – *This literature review paper presents the history and background of the solar updraft tower which explains the working principle of the system and also describe the major components of the solar updraft tower. The system utilized solar thermal technology by heating up the air below the solar collector through solar radiation, convection and greenhouse effect. The heated up air tends to travel to the bottom of the tower and rise up the chimney due to differential temperature. The upward velocity is used to turn a turbine installed at the bottom end of the tower either vertical or horizontal to generate power. This paper also explains the experimental and numerical studies conducted throughout the years and the improvement to the solar updraft tower power generation system. The challenges and limitation of the system is also being discussed and the improvement conducted to bridge the gap to further improvement of the system.*

Keywords: *Solar Updraft Tower, Solar Chimney Power Plant, Solar Power, Renewable Energy, Power Generation*

1.0 INTRODUCTION

During the pass few couple of decades, the solar power technology is categorized as a viable source of clean energy. There has been considerable advancement to the solar photovoltaic (PV) power generation system development throughout the years. Currently electricity power generation from fossil fuels such as oil or coal is damaging our environment. Nuclear power stations are an unacceptable risk in most locations [1] .Therefore we need to diversify away from this non-renewable energy sources and look for alternatives. Many developing countries including Malaysia cannot fully rely on these conventional methods as we are aware on the damaging effect of the CO_2 emission and try to source for other types of green and renewable energy source. With a good amount of rainfall in our country, hydroelectric is one of our power generation source and we also have good amount of sun light throughout the whole year where it is a good opportunity for solar harvesting. The need for a green and environmental friendly electricity power generation method is thus obvious and will become further expand in near future.

As to consider alternative energy source for contributing to the overall power demand of the country, this alternative energy must be sustainable and have minimum ecological impact as it will be costly to modify or upgrade the existing power distribution infrastructure that is being used today. The current existing capacity of power generation in Malaysia is shown in Table 1-1: Installed Capacity by Type.

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Table 1-1: Installed Capacity by Type [2]

Type	Fuel	Capacity (MW)
Conventional Thermal	Coal	7,056
Combined Cycle Gas Turbine (CCGT)	Gas	9,200
Conventional Thermal	Gas	564
Open Cycle Gas Turbine (OCGT)	Gas	2340
Hydroelectric	Hydro	1,899
Total Capacity (MW)		**21,060**

The new power source must be capable to be fit into the existing power grid. One of the most promising renewable energy available is the Solar PV Power. The Solar PV Power definition is to harvest the sunlight from the sun and converting it to electricity at the atomic level. It is estimated that one hour of solar energy received by the earth is equal to the total amount of energy consumed by humans in one year [3]. Solar PV Power is a technology that allows the conversion of the radiation from the sunlight to be converted into electricity in a green and environmental friendly way. Similar to plants, they use chlorophyll to photosynthesize the sun's irradiation in order to provide in order to provide energy for their growth. Only 14.4% of sunshine survives filtering from the Earth's atmosphere and falls on the land where it can be harvested. This is however 2,800 times more than our energy needs [3].

During the United Nations Climate Change Conference 2009, Malaysia announced that they will be adopting an indicator of a voluntary reduction of up to 40 per cent in terms of emissions intensity of GDP (gross domestic product) by the year 2020 compared to 2005 levels [4]. Therefore we still need to reduce 39.5% before year 2020. Currently the overall power generation in Peninsular Malaysia is totally relying on coal and natural gas and it has been the mainstay of source of power generation for more than two decades and we foresee that it will continue to be the an important source for years to come unless a more reliable alternative and sustainable power source generation in large scale can be identified.

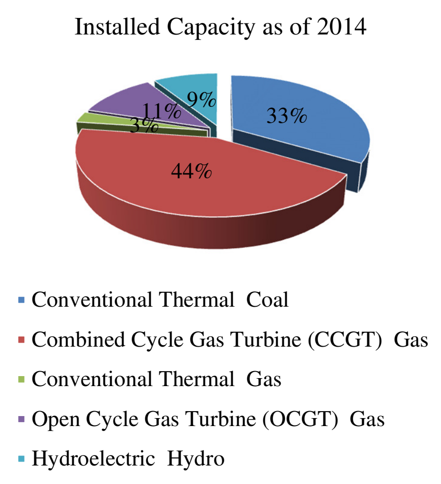

Figure 1-1: Percentage of Type of Power Generation in Malaysia [2]

The Solar Updraft Tower is another alternative renewable energy source for areas that are rich in sunlight where it can be also considered as alternative to solar concentrating or solar PV cell (Solar PV farms) power generation facilities. There have been successfully implemented several large tower being constructed in countries with well-developed energy infrastructures.

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Therefore there are high potential of implementing a smaller scale solar updraft towers in remote area in Malaysia for power generation.

2.0 SOLAR UPDRAFT TOWER

2.1 History

Up till date, there are many researchers around the world have introduced various projects of solar tower. Leonardo Da Vinci made a sketch of a solar tower called a smoke jack as showing in Fig. 2-1. Later in the year of 1903, Isodoro Cabanyes, a Spanish engineer was the first to propose the idea of using a solar chimney to produce electricity.

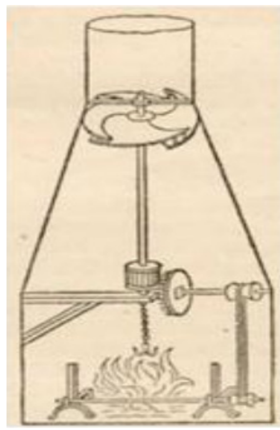

Figure 2-1: The spit of Leonardo da Vinci (1452-1519) (Library of Entertainment and Knowledge 1919)

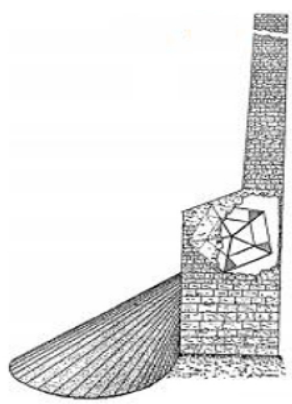

Figure 2-2: Solar engine project by Isodoro Cabanyes [5]

During the 1931, a German Science Writer Han Gunther had proposed a design in 25th August 1903 issue of "La Energia Eléctrica", entitled ―Projecto de motor solar. In this bizarre contraption, a collector resembling a large skirt heats air, and carries it upwards towards a pentagonal fan inside a rectangular brick structure vaguely resembling a fireplace (without a fire). The heated air makes the fan spin and generate electricity, before it escapes up a 63.87 m

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tall chimney, cools, and joins the atmosphere [6]. In 1926, Prof Engineer Bernard Dubos proposed to the French Academy of Sciences the construction of a Solar Aero-Electric Power Plant in North Africa with its solar chimney on the slope of the high height mountain after observing several sand whirls in the southern Sahara.

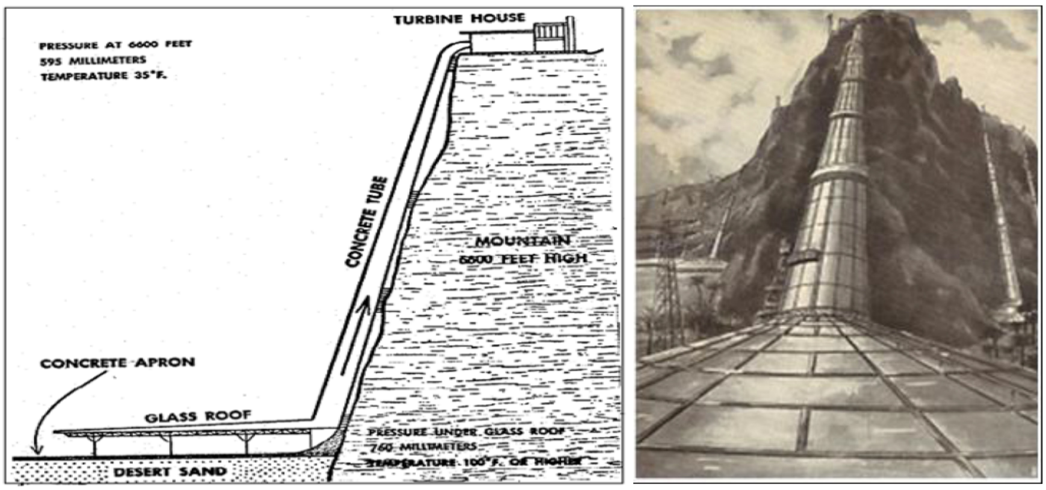

Figure 2-3: Principle of Professor Dubos's power plant [5]

In 1956, Bernard Dubos filed his first patent in Algeria. It was artificially generate ancestry atmospheric vortex in a sort of round-shaped Laval nozzle and recover some energy through turbines. The solar tower "Nazare" received a French patent for his invention in 1964. In 1975 the American Robert Lucier filed a patent request based upon a more complete design. This patent was granted in 1981.

In 1982, Jörg Schlaich a German civil engineer and his team took the initiative to construct the first Spanish prototype in Manzanares Spain, with a 200 m high and a maximum power output of 50 kW [7]. The results of the Spanish prototype was successfully put in operation demonstrated the feasibility and reliability of the solar updraft tower power generation technology. Since then, many researchers have shown strong interest and began to conduct extensive studies in experimental, analytical and also numerical on the potential of Solar Updraft Tower technology all over the world [8].

2.2 Description of Solar Updraft Tower

The Solar updraft Tower utilize the concept of converting the solar radiation from the sun to electricity by using three types of working principle which consists of the Greenhouse effect, the rising tower and wind turbine generator. During the sunny day, when the solar radiation falls upon the solar collector which usually made out of large pieces of glass roof which is similarly with glass skylight. Hot air is produced by the sun when the solar radiation lands on the glass roof [9]. Part of the sun light is reflected, absorbed and transmitted as not all of it can be utilized. The amount of solar that is absorbed depends on the optical characteristic of the glass such as transparency index, extinction coefficient and thickness of the glass. The transmitted solar radiation lands on the surface of the ground; a part of the energy is being absorbed while another part of it is being reflected back to the glass roof bottom surface, where it is reflected again back down to the ground. This effect of multiple reflection of radiation continues, resulting in a higher fraction of energy can be absorbed into the ground, known as

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the transmittance-absorptance product of the ground. The heated up ground surface will heats up the adjacent air through natural convection and causing the temperature to increase and to rise up. The buoyant air rises up into the chimney of the solar updraft tower, thereby creates a drawing effect for air from the collector perimeter to enter into the collector region and thus initiating forced convection which heats the collector air more rapidly. Through mixed convection, the warm collector air heats the underside of the collector roof. Some of the energy absorbed by the ground surface is conducted to the cooler earth below, while radiation exchange also takes place between the warm ground surface and the cooler collector roof. In turn, via natural and forced convection, the collector roof transfers energy from its surface to the ambient air adjacent to it. As the air flows from the collector perimeter towards the chimney its temperature increases while the velocity of the air stays approximately constant because of the increasing collector height. The heated air travels up the chimney, where it cools through the chimney walls. The chimney converts heat into kinetic energy. The pressure difference between the chimney base and ambient pressure at the outlet can be estimated from the density difference. This in turn depends upon the temperatures of the air at the inlet and at the top of the chimney. The pressure difference available to drive the turbine can be reduced by the friction loss in the chimney, the losses at the entrance and the exit kinetic energy loss [9]. As the collector air flows across the turbine(s), the kinetic energy of the air turns the turbine blades which in turn drive the generator(s) [10].

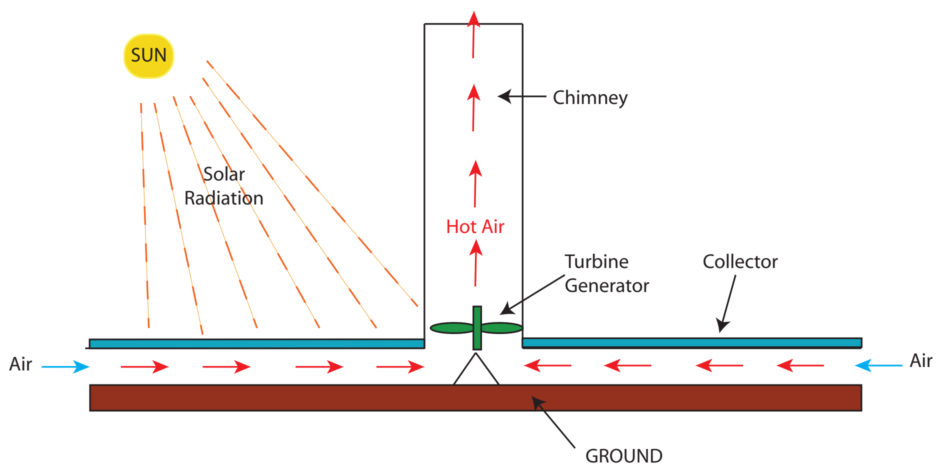

Figure 2-4: Solar Updraft Tower Schematic Diagram

2.3 The Solar Updraft Tower

The solar updraft tower is the most important component in the solar updraft power station. The solar chimney acts as a large rising tube located at the centre of the glass collector. The solar updraft tower is also defined as the thermal engine. The updraft tower consist of two temperature differential between the cool air at the exist of the tower where the temperature is surrounding ambient and the heated air at the bottom of the updraft tower after the air is being heated up when it flows through the collector. The design criteria of the solar updraft tower shall have minimal friction loss on the internal surface finishing and to maximize the differential pressure of the tower.

Based on the review findings, the updraft tower must achieve sufficient height to enable the flow of hot air rise up to the exist of the chimney. The turbine is usually located at the base of

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the tower to ease the construction purposes compare to location at the middle of the updraft tower or at the exit of the tower.

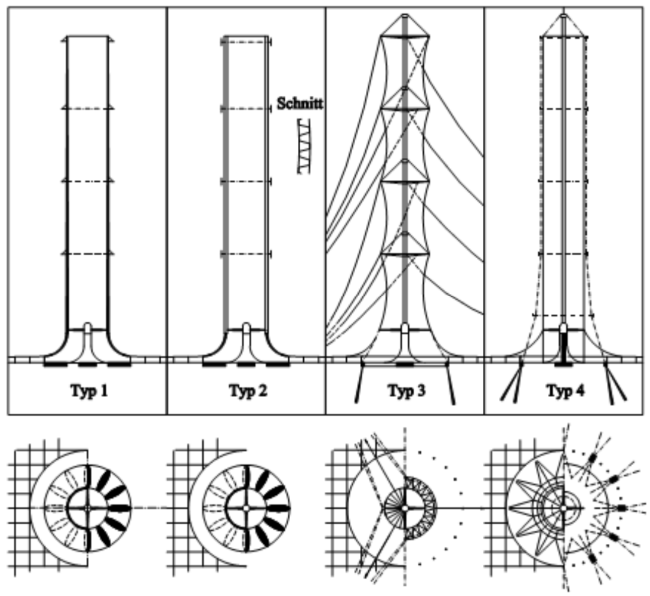

Figure 2-5: Typical Construction of Updraft Tower [5]

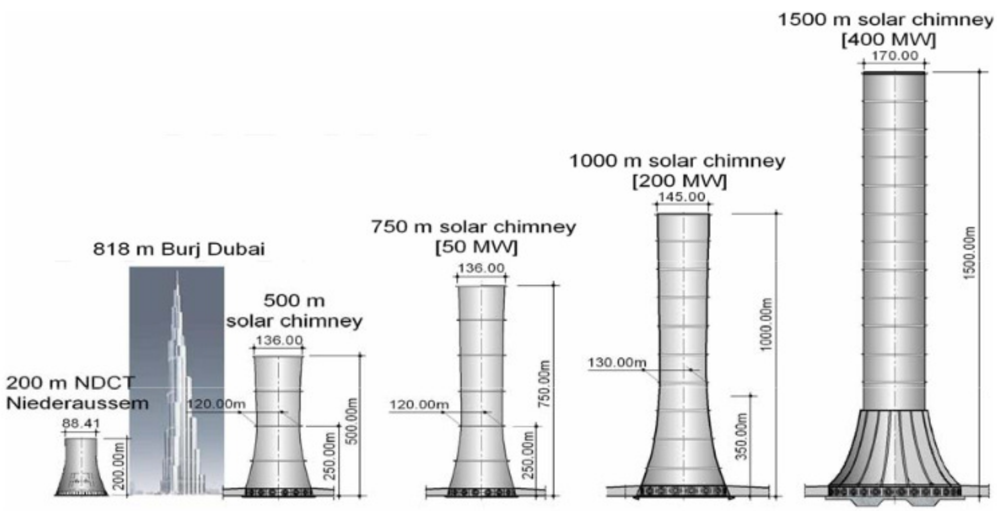

Figure 2-6: Solar Updraft Tower Illustration (Image Source: Kratzig & Partner GmbH Bochum, Germany)

There are several types of configuration of the solar updraft tower which is illustrate in the Figure 2-5: Typical Construction of Updraft Tower [5]. Currently the maximum tower height is 1500 m and to support high chimney structure, compression ring stiffener are installed with vertical spacing [8].

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2.4 The Solar Collector

The component that takes up the most footprint of the solar updraft tower power generation system is the collar collector. Therefore it is considered the major component of the whole system. The solar collector acts as a heat exchanger that converts the solar radiation energy to internal energy to the air that passes through between the bottom of the collector and the ground [11]. The solar collector utilize the greenhouse effect. The collector is made out of transparent material such as glass or plastic film where the radiation is allowed to pass through but part of it will be reflected back.

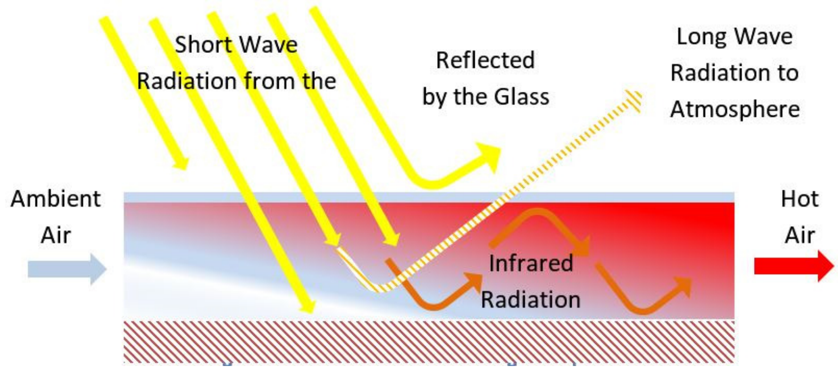

Figure 2-7: Solar Collector Schematic Diagram

The solar collector may extend horizontally to the ground but is separated by a gap for the flow path of the air as shown in Figure 2-7: Solar Collector Schematic Diagram. This is the called the collector height which is usually two to six meters above the ground [5]. For conventional system, there are no slope for the collector and recent studies have shown that sloped collector have the following advantages

a) Reduce the friction loss at the base of the updraft tower to enable the smooth transition from horizontal flow to vertical flow where the air will pass through the turbine. This can be done by increasing the height of the roof adjacent to the updraft tower base.
b) Sloped collector may increase the efficiency and also power generation comparing to similar footprint for of a horizontal collector where smoother air flow and less eddy was observed [12].

The collector will have the capability to retain the short wave solar radiation and the long waves are reflected from the heated ground back to the atmosphere passing through the transparent collector. The collector allows short wave radiation to pass and prevents them from exiting, and insulation which resists back and rear side heat losses. This heats up the ground / soil under the collector where it acts as a thermal storage and transfer its heat to the air flowing horizontally in between the bottom of the collector and the ground surface.

The larger the coverage of the solar collector footprint hence the higher the power generation where this is always been a restriction as land use is very important and acquiring the land is difficult although the collectors has a low construction costs and minimal effect in pressure drops. It is said that utilizing glazed glass collector is the most efficient as it converts approximately 70% of solar radiation into heat.

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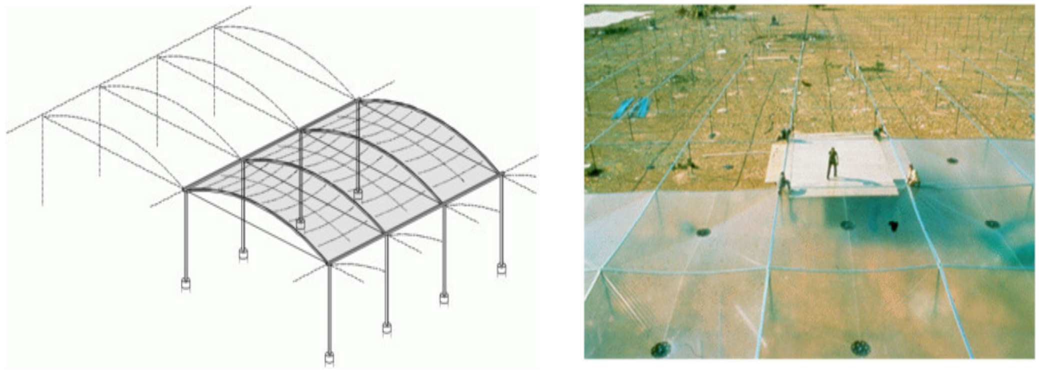

Figure 2-8: Typical Solar Collector [1]

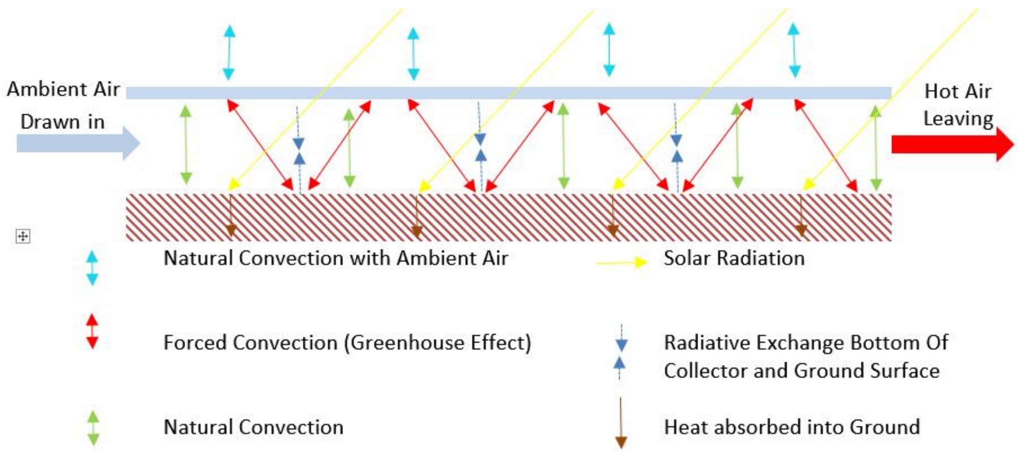

Figure 2-9: Thermal Balance of Solar Collector

2.5 The Power Generation Turbine

The most important component for the solar updraft tower power plant is the power generation turbine. The function of the turbine is to convert the energy from the air flow and transmitting it to a generator for power generation. It is has significant influence to the turbine pressure drop and transmits it to the generator. The specification of the wind turbine has many similarity to the large wind turbine but the principle of operation is slightly different. The pressure turbine relies on differential pressure which results on the shrouded blades to move and then the conversion of kinetic energy to power. Whereas for the large turbines are free movement blades where it will spins when the wind flow through the blades. There are no housing or containment to channel the air flow pass the turbine blades. Various turbine layouts and configurations have been successfully installed for the application of the solar updraft tower power conversion unit (PCU). A single vertical axis turbine without inlet guide vanes was used in the pilot plant in Manzanares. There are some setups with multiple vertical axis turbines has been proposed as well [7], and an efficiency model at design performance for counter-rotating turbines is developed and validated. Based on the efficiency equations, an off-design performance model for counter-rotating turbines is developed [13]. Many other researches were conducted to evaluate the pressure drop across the turbine as a part of the total available pressure difference in the system such as [7,14-17].

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2.6 The Soil Energy Storage

The soil beneath the solar collector behaves as a storage medium, and it can be heated up by the air for a significant time frame after the sunset until the temperature reach equilibrium with the ambient. The efficiency of the solar chimney power plant is below 2% and depends mainly on the height of the tower. Due to the wide coverage required by the solar collector, the solar updraft tower can only be built on cheap land where it is usually at the outskirt of the city. However the area under the solar collector can be used for agricultural purposes since it utilizes the greenhouse effect [11,18,19]. Also studies the temperature distribution in to the ground below the solar collector where it is found that the grounds plays an important role in the energy consumption. Various types of soil was compared including dry and wet soil. They found out that the solar updraft tower using wet soil and sand have the lowest and highest power output respectively and different materials leads to varying power output during the daytime and night time [11].

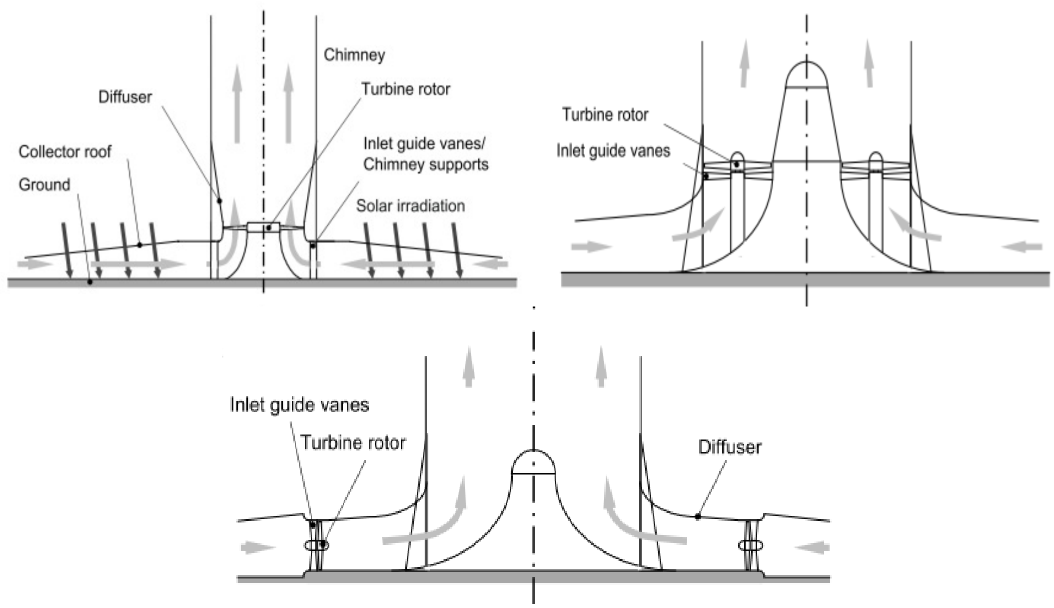

Figure 2-10: Typical Installation Method for Turbine Power Generator [20]

One of the strange finding from Manzanares was that the solar updraft tower can produce power at night, but not at the same levels as during the day. This is caused by the soil beneath the collector releasing the heat stored in it during the day at night, while the night air cools. In a modern simulation done at Stellenbosch University, roughly a sixth of the maximum power generated at midday is shown to be generated throughout the night [6].

To improve the storage capacity to enable the plant to be run during the night, [21] proposed placing coils of black plastic filled with water tube under the solar collector Water is heated up during the day will be pumped into an insulated storage tank where it can be returned back to the coils during the night time allowing the plant to work at full capacity for 24 hours a day.

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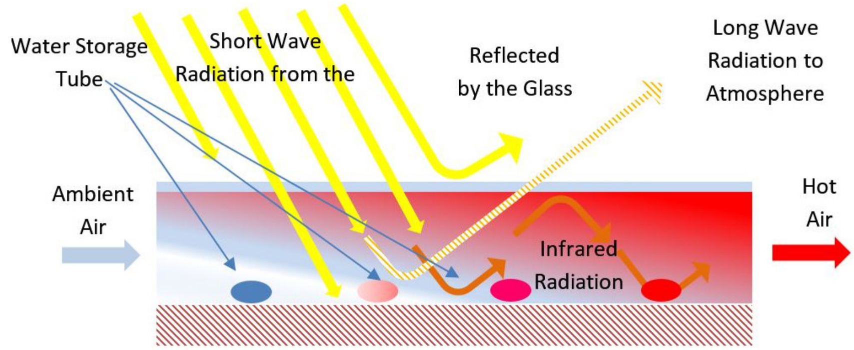

Figure 2-11: Water Storage Tube Absorbs Heat during Day Time

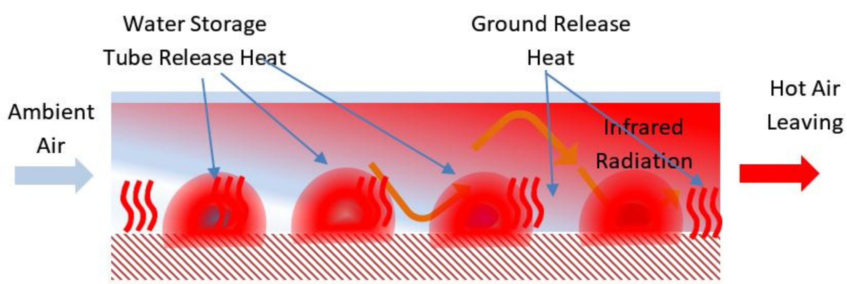

Figure 2-12: Water Storage Tube during Night Time

3.0 EXPERIMENTAL ANALYSIS

The solar updraft tower is uses the upward momentum to create by the flowing of air, thereby converting the thermal energy into kinetic energy. A study was conducted to evaluate the performance characteristics of the solar updraft tower both theoretically and experimentally where a mathematical model which was developed to study the effect of various parameters on the air velocity, temperature and power output of the solar updraft tower [22].

Another an economic assessment of the system cost was presented by [23]. A pilot experimental solar updraft tower was setup consisted of air collector with a diameter of 10m and height of the chimney of 8 m was constructed. The temperature distribution in the solar updraft tower was evaluated and measured. The greenhouse effect produced in the solar collector and found that the air temperature inversion appears in the latter tower after sunrise both on a cool day and on a warm day. Air temperature inversion is formed by the increase of solar radiation from the minimum and clears up some time later when the temperature inversion layer and flow through the chimney outlet [24]. A feasibility study of a solar updraft tower for drying agricultural products was conducted to assess the technical feasibility of this drying device, a prototype solar chimney, in which the air velocity, temperature and humidity parameters were monitored as a function of the solar incident radiation, was built. The constructed chimney generates a hot airflow with a yearly average rise in temperature (compared to theambient air temperature) of 13 ± 1°C. The low thermal efficiency observed can be explained mainly by the heat diffusion through the ground, by the low transmittance of solar radiation and by the high transmittance of infrared radiation from the plastic cover. These losses can be minimized by implementing thermal insulation in the ground and replacing the

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plastic material of the cover. Solar dryers use free and renewable energy sources, reduce drying losses (as compared to sun drying) and show lower operational costs than the artificial drying, thus presenting an interesting alternative to conventional dryers [25].

Table 3-1: List of Prototypes Experimental Analysis

References	Constructed Year	Constructed Location	Chimney Height	Chimney Diameter	Collector Diameter	Collector Material
Krisst 1983 [56]	1983	Connecticut, USA	10m		6m	
Kulunk 1985 [57]	1985	Izmir, Turkey	2m	0.07m	9m2	
Pasumarthi and Sherif 1998 [22]	1997	Florida, USA	7.92m	2.44-0.61	9.14m	Plastic
Golder 2003 [54]	2002	Bundoora, Australia	8m	0.35m	4.2m	
X. Zhou, et al. 2007 [24]	2002	Wuhan, China	8.8m	0.3m	10m	Glass
Ferreira, et al. 2008 [25]	2003	Belo, Brazil	12.3m	1.0m	25m	Plastic
Koyun 2006 [58]	2004	Isparta, Turkey	15m	1.2m	16m	Glass
Najmi, M. and Mansour 2012 [59]	2005	Kerman, Iran	60m	3m	40 x 40 m2	Glass
Motsamai, et al. 2013 [60]	2008	Gaborone, Bostwana	22m	2m	15 x 15 m2	Glass
Hartung, et al. 2008 [61]	2008	Weimar, Germany	12m	-	420 m2	Plastic
Zuo, et al. 2012 [62]	2008	Nanjing, China	2.5m	0.08m	-	Glass
Ahmed and Chaichan 2011 [63]	2009	Baghdad, Iraq	4m	0.2n	6m	Plastic
Al-Dabbas 2011 [64]	2009	Karak, Johan	4m	0.58m	36m2	Plastic
Dhahri and Omri 2013 [5]	2009	Gafsa, Tunisia	16m	0.4m	15m	Glass + Plastic
A. Koonsrisuk 2009 [65]	2009	Nakhon, Thailand	8m	2m	8m	Plastic
Kasaeian, Heidari and Vatan 2011 [66]	2010	Zanjan, Iran	12m	0.25m	10m	Plastic
Buğutekin 2012 [67]	2010	Adiyaman, Turkey	17.15m	0.8m	27m	Glass
Manon, et al. 2011 [68]	2011	Pau, France	2.5m	0.041m	3.65 m2	Plastic
Mohammad and Obada 2012 [69]	2011	Al Ain, UAE	8.25m	0.24m	10 x 10 m2	Plastic
Raney, Brooks and French 2012 [70]	2012	Texas, USA	5.08m	0.19m	11.58 m2	Plastic

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References	Constructed Year	Constructed Location	Chimney Height	Chimney Diameter	Collector Diameter	Collector Material
Kalash, Naimeh, and Ajib 2013 [71]	2012	Damacus, Syria	9m	0.31m	12.5 m2	Glass
Herrick 2013 [19]	2012	New Jersey, USA	7.1m	-	100 m2	Plastic
Papageorgiou 2013 [72]	2013	Kompotades, Greece	25m	2.5m	1020 m2	Plastic
Papageorgiou 2013 [72]	-	-	70 m	8m	20,000 m2	Plastic
Papageorgiou 2013 [72]	-	-	150 m	15 m	100,000 m2	Plastic with PV
Kasaeian, Ghalamchi, and Ghalamchi 2014 [73]	2013	Tehran, India	2m	0.2m	3m	Glass

4.0 NUMERICAL ANALYSIS

Numerical studies using CFD was becoming an indispensable computing tools for engineers. The CFD simulation provides insight to the details of how the solar updraft tower works and allow modification and new concepts to be evaluated using a computer simulation where the output of the solar updraft tower can be predicted before the actual plant is being constructed. The simulation also allow engineers to locate and identify problems in the design and further optimize the system before the construction. It is very suitable for large scale products such as the solar updraft tower to be simulated and obtain results near to the actual based on the assumptions made and it is impossible to build a large prototype within this kind of scale. Therefore CFD simulation is the solution.

Several researchers have contributed into the construction, numerical simulation of the solar chimney collector [22] have tested two different types of collector which is the extending of the collector base and also the intermediate absorber was being introduced. The results of the experimental shows that the temperature reported are higher than the theoretically predicted temperatures. This behaviour was the fact that the experimental temperature reported are the maximum value of the temperature attained inside the solar updraft tower where the theoretical model predicts the bulk air temperature [22].

The first known attempt to simulate the convective flow in a solar updraft tower using CP [26]. He presented a solution using Navier-Stroke and Energy Equation for the natural laminar convection in steady state, predicting its thermo-hydrodynamic behaviour [7]. Also presented an analytical model of the solar updraft tower system. A boundary layer analysis was performed to determine the pressure differential due to frictional effects and the heat transfer coefficient during turbulent flow between two approximately parallel disc or surface where it applied to the flow at the inlet of the collector of the solar updraft tower collector [27]. A comprehensive analysis of the helio-aero-gravity concept, power production, efficiency, and estimated the cost of the solar chimney power plant set up in developing nations was conducted [28]. [22,29] developed a mathematical model of differential equations is developed to study the effects of various environment and geometry conditions on the heat and flow characteristics and power output

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Early numerical models have been presented by [10], where tower friction, system turbine and exit kinetic energy losses is introduced. Other researches contributed also were [19,30] in the improvement on the solar updraft tower numerical analysis. [11] also evaluated the influence of a developed convective heat transfer equation, more accurate turbine inlet loss coefficient, various types of soil and quality collector roof glass, on the performance of a large scale solar chimney power plant. [31] developed a comprehensive analysis of the solar updraft tower both analytical and numerical model to describe the performance of the system based on estimated power output of the solar updraft tower as well as to evaluate the effects of various types of ambient condition and structural dimension of the tower to the power output of the plant.

A mathematical model was proposed that could predict the affects parameter of the solar updraft tower such as tower height, the collector radius and the effects of the solar radiation from the sun, on the relative static pressure, the driving force, the power output and the efficiency of the solar updraft tower [32]. Another simulation study was carried out to investigate the performance of the power generating system based on a developed mathematical model. The simulated power outputs in steady state were obtained for different global solar radiation intensity, collector area and chimney height [24]. The effects of the solar radiation intensity on the flow of the solar updraft tower were analyzed by [33] where Boussineq model was adopted for natural convection, discrete ordinate radiation model (DO) was employed for radiation and ground under collector cover was seen as a constant inner heat source. [34] compared theoretical models from previous works to study the accuracy of those theoretical models for the prediction of the solar updraft tower performance varying the plant geometrical. Computational fluid dynamics (CFD) studies were conducted to compare the results with these theoretical models and found that the results were very well compared with the CFD results and thus are recommended for the prediction of solar updraft tower performance

[35] presented the development of a model using airflow turbulent simulation in the solar updraft tower found that the most physical element in the solar updraft tower system are the tower dimension as they cause the most significant variation in the flow behavior. A numerical model was presented for the process of laminar natural convection in a solar chimney. They have focused on airflow and heat transfer inside the system and analyzed the effect of the geometry and Rayleigh number [36]. A mathematical model based on the Navier–Stokes, continuity and energy equations was developed to describe the solar chimney power plant mechanism in detail. Numerical simulation was performed using the CFD software FLUENT that can simulate a two-dimensional axisymmetric model of a solar chimney power plant with the standard k-epsilon turbulence model [37]. A comprehensive theoretical model has been developed by taking account of the detailed thermal equilibrium equations in the collector, the system driving force and the flow losses based on existing experimental data or formulas for the chimney height and collector radius [38]. The effect of the geometric dimensions on the fluid dynamics and heat transfer was investigated. The thermal efficiency of the collector was found to improve with increasing scale, due to an increase of the heat transfer coefficient [39]. Recent works for a few years back, [40] who conducted a detailed numerical analysis of solar chimney power plant system with a curve junction. The results are related to the temperature distribution and the velocity field in the chimney and in the collector. The performance evaluation of solar chimney power plant was done by FLUENT software by changing three parameters including collector slope, chimney diameter and entrance gap of collector. The results were validated with the solar chimney power plant which was constructed in Zanjan [41].

Another numerical research was conducted to study the influence of solar radiation and ambient temperature on the electrical energy produced by a solar chimney in the region of M'Sila (Algeria). The results indicates that the production of electrical energy is closely related to solar radiation and ambient temperature [42]. Up until recently, a mathematical model based on the Navier Stokes, continuity and energy equations was developed to describe the solar updraft power plant mechanism. Two different numerical simulations were performed. The first one is transient simulation for the geometry of the prototype in Manzanares, Spain under Dire Dawa climate condition. The numerical simulation was performed using the CFD software FLUENT that can simulate a two-dimensional ax symmetric model of a solar chimney power plant with the standard k-epsilon turbulence model and Discrete ordinates irradiation model [43]. Patel *et al* 2014 presented their work for optimizing the geometry of the major components of the solar updraft tower power plant using a computational fluid dynamics (CFD) software ANSYS-CFX to study and improve the flow characteristics inside the solar updraft tower power plant.

The researches was now mainly to optimize the previous design such as performance evaluation of a solar updraft tower is carried out based on the parameters such as roof angle, inlet height and for different irradiation values using ANSYS Fluent [44]. A 3D CFD (Computational fluid dynamics) model of a Solar Updraft Tower Power Plant was developed and validated through comparison with the experimental data of the Manzanares plant. Then, it was employed to study the system performance for locations throughout Tunisia [45]. A 3D numerical approach that incorporates the radiation model, solar load model, and a real turbine was used in this study. Variations in turbine performance with rotational speed were studied to investigate the power regulating strategy option for solar chimney turbines [46]. A mathematical model was developed to estimate the performance of SUPP based on tracking solar collector consideration in Malaysia. The objective is to verify the suggested model and to optimize the slope angle of tilted tracking solar collector and the results were promising for implementation in Malaysia [47]. Lately Computational Fluid Dynamics modelling are used to calculate the specific parameters, energetic and exergetic efficiencies of the solar updraft tower where the results from experimental and simulation were statistically assessed and very closed to measured data [48]. A model for time dependent analysis of solar chimneys is presented. The energy balance equations for three components of solar chimneys, absorbing plate, cover glass and air-gap are discretized with respect to time using an implicit finite difference model. The discretized nonlinear energy balance equations are solved for numerous time steps over a 24 hours period using the Newton–Raphson method [49].

5.0 ADVANTAGES OF SOLAR UPDRAFT TOWER

The solar updraft tower although it looks very simple in principle and the built of the power generation system using cheap and abundant materials such as glass, plastics and concrete. The system is the easiest, less sophisticated technology and user friendly power generation plant compared to the rest of the solar thermal technologies.

- The solar collector is capable to utilize all the solar radiation which is both direct and diffuse. There is a crucial advantages if the solar updraft tower were to be implemented in tropical countries where the sky is frequently overcast.
- The soil under the solar collector acts as a natural heat storage system where the heat is being stored up and released during the night time enabling the power plant to operate until the soil temperature reaches equilibrium with the ambient temperature. Although the power reduces during the night time, this can be easily overcome by introducing the water tubes placed under the solar collector as an additional heat storage.

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- Compared to conventional power station and some other solar thermal power station, water is required to act as a cooling medium. For countries which have very good solar radiation will have problem with the water supply (E.g. Installation in the middle of the desert)
- The materials used for constructing the solar updraft tower are very common as it mainly consists of glass, concrete, reinforcement bars, steel thrust etc. which is easily available in every country. The most complex equipment is the power generator turbine, gear drive and power converter unit (PCU)
- The solar updraft tower is also a very environmental friendly power plant as it utilizes steady flow of air, buoyancy and differential temperature and pressure to generate power. There are no burning and fuel consumption hence leads to no potential of emission harmless gas when it is compared with coal fired power plant. Therefore the system is far more reliable compared to other conventional power plants due to their vast amount of machineries and controls.

Therefore the technology advancement of the solar updraft tower is reaching maturity and it is possible to build a large plant without high foreign currency expenditure by using local resources and work-force; this creates large numbers of jobs while significantly reducing the required capital investment and thus the cost of generating electricity [50].

6.0 CHALLENGES & LIMITATIONS

6.1 Low Efficiency

Due to the low efficiency for conversion of solar power to electricity compared among the other types of solar thermal technologies, the solar updraft tower requires a large coverage of land to enable sufficient solar collectors to be installed. The main limitation of the conventional solar updraft tower is its low efficiency which is lower than 1%. Normally the efficiency is directly proportional with the square root of the chimney height. Based on the data obtained from the Spanish Prototype a 100 MW solar updraft tower will need approximately 15 km^2 of area for the solar collector. Therefore the land requirement for the solar updraft tower is approximately 6.9 MW/km^2 [1]. For countries which does not have sufficient land, the solar updraft tower power plant will be a limitation or acquisition of land with high cost.

Therefore land use is an important factor for studying the feasibility of implementing the solar tower in large scale.

6.2 Structural Integrity

The structural integrity of the solar updraft tower is also very important. The higher the tower, the more energy can be produce due to the differential temperature from the bottom entrance of the tower and ambient temperature at the other end of the tower. As to achieve a very high tower, the foundation design to cater the loading of the whole tower taking into consideration of the wind load and seismic activities in the structural design may increase the construction cost of the tower. For regions which have risk of high magnitude earthquakes are unsuitable for implementing the solar updraft towers because the costs of building tower to take into the consideration of the external force and to prevent the tower for resonating will increase the construction cost. Therefore the overall cost per kWh generated may increase drastically.

Therefore o support high tower structure and the weight of the turbine (if mounted vertically), compression ring stiffeners, concrete ring beams are installed with a vertical spacing [8].

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6.3 Operation & Maintenance

The solar updraft tower is considered as the most maintenance free type of solar thermal technology as it does not have sophisticate power conversion unit (PCU) or heavy machineries for maintenance. The power plant does not require any cooling water compared to the others where its operation expenditure (OPEX) is low. Although there are less equipment to maintain but there will be still components that require frequent preventive maintenance such as the turbine gear box which need regular servicing. The turbine contributes to the head loss to the overall system, therefore the lubrication for the gear box must be well maintained to prevent additional friction to the system.

As there are a few configuration for the location of the turbine, the location for the horizontal installation and vertical installation for the lower part may ease the maintenance of the plant compared to turbines installed at the exit of the updraft tower. Due to the large coverage of the solar collector, it will be impossible for mobile crane to access to the turbines and gear box. Therefore the sizing of the equipment must take into consideration on this matter. It should be mentioned that the designers of the Manzanares prototype plant were aware of the fact that the collector height was slightly larger than its optimum value. It was intentionally made larger so that a small truck could be driven to the turbine section for maintenance purposes [39].

Peninsular Malaysia have an average rainfall of 2500 mm per year, therefore the conventional horizontal collector will have a problem of ponding on the collector and trapping of leaves and dirt blocking the solar radiation passing through the collector. For consideration of routine cleaning of the solar collector, the structural design will need to take into consideration of this problem hence increasing the construction cost. Maintenance will be reduce if the solar collector is installed at an inclined angle and the angle for best efficiency.

6.4 Various Losses Reduces Overall Efficiency

The solar collector are usually installed in steel thrust similar to roof installation, therefore to take into consideration the live and dead load on the solar collector, this loading will be need to be transmitted to the ground. This will determine the size of the vertical columns and quantity of columns to fastened the large piece of collector to anchor it to the ground. Therefore the amount of columns are quite a number and the hot air approaching the inlet at the bottom of the solar tower will have frictional losses as to flow around the columns. Therefore the distance between columns may affect the efficiency of the system.

Secondly each glazed glass collector may come in a variety of sizes as for easy maintenance and replacement, the size shall be limited. Due to the large coverage of the solar collector, there will be a lot of strutting and brazing between the purlins and the horizontal beams to support the loading of the glass and the design load. Therefore all the components may contribute to the frictional losses as the collector bottom surface is not completely flat [17].

The connection between the collector and tower based on a curvature joint and showed that the maximum velocities are gotten at the inlet of the chimney tower and its values were increased by increasing the difference between ground and roof of the collector. This result will help the solar chimney designer correctly locate the turbine in the solar chimney power plant [40].

System Losses occurring in the PCU can be divided into three groups, namely aerodynamic, mechanical and electrical losses. The overall system loss of various component of the solar updraft tower may contribute to the deviation of the actual performance compared to the results

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produce by the numerical method as there are losses that need to be taken into consideration such as

a) Intake Losses - intake geometry with converging sections and a transition from rectangular to circular and analyse it with CFD.
b) Turbine Losses – different losses for different types of installation method and type of turbine (Single or Multiple)
c) Diffusion Losses - There are two areas in the solar updraft tower power conversion unit (PCU) where significant diffusion losses can occur; the first is after the turbine rotor(s) where the hub ends, the second is in the actual diffuser.
d) Mixing Losses - multiple turbine configuration, losses will be generated where the outflow of the various turbines merge.
e) Horizontal-to-Vertical Flow Transition Losses – the losses between the transitions of the solar collector to the tower.
f) Aerodynamic Losses - The friction losses in the straight runs are insignificant in relation to the losses due to flow obstructions and components in the PCU and are usually neglected during simulation.
g) Drive Train Losses - includes all components necessary to convert the mechanical power delivered by the turbine rotor to electrical power ready for grid feeding, i.e. gearbox, electrical generator, power electronics and grid interface systems.

A research was conducted to estimate the above losses and the results show that, with designing the flow passages in an appropriate manner, the aerodynamic losses over the various components of the PCU can be kept low. The assumption made by many other researchers that the total-to-total efficiency of the PCU is 80% has been confirmed [20].

6.5 Heat Storage

Conventional solar updraft tower power plant use the soil or earth as heat storage to enable the power plant to extend the power generation even after sunset. Although the heat release from the soil can extend a few hours of power generation, it is still unable to perform 24 hours continuous power generation. Therefore additional heat storage mediums have been introduced to enable the heat to be absorbed into water tubes and store for night use. Since the heat capacity of water is approximately 5 times higher than soil, therefore this allows the plant to be able to operate during the night time [24]. Therefore the location of the solar updraft tower is preferable to be located near a water source where the water can be replenish during low level.

7.0 EVOLUTION OF SOLAR UPDRAFT TOWER

7.1 Sloped Solar Updraft Tower

The basic concept explored by this author is to construct a chimney with a collector in a sloppy section [51]. In another study conducted, it was suggested that a hole can be excavated at the centre of a high rising mountain, which will act as the chimney. The collector area would be spread around the mountain [52]. This kind of solar power plant has a sloped solar collector and a short vertical solar chimney. It is called the sloped solar chimney power plant (SSCPP). The recently, works conducted was to compare the performance of a conventional solar chimney power plant (CSCPP) and two sloped solar chimney power plants (SSCPPs) with the collector oriented at 30° and 60°, respectively [12]. The following figure shows the schematic diagram of the sloped solar chimney power plant.

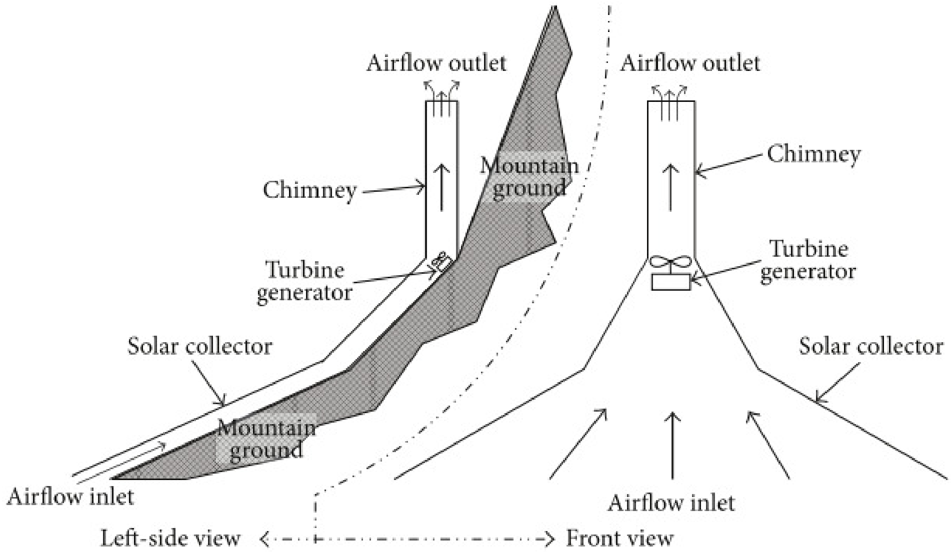

Figure 7-1: The schematic diagram of the sloped solar chimney power plant [12]

7.2 Floating Solar Chimney

The floating solar chimney was introduced by Prof. Christos D. Papageorgiou. It is a low cost alternative of the concrete solar chimney. The Floating solar chimney, as a lighter than air structure, can be raised anywhere and its cost is as low as 2% of the cost of the respective concrete chimney [53]. A Floating Solar Chimney (FSC) power plant consists of three major components:

a) A tall concrete cylindrical tower at the center of the solar collector similarly to the solar updraft tower concept.
b) A large circular solar collector with transparent glass roof with intermediate support and located a few meters above the ground utilizing the Greenhouse effect.
c) A set of air turbines geared to appropriate electrical power generators to produce electricity.

The floating in the air, lighter than air, "Floating Solar Chimney" (FSC) is a low cost alternative of the reinforced concrete solar chimney structure. The FSCs can easily be constructed to heights up to 600-700 m [53].

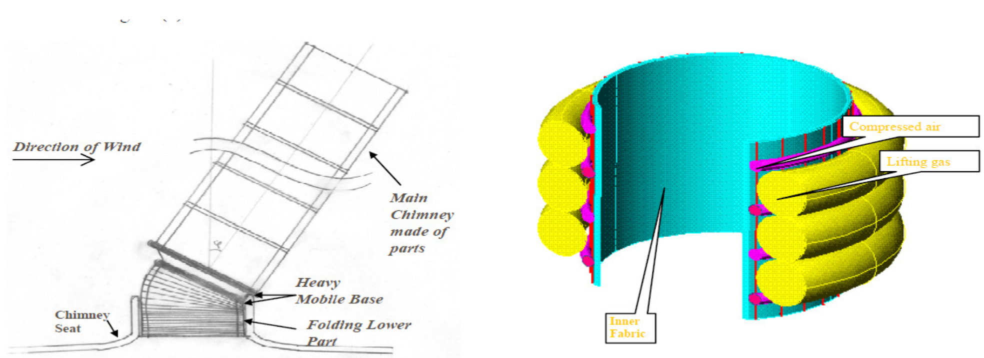

Figure 7-2: Floating Solar Tower Schematic and Sectional View [53]

7.3 Chimney solar pond combination

In 2002, a small prototype using a combination of a solar pond with a chimney was constructed at the RMIT Campus in Bundoora which is located approximately 20 km from north of Melbourne. The tower was constructed from flexible circular ducting as used in domestic heating systems. Since this material is flexible the duct was supported by the structure of a small experimental aero generator which was within a few meters of a small experimental solar pond [54].

Figure 7-3: Bundoora Chimney Solar Pond Combination [5]

7.4 Hybrid Geothermal / Photovoltaic cogeneration with Solar Updraft Tower

Using the concept of the conventional solar updraft tower configuration, the hybrid system is to introduce a new concept capable to produce more electrical energy by recapturing the rejected heat from the condenser supplemented by the solar energy gain from the solar collectors [55]. The working principle of this hybrid system is as follow: The ambient cool air enters the hybrid system from the open base slots and passes through the heat exchangers (radiators) and cools down the condenser water within its path. The heat from the condenser water assist to further heat up the air then passes through the space under the transparent solar collector and gains more heat from solar radiation. The transparent solar collector and the ground below it act as a collector and heat up the flowing air more via greenhouse effect.

The buoyant airflows radially towards the center of the system, where it is directed through wind turbine for power generation, which is installed at the throat of the chimney. The air drives the turbine in its path and generates electrical power similar to that in solar chimneys [5].

Another type of hybrid system is to combine the solar chimney and Solar PV via cogeneration system where the heat is removed from the transparent PV array, used to heat the air underneath the solar collector of the solar updraft power plant. The heat production per square meter of solar PV array can be as much as four times greater than the electrical energy produced to putting this heat to use improve the system total efficiency and cost.

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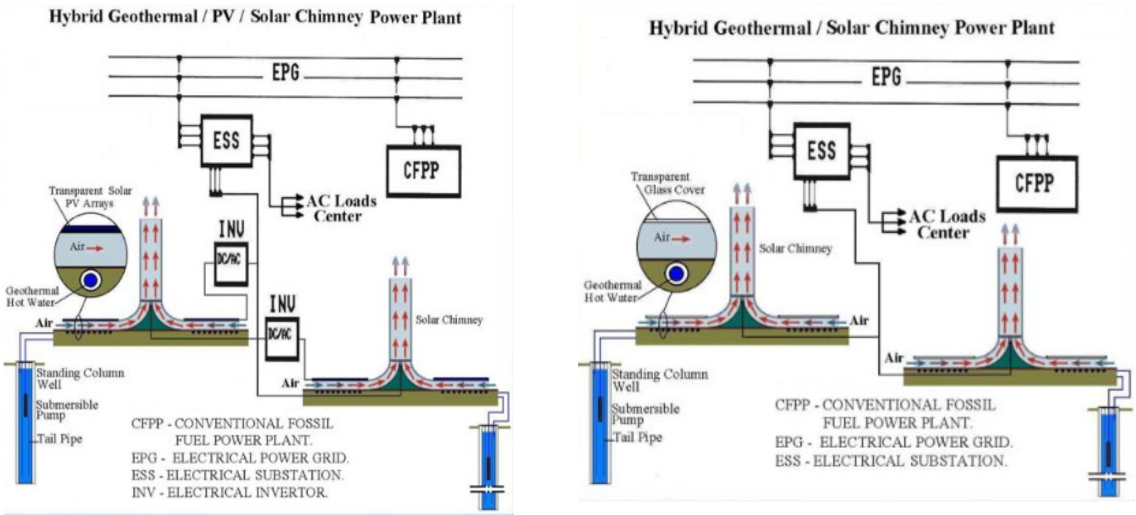

Figure 7-4: Hybrid Solar Power Plant using PV Transparent Panel, Geothermal and Solar Updraft Tower [53]

8.0 SUMMARY

The solar updraft tower is a very good alternative renewable energy power generation system to replace conventional coal and fired power plant. It does not required sophisticated technical infrastructure and low in maintenance cost due to the less moving parts. The previous researches shows that the solar updraft tower has an outstanding technology development and improvement throughout the year to achieve stability and maturity in construction, operation including its technical development. Due to the large coverage of the solar collector, the soil under the collector can be used for agricultural business such as plantation for fruits, herbs and vegetable to maximize the land use. Latest Development is to also utilize the space below the collector for cogeneration of hot water and also installation of solar photovoltaic panels below the collector as it is said to increase the efficiency of the PV panels due to the part of the heat is removed through the air flowing through the collector. This helps maximize the power output during peak hours.

This review paper discusses on the principles and working principle of the system, its requirement, construction and operation of the solar updraft tower. It also briefly explain the overall view of the present state of research at the solar chimney power plant for experimental and numerical where the advantages and disadvantages of future prospects for large-scale plants. A list of prototypes have been tested worldwide to prove the liability of the solar updraft tower and also a comparison of numerical studies that have been conducted. Due to the high capital cost of construction of solar updraft tower, many researchers have chosen the numerical method in their studies especially CFD methods to obtain preliminary results before implementing the project in large scale.

REFERENCES

[1] Bergermann, Schlaich, Solar Updraft Tower, Schlaich Bergermann Solar GmbH, 2011.

[2] Tenaga, Suruhanjaya, Peninsular Malaysia Electricity Supply Industry Outlook. Industry

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 I Vol. 18, No.1. Pages 1-25, 2016

Outlook, Putrajaya, Malaysia: Suruhanjaya Tenaga (Energy Commission), 2014.

[3] Pasad, Deo., Solar Power, USA: The Images Publishing Group Pty Ltd & Earthscan, 2005.

[4] Bernama, UK lauds Malaysia's pledge to cut, News, the Star Online, 2009.

[5] A. Dhahri, A. Omri, A review of solar chimney power generation technology, International Journal of Engineering and Advanced Technology 2 (2013)1-7.

[6] C.M. Meyer, La Mancha, Towers of power: The solar updraft tower, (2008) 51-4.

[7] J. Schlaich, The Solar Chimney, Edition Axel Menges, 1995.

[8] X. Zhou, F. Wang, R.M. Ochieng, A review of solar chimney power technology, Renewable and Sustainable Energy Reviews 14 (2010) 2315-2338.

[9] I.S. Jones, Engineering strategies for greenhouse gas mitigation. Cambridge University Press, 2011.

[10] T.W. Von Backström, R. Harte, R. Höffer, W.B. Krätzig, D.G. Kröger, H.-J. Niemann, G.P.A.G. Van Zijl, State and Recent Advances in Research and Design of Solar Chimney Power Plant Technology, VGB Powertech 88 (2008) 64-71.

[11] J.P. Pretorius, D.G. Kröger, Critical Evaluation of Solar Chimney Power Plant Performance, Solar Energy 80 (2006) 535-544.

[12] F. Cao, H. Li, Y. Zhang, L. Zhao, Numerical simulation and comparison of conventional and sloped solar chimney power plants: the case for Lanzhou, The Scientific World Journal (2013).

[13] F. Denantes, E. Bilgen, Counter-rotating turbines for solar chimney power plants, Renewable Energy 31(12) (2006) 1873-1891.

[14] W. Haaf, K. Friedrich, G. Mayr, J. Schlaich, Solar chimneys part I: principle and construction of the pilot plant in Manzanares, International Journal of Solar Energy 2(1) (1983) 3-20.

[15] L.B. Mullett, The solar chimney—overall efficiency, design and performance. International Journal of Ambient Energy 8(1) (1987) 35-40.

[16] T.W. Von Backström, A.J. Gannon, Solar chimney turbine characteristics. Solar energy, 76(1) (2004) 235-241.

[17] M.D.S. Bernardes, A. Voß, G. Weinrebe, Thermal and technical analyses of solar chimneys, Solar Energy 75(6) (2003) 511-524.

[18] A.O. Chikere, H.H. Al-Kayiem, A.A Abdul Kari, Enhancement Techniques and Introduction of an Alternate Enhancement Technique of Solar Chimney Power Plant, Journal of Applied Science 11 (2001) 1877-1884.

[19] R.A. Hedderwick, Performance evaluation of a solar chimney power plant, A Model Solar Updraft Tower Power Plant (2013).

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 18, No.1. Pages 1-25, 2016

[20] T.P. Fluri, T.W. Von Backström, Performance Analysis of the Power Conversion Unit of a Solar Chimney Power Plant, Solar Energy 82 (2008) 999–1008.

[21] J. Schlaich, R. Bergermann, W. Schiel, G. Weinrebe, Design of Commercial Solar Updraft Tower Systems – Utilization of Solar Induced Convective Flows for Power Systems, Journal of Solar Energy Engineering 127 (2005) 117-124.

[22] N. Pasumarthi, S.A. Sherif, Experimental and theoretical performance of a demonstration solar chimney model - Part II: Experimental and Theoretical results and economic analysis, Journal of Energy Research 22(5) (1998) 443-461.

[23] A.J. Gannon, T.W. Von Backström, Solar chimney turbine part 2 of 2: Experimental results, International Solar Energy Conference. Reno, 2002.

[24] X. Zhou, J.K. Yang, B. Xiao, G.X. Hou, Simulation of a pilot solar chimney thermal power generating equipment, Renewable Energy (2007) 1637-1644.

[25] A. Ferreira, C. Maia, M. Cortez, R. Valle, Technical feasibility assessment of a solar chimney for food drying, Solar Energy 82 (2008) 198-205.

[26] M.A. dos Santos Bernardes, Numerical Analysis of Natural Laminar Convection in a Radial Solar Heater, International Journal of Thermal Sciences 38 (1999) 42-50.

[27] D.G. Kroger, J.D. Buyst, Radial Flow Boundary Layer Development Analysis 5 (1999) 3–10.

[28] M.A.K. Lodhi, Application of Helio-Aero-Gravity Concept in Producing Energy and Suppressing Pollution, Energy Conversion and Management 40 (1999) 407–421.

[29] M.M. Padki, S.A Sherif, On a simple analytical model for solar chimneys, International Journal of Energy Research 23 (1999) 345–349.

[30] J.H.M. Beyers, T.M. Harms, D.G. Kröger, A Finite Volume Analysis of Turbulent Convective Heat Transfer for Accelerating Radial Flows, Numerical Heat Transfer 40 (2001) 117-138.

[31] M.A. dos Santos Bernardes, Solar Chimney Power Plants-Developments and Advancements, INTECH Open Access Publisher (2010) 953–978.

[32] T.Z. Ming, W. Liu, G.L. Xu, Analytical and Numerical Investigation of the Solar Chimney Power Plant Systems, International Journal of Energy Resources 30 (2006) 861-873.

[33] H.L. Huang, H. Zhang, Y. Huang, F. Lu, Simulation calculation on solar chimney power plant system, In Challenges of Power Engineering and Environment (2007) 1158-1161.

[34] A. Koonsrisuk, T. Chitsomboon, A Single Dimensionless Variable for Solar Chimney Power Plant Modeling, Solar Energy 83 (2009) 2136–2143.

[35] C.B. Maia, A.G. Ferreira, R.M. Valle, M.F.B. Cortez, Theoretical evaluation of the influence of geometric parameters and material on the behaviour of the airflow in a solar chimney, Computers & Fluids 38 (2009) 625-636.

[36] T. Chergui, S. Larbi, A. Bouhdjar, Thermo-hydrodynamic aspect analysis of flows in solar chimney power plants—A case study, Renewable and Sustainable Energy Reviews, 14 (2010) 1410-1418.

[37] R. Sangi, M. Amidpour, B. Hosseinizadeh, Modeling and numerical simulation of solar chimney power plants, Solar Energy 85 (2011) 829-838.

[38] J.Y. Li, P.H. Guo, Y. Wang, Effects of Collector Radius and Chimney Height on Power Output of a Solar Chimney Power Plant with Turbines, Renewable Energy 47 (2012) 21-28.

[39] H. Fasel, E. Shams, A. Gross, CFD Analysis for Solar Chimney Power Plants 1 (2012) 1524–32.

[40] T. Tayebi, M. Djezzar, Numerical Analysis of Flows in a Solar Chimney Power Plant with a Curved Junction, International Journal of Energy Science 3 (2013) 280-286.

[41] M. Ghalamchi, M. Ghalamchi, T. Ahanj, Numerical Simulation for Achieving Optimum Dimensions of a Solar Chimney Power Plant, 1 (2013) 26-31.

[42] S. Djimli, A. Chaker, Numerical Study of the Solar Chimney Power Plant Performance in the Region of M' Sila, Algeria Key Words 12 (2014) 1–5.

[43] B. Yetimgeta, Modelling and Simulation of Solar Chimney Power Plant for Electrification, Dire Dawa 1 (2014) 1–14.

[44] S. Adarsh, Numerical simulation on the performance evaluation of a solar updraft tower, International Journal of Mechanical Engineering and Robotic Research 3 (2014).

[45] A.F. Bahar, M.S. Guellouz, M. Sahraoui, S. Kaddeche, A numerical study of solar chimney power plants in tunisia, J. Phys. Conf. Ser 596 (2015).

[46] P. Guo, J. Li, Y. Wang, Y. Wang, Numerical study on the performance of a solar chimney power plant, Energy Conversion and Management 105 (2015) 197-205.

[47] A.A. Gitan, S.H. Abdulmalek, S.S. Dihrab, Tracking Collector Consideration of Tilted Collector Solar Updraft Tower Power Plant under Malaysia Climate Conditions Energy 93 (2015) 1467–77.

[48] S. Lal, S.C. Kaushik, R. Hans, Experimental Investigation and CFD Simulation Studies of a Laboratory Scale Solar Chimney for Power Generation, Sustainable Energy Technologies and Assessments 13 (2016) 13–22.

[49] M.H. Naraghi, S. Blanchard, Twenty-Four Hour Simulation of Solar Chimneys, Energy and Buildings 94 (2015) 218–26.

[50] J. Schlaich, R. Bergermann, W. Schiel, G. Weinrebe, Design of Commercial Solar Updraft Tower Systems – Utilization of Solar Induced Convective Flow of Power Generation, Journal of Solar Energy Engineering 127 (2005) 117-124.

[51] B.O. Ahmed, Design and thermodynamic analysis of, Thesis, University of Applied Sciences, Schmalkalden (2011).

[52] X. Zhou, J. Yang, A Novel Solar Thermal Power Plant with Floating Chimney Stiffened

onto a Mountainside and Potential of the Power Generation in China's Deserts, Heat Transfer Engineering (30) (2009) 400-407.

[53] C.D. Papageogiou, M. Psalidas, S. Sotiriou, Floating Solar Chimney Technology Scale Analysis, 1982.

[54] K. Golder, Combined solar pond and solar chimney. Final year Mechanical Engineering Project, RMIT University, Melbourne, Australia: School of Aerospace, 2003.

[55] H. Alrobaei, Hybrid Geothermal / Solar Energy Technology for Power Generation, 2005.

[56] R.J.K. Krisst, Energy Transfer System, Alternative Source of Energy 63 (1983) 8-11.

[57] H. Kulunk, A prototype solar convection chimney operated under Izmit Condition, Proceedings of 7th MICAES 162 (1985).

[58] V.A. Koyun, Gunes Bacast Ile Enerji Uretiminin Incelenmesi S.D.U Fen Bilimleri Enstitusu, PhD Thesis, Isparta, Turkey, (2006).

[59] N. Najmi, H. Mansour, Feasibility Study on optimization of a typical solar chimney power plant, Heat Mass Transfer 48 (2012) 475–485.

[60] O. Motsamai, L. Bafetanye, K. Mashaba, O. Kgaswane, Experimental Investigation of Solar Chimney Power, Journal of Energy and Power Engineering 7 (2013) 1980-1984.

[61] C. Hartung, H. Marschetzky, T. Link, M. Bauer, M. Kunzel, M. Ellwanger, T.P. Thanh, L.N Dang, Solar power plant, Germany, 2008.

[62] L. Zuo, Y. Yuan, Z. Li, Y. Zheng, Experimental research on solar chimneys integrated with seawater desalination under practical weather condition, Desalination 298 (2012) 22-33.

[63] S.T. Ahmed, M.T. Chaichan, A study of free convection in a solar chimney model, Eng. & Tech, Journal 29 (2011) 2986-2997.

[64] M.A. Al-Dabbas, The first pilot demonstration: solar updraft tower power plant in Jordan, International Journal of Sustainable Energy iFirst (2011) 1–12.

[65] A. Koonsrisuk, A single dimensionless variable for solar chimney power plant, Solar Energy 83 (2009) 2136–2143.

[66] A.B. Kasaeian, E. Heidari, S.N. Vatan, Experimental investigation of climatic effects on the efficiency of a solar chimney pilot power plant, Renewable and Sustainable Energy Review 15 (2011) 5202-5206.

[67] A. Buğutekin, Experimental study of temperature field in a solar chimney power plant in Adiyaman, J. of Thermal Science and Technology 32 (2012) 73-80.

[68] U. Manon, R. Maxime, L. Boris, L. Mathias, Cheminee tour solaire. Project 1112 on Anne ´e universitaire. France: Universite ´ de Pau et des Pays de l'Adour, Pau, France, 2011.

[69] O.H. Mohammad, R. Obada, Experimental Solar Chimney Data with Analytical Model Prediction, World Renewable Energy Forum, Denver, Colorado, 2012.

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[70] S.M. Raney, J.R. Brooks, J.P. Schaffer, J.J. French, Experimental Validation of Solar Chimney Performance Models and Operational Characteristics for Small Scale Remote Applications, ASME 2012 6th International Conference on Energy Sustainability. San Diego, California, USA: ASME (2012) 27-32.

[71] S. Kalash, W. Naimeh, S. Ajib, Experimental Investigation of the Solar Collector Temperature Field of a Sloped Solar Updraft Power Plant Prototype, Solar Energy 98 (2013) 70-77.

[72] C.D. Papageorgiou, Enclosed Solar Chimney Technology, 2013.

[73] A. Kasaeian, M. Ghalamchi, M. Ghalamchi, Simulation and Optimization of Geometric Parameters of a Solar Chimney in Tehran, Energy Conversion and Management 83 (2014) 28–34.

[74] G. Xu, T. Ming, Y. Pan, F. Meng, Ch. Zhou, Numerical Analysis on the Performance of Solar Chimney Power Plant System, Energy Conversion and Management 52(2) (2011) 876–83.

[75] K.P. Sandeep, D. Prasad, M.R. Ahmed, Computational studies on the effect of geometric parameters on the performance of a solar chimney power plant, Energy Conversion and Management 77 (2014) 424-431.

[76] X. Zhou, Y. Xu, Solar Updraft Tower Power Generation, Solar Energy (2014).