A Survey on Performance Enhancement of Solar Updraft Tower Power Plants

Ayad T. Mustafa, Hussain H. Al-Kayiem, Syed I. U. Gilani

***Abstract*— So as to promote the power plant performance, some developments and progressive configurations were suggested for the components of the solar updraft tower power plants. A detailed literature survey of development of performance enhancement techniques were presented and discussed in the present paper. The survey gives a summarize overview of the developments in each of the components key area inspect to raise the performance of the currently solar power plants.**

***Index Terms*— Performance enhancement, solar energy conversion, solar systems development, solar updraft tower power plant.**

I. Introduction

To conquer the negative effects on the environment and other problems connected with fossil fuels many countries to clarify into and change to ecological intimate alternatives that are renewable to incur the growing energy request. Solar energy is one of the best renewable energy sources with minimum negative influence on the environment [1].

Solar updraft tower plants are known as low temperature solar power plants, which use the environment air as an operating fluid [2]. The solar updraft tower is a power plant that utilizes (1) solar radiation intensity to increase the temperature of the air and (2) the buoyancy force of warm air to accelerate the air flow through the system [3]. Updraft hot air in solar updraft tower works as a heat engine, enhancements of heat engine cycle participate with: (1) Increase the temperature difference in the heat engine by raise the worm side temperature in the solar collector, and (2) Achievement the chemical properties of the working fluid [4].

II. Solar Systems Development

A. Solar Energy Support

To study the thermal systems behavior with solar radiation donating, it's an important to guarantee a regular and planned distribution. Akbarzadeh et al. [5] examined notions of integrate salinity solar pond has updraft tower to produce power in Australia as a case study. When evaporation open reservoirs are used in series as in a ''salt work", the beginning reservoir supplies perfect ways for making solar ponds while the last reservoir in the series can be the source of quite salty brine to keep the salinity of the bed of the solar pond. Thermal heat is extracted from the bed interface between the gradient layer and the undermost convective region, then pumping it over a water-to-air direct contact heat exchanger inside the tower. Next to transfer its heat, the water is returned to the bed of the solar pond. Therefore the ambient air is heated as a result of the required draft inside the tower, Fig. 1. When the conditions of outlet air know, air exit velocity U_o can be calculated for the maximum point of a desired power, Eq. (1):

$$U_o = \sqrt{\frac{2}{3} g H_c \left(\frac{\rho_i}{\rho_o} - 1\right)} \quad (1)$$

Results show the thermal model of solar pond has 10% greater than the solar collector used in the Manzanares solar updraft tower project and could produce 60 kW generated power for warm air condition between 20˚C to 50˚C in the tower [5, 6]. Furthermore, Ranjan et al. [7] reviews a thermodynamic feasibility of solar ponds with performance analysis investigation of solar ponds, as well as various thermal applications were reported as desalination and salt production, agriculture and dairy plants, swimming pool heating, space heating, refrigeration and air-conditioning, and power generation.

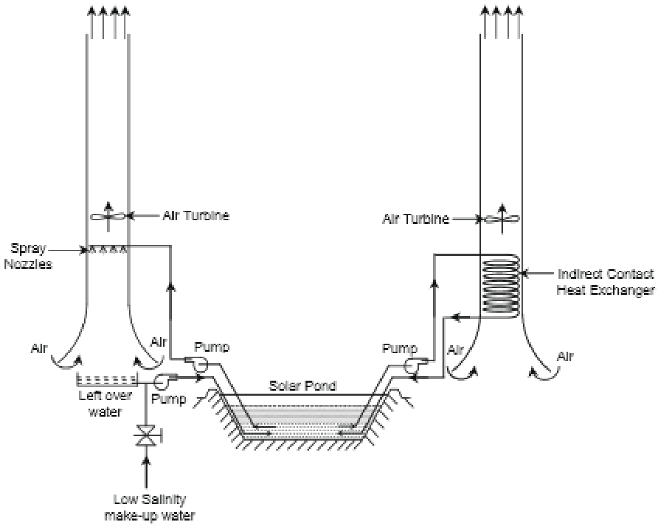

Fig. 1: Concepts of integrate updraft tower with a solar pond to generate power [5]

Negrou et al. [8] presented the description of hydrogen gas mass product by electrolysis of water; Fig. 2. The solar updraft tower that conveys solar thermal energy into electrical power is supplied to the electrolytic cells (a case study in Algeria). Pumping system used for electrolysis cells is

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provided with a 5 kg/s of water flow, and 9 MW gross capacities. By electricity generated through a solar tower, a simulation utilized to the facility with solar resources, the mass product of hydrogen is less costly than traditional energy. The results estimate the huge production of hydrogen. The collection of solar energy and hydrogen product is obviously enjoyable and has a future glance of energy demand.

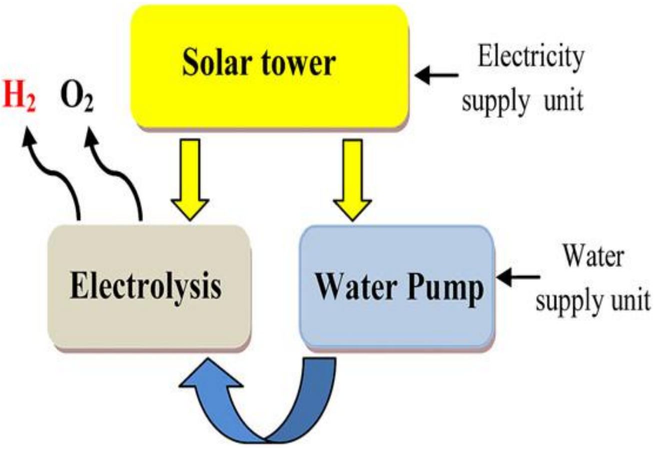

Fig. 2: The synoptic diagram of the solar hydrogen production system [8]

B. Desalination of Seawater

When the combination of solar power and fresh water by seawater desalination are the objective, Zhou et al. [9] investigated a substitutional method of thermal heat and humidity extract from seawater pass under the solar collector canopy of system included turbine and high-efficiency condenser installed at top of the solar updraft tower. The system depend on warm and saturated ambient air flows over seawater pulled from close sea, when this air flow pass through updraft tower; the temperature will decreases toward the top and freshwater of vapor is condensed. The freshwater is collected at the bed and drawn out constantly. Results show that temperature and velocity in combined system is less than that in conventional power plant when it's compared at the solar updraft tower; because of latent heat redaction as air flow rises.

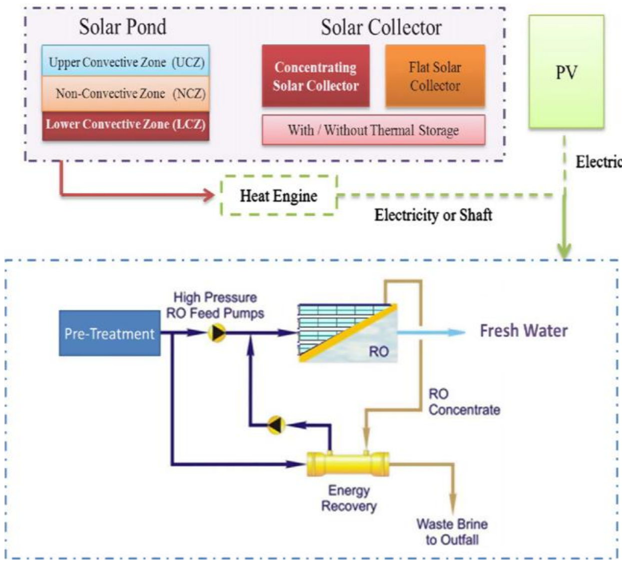

Fig. 3: Schematic of solar assisted RO process [14]

So as to overcome the restrictions of available water resources, Mekhilef et al. [10] developed water desalination industry process which can supply beneficial clean water from sea water. The results concluded from water desalination capability installed worldwide show that an exploitation of \$10 billion is required to desalinate 5million m^3/d water [10, 11]. Zuo et al. [12] suggest the solar updraft tower power generation for artificial system performance of seawater desalination, moreover causes analysis for the low productive rate of solar water distillation, also seawater characteristics are presented for an emperical system of power generation and seawater desalinization [13]. Furthermore, Chennan et al. [14] reviews the solar assisted sea water desalination processes of MSF, MED, HP, RO, PVD, HDH, and MD. Which RO is the biggest international desalination process by means of capacity, Fig. 3. Although solar desalination processes have not been commercial up to now, but it's still a useful choice for future desalination plants.

C. The Solar Cyclone with Vortex

By signify of pulling fresh water from air atmosphere, the solar cyclone was introduced by Kashiwa et al. [15]. The solar updraft tower power plant composed of a solar collector with heat storage which storing the energy as heat and a solar updraft tower that conduits a path of an updraft warm air. A separator cyclone set at the base of the updraft tower for condensing vapor and separating water, Fig. 4. The separator includes a powerful swirly vortex, where moist air temperature at the vortex center is lower than a dew point for warm air at the solar collector.

Updraft air in the tower is powered the separation process with turbulent flow for raise and enhance the separation force, furthermore updraft warm air utilized to generate electricity [15, 6].

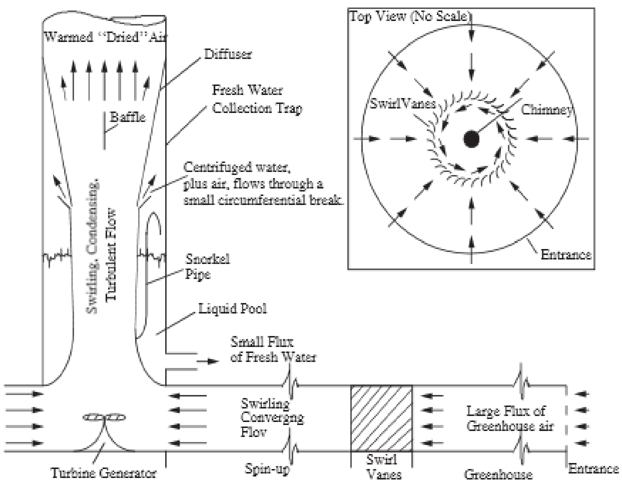

Fig. 4: Schematic of the expansion cyclone separator [15]

Stratified of heated air-vapor availability in the gravitational atmosphere was developed by Ninic et al. [16], this method concentrates on the availibility possibility to be stiff vertical conduit on the ground instead of using a rigid tower of solar updraft tower power plant. The activity of heated air-vapor availability can be defined as an obtained work by reversible process with stable equilibrium condition of atmosphere and known as "gravitational vortex column" (GVC) [16, 2]. Ninic et al. [17] introduced their idea of GVC by the title "solar power plant with short diffuser" to the

International Application Published under the Patent Cooperation Treaty (PCT) and gets a patent with number No: PCT/HR2007/000037 on May 14, 2009.

III. ENHANCEMENT TECHNIQUES

Due to the low efficiency associated with solar updraft tower power plant, growing performance is necessary for future application. Aja et al. [18] reported survey of previous studies involve with the performance increases of solar updraft tower power plant. The studies also presented a stand by approach to increase the solar updraft tower plant performance via crossbred of the solar radiation energy and energy waste from flue gas. Modern method utilization of thermal energy in solar updraft tower power plant converted from the waste energy, Fig. 5. Al-Kayiem et al. [19] showd that flue gas exhausted from thermal power plants contains more than 50% of the fuel thermal energy. Waste heat from flue gases can be classified base on the source and the exhaust gas temperature as high temperature, medium temperature or low temperature heats. Experimental investigation consists of wind rotor with chimney to utilized thermal energy in the flue gas which transfers to the air across the absorber plate for enhance the performance of a solar chimney. Hussain [20] proposed Hybrid Geothermal/SCPP and Hybrid Geothermal / PV / SCPP for prospective SCPP in the south region of Libya. The technology for this hybrid system can be described from the diagram Fig. 6, geothermal hot water is pumped and circulated through pipes embedded on the soil surface under the collector roof thus hating up the adjacent air to generate artificial wind (hot air stream) that turns the turbine. The Hybrid Geothermal / PV / Solar Chimney Power Plant is similar to Hybrid Geothermal / Solar Chimney Power Plant but includes PV as auxiliary energy converted and an inverter which convert the DC power generated by the PV to AC power to enhance the power generation.

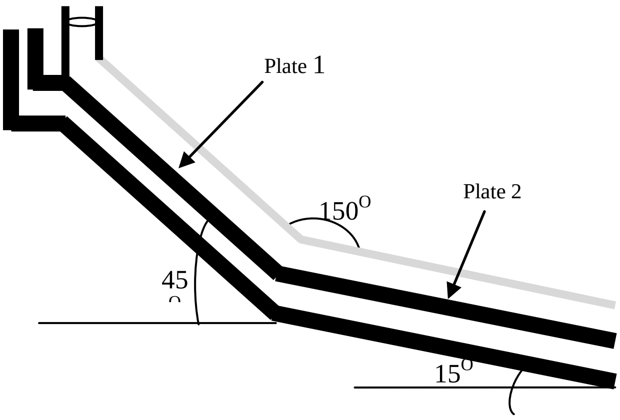

Fig. 5: Modern method of waste energy converted to thermal energy in solar updraft tower power plant with model design angles [18]

New model of air flow solar collector with a floating solar chimney (FSC) technology was presented by Papageorgiou et al. [21]. The technology of floating solar chimney no need of water for working and gives power production continuously, so it's appropriate for desert zone applications [21, 6]. The suggested model will minimize cost and building work of the solar collector in power plant, which used for warm air flow over the ground. The solar collector will be made by triangular shape tunnels with double glazing which put it in parallel series on the ground elevation, Fig. 7. The efficiency of new solar collector model is evaluated to be higher than 50% [21].

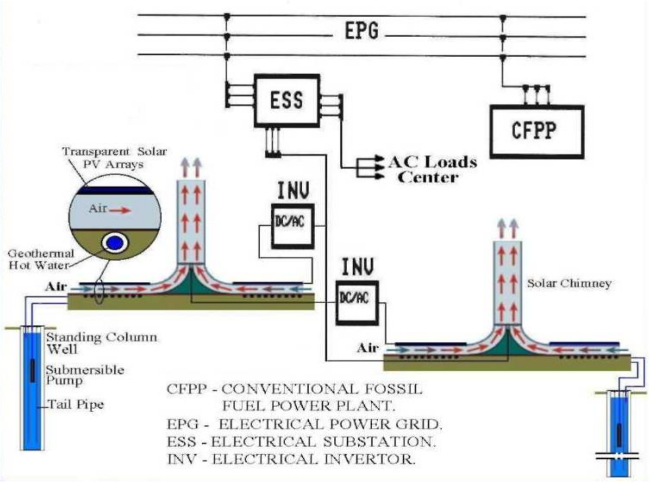

Fig. 6: Hybrid Geothermal/PV/Solar Chimney Power Plant [20]

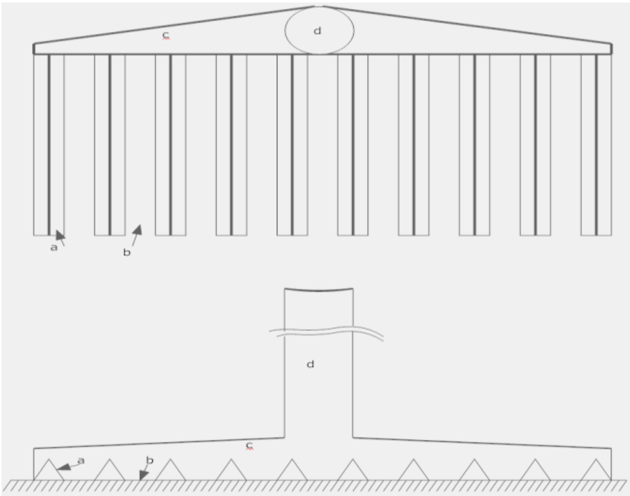

Fig. 7: Modular solar collector with ten air tunnels (a) Triangular tunnel, (b) Maintenance corridor (c) Central air collecting tube, (d) FSC [21]

IV. THE SOLAR COLLECTOR ENHANCEMENT

Output power from the solar updraft tower power plant is proportional to the air flow rate and temperature difference produced from the solar collector. The air flow rate can be raise by increasing the rise of the tower and/or enhancing its efficiency. The temperature difference can be raise by increasing the area of the collector and/or enhancing its efficiency. So as high financial investment with any increasing of updraft tower height, increasing the area of the solar collector and its efficiency are appropriate. First enhanced can be done by extending the area of the solar collector, and second enhanced can be done by add or install an absorber material at the collector base to absorb a thermal heat and rise the collector working period [22].

Panse et al. [23] introduced an inclined solar chimney (updraft tower plant) for high hill application. An integrated area of the solar collector and the tower (chimney) are built together along a high hill surface which facing the solar radiation intensity. The air flow rate intensity inside the updraft tower gradually decreases with the height of the tower, so the velocity of air flow at the exit is maximal than that at the input. Another enhanced parameter appears at high elevation of the hill which raises the velocity of updraft air flow that is wind velocity. So an inclined solar chimney employing the solar energy with the wind effect to produce power. The design of the chimney dimensions determine the temperature can be reached by the growing updraft air.

Mohsen et al. [24] present appropriate method for enhanced the power production which include: employment of asphalt at the base of the solar collector as an absorber, a collector canopy with double surfaces of glass, maximum usage height of collector canopy is 1.3 m, and employ of conic model in the inlet of the updraft tower. Thermal simulation model presented for the solar collector with space zone between canopy and the ground. The air flow inside the collector driven by a free convection heat transfer. The coefficient of free convection heat transfer could be determined by Nusselt number for a low canopy height, Eq. (2), and high canopy height, Eq. (3):

$$Nu = \frac{0.037\, Re^{0.8} Pr}{1 + 2.44 Re^{-0.1}(Pr^{2/3} - 1)} \tag{2}$$

$$Nu = 0.14 Ra^{1/3} \tag{3}$$

Pascual-Muñoz et al. [25] showed a new design of a multilayered asphalt solar collector as well as analysis of the collector behavior parameters. Very good experimental thermal efficiencies were obtained of the asphalt collector with values range from 75% to 95% depending on the irradiance, porosity of the intermediate layer, and slope of the collector. Low flow rates of water were obtained accompanied with high thermal efficiencies of the asphalt solar collector. Furthermore, Vanesa et al. [26] reported a review of asphalt solar collector systems, where apply a method of energy balance through different materials. First two materials are solids, asphalt covering the base and the pipes, and second two materials are fluids, the atmosphere air and the pipes fluid flow. The mechanism of asphalt heat exchange in the solar collector are in three modes of heat transfer. For energy balance through asphalt pavement, firstly thermal heat flux effect on the pavement surface by the solar radiation intensity which cause a temperature difference between the pavement surfase and an asphalt surfase at another depth. Secondly a conduction heat transfer between an interior surfaces of asphalt pavement will occure. Thirdly the conduction heat transfer reached the pipes wall implant in an asphalt pavement. Fourthly a convection heat transfer occurs between the pipes wall and fluid flowing inside it causing raising in temperature of fluid flow. The coefficient of convection heat transfer of fluid inside the pipes at turbulent mode could be determined by the Dittus–Boelter equation, Eq. 4:

$$Nu = 0.023 Re_D^{(4/5)} Pr^n \tag{4}$$

Azeemuddin et al. [27] and Azeemuddin et al. [28] suggested an enhancement technique using waste heat energy as a flow of flue gases passing through conduits in the solar collector, Fig. 8. By using ANSYS software the process of the heat flow was simulated then validated with Manzanares prototype results. The simulated model shown good enhancement for the performance and gives contributes to the reduction of global warming. The proposed hybrid technique befits to generate electricity 24 hours.

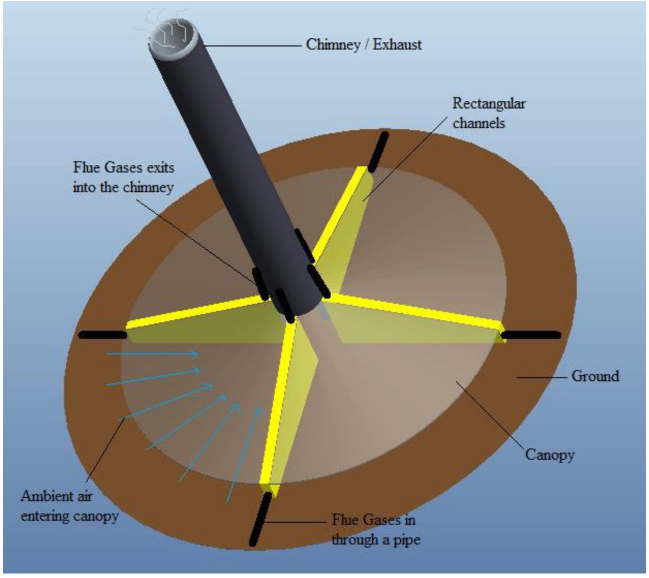

Fig. 8: Schematic diagram of proposed model [27]

Saw et al. [29] presented an experimental investigation of a solar collector integrated with the phase change material PCM and nano-enhanced PCM. The material employ for the phase change material is paraffin wax. For properties progress of compound PCM, 1% weight fraction of 20nm copper nanoparticles was added. Experimental investigation cases include: PCM, without PCM, with nano-PCM. Results show for operational mode of 0.5 kg/min flow rate and at 10º inclination angle of the collector, hot water produced at 40.2ºC and 40.8ºC with PCM and nano-PCM. While the case of (without PCM), hot water was produced at 35.2ºC. In conclusion, the system was enhanced with usage of PCM and nano-PCM by 6.9% and 8.4% respectively.

V. Conclusion

Solar updraft tower power plant has a simple technology of solar power plants, which includes three familiar components: solar collector, solar updraft tower, and wind turbine. So as to promote the power plant performance, some developments and progressive configurations were suggested for the components of the solar updraft tower power plants. The survey gives a summarize overview of the developments in each of the components key area inspect to raise the performance of the currently solar power plants.

When the diameter of updraft tower increase the volumetric air flow rate increases, and an increase of tower height yield increases in air flow velocities. The solar updraft tower power generation with sea water distillation system has a suitable frugal performance through the solar energy enhancement when compared with individual solar updraft tower power generation system.

The efficiency of the solar collector relies on flow rate; when flow rate increase, convection heat transfer of fluid increases. The temperature of asphalt varies strongly with the absorptivity; while through increasing of depth the temperature be influenced by thermal conductivity.

Important parameters affected on performance enhancement could appear in pressure drop factor of the turbine, and solar radiation intensity; which lead to the characteristics of commercial solar updraft tower power plant [30].

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