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Hybrid Geothermal and Wind Power Generation System Using Geothermal Waste Water as a Heat Source

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ABSTRACT

Increasing demand and cost for energy and declining fossil fuels in near future make researches and developments on renewable energies feasible. Utilization of renewable energy sources are limited by their availability and efficiency. There is absolute exergy loss in most of geothermal power plants from separated brine; low temperature geothermal fields are also widely distributed worldwide. Several attempts have been made to utilize low temperature geothermal fields. In this paper the novel idea of hybrid power generation system has been proposed as a simple and renewable method to achieve sustainable utilization of renewable resources. The new hybrid system will benefit from solar chimney to produce electricity with windmill, and geothermal heat will be used as a heat source to achieve desirable air speed inside the chimney. Results promise, and it seems that suggested idea is competitive with other renewable energy sources. Further studies are necessary to achieve more realistic results to start actual projects.

1. INTRODUCTION

Increases in energy demand, declines in energy resources, and potential environmental impacts of conventional energy resources development underscore needs for a sustainable approach to the development and management of earth's energy resources (Rosen and Dincer, 2001). This increasing demand and higher cost for energy and declining fossil fuels in near future make researches and developments on renewable energies feasible. Utilization of renewable energy sources is limited by their availability and efficiency. Among them geothermal energy has been developed and its reliability has been proven. The main problem with geothermal electricity production is its locally dependence, meanwhile there are low and medium temperature fields that electricity production in those fields is not possible with current technologies. In such fields, direct utilization of geothermal resources is possible if there are demands from local people. In this regard, utilization of geothermal resources and better understanding of conversion systems are becoming increasingly more important.

Geothermal heating has been used since Roman times for bathing and cooking and as a way of heating buildings and spas by using sources of hot water and hot steam that exist near the earth's surface. Water from hot springs is now used worldwide in spas, for space heating, and for agricultural and industrial uses (Dickson and Fenelli, 2004).

Geothermal energy utilization is commonly divided into two categories: electric production and direct application. The utilization method depends on parameters such as local demands for heat or electricity, distance from potential market, resource temperature, and chemistry of the geothermal fluid. These parameters are important for the feasibility of exploitation. Utilization of geothermal fluid depends heavily on its thermodynamic characteristics and chemistry. These factors are determined by the geothermal system from which the fluid originates (Jalilinasrabady and Itoi, 2012).

Sustainable utilization of earth resources has been highly demanded, which is under improvement and development. Geothermal energy is one of the renewable resources that need further studies for its sustainable utilization. Cascade use of geothermal fluid is an ideal way of its optimum usage, but uncertainty always accompanies these projects (Jalilinasrabady et al., 2012). Plant operations of geothermal fields depend on demands for heat or electricity in the region and reservoir ability to support these utilization units.

Wind is another renewable energy source. The investment for wind farms has been increased worldwide, but its cost and effectiveness need improvement.

Solar Chimney developed by J. Schlaich, which absorbs thermal energy through transparent solar collector, induces thermal ascent flow within the chimney set in the center of the solar collector and generates electricity using wind turbine at the bottom of the chimney (Fujiwara et al., 1983). 100 kW prototype had been operated for 7 years from 1982 in Spain with success of generating 50 kW (Richards 1981, 1982, 1982).

A new wind turbine system that consists of a diffuser shroud with a broad-ring brim at the exit periphery and a wind turbine inside it has been developed by Oyha et al. (2006).

The shrouded wind turbine with a brimmed diffuser has demonstrated power augmentation by a factor of about 2-5 compared with a bare wind turbine, for a given turbine diameter and wind speed. This is because a low-pressure region due to a strong vortex formation behind the broad brim drew more mass flow to the wind turbine inside the diffuser shroud (Ohya and Karasudani, 2010).

The efficiency has been challenging for development of renewable energy sources; it is one of the key parameters which make them cost-effective and economical. To increase their efficiency parallel to technical development in each of renewable energy sources, their combination has been taken into account.

In geothermal fields, there is enormous research on low temperature electricity production technology such as innovative ORC cycles, EGS and etc., but authors couldn't find any combination between solar, wind and geothermal. This paper is to explain the possibility of creating hybrid system which will use the idea from solar chimney, heat from geothermal and power from wind.

2. METHODOLOGY

In most of geothermal power plants, there is considerable amount of exergy loss due to reinjection. Despite the technical issues related to reservoir management if this reinjection doesn't participate in sustainability of the reservoir, the injected waste fluid usually with temperature around 100°C can be considered as a total exergy loss (Jalilinasrabady and Itoi, 2012, Jalilinasrabady et al., 2010).

As it was mentioned before, one of the disadvantages of geothermal resources is that, they are locally dependent resources; high temperature zones are located in active volcanic areas. Meanwhile there are plenty of places on the planet with low temperature geothermal fields, such as Middle East, Africa, the direct utilization of geothermal is usually limited to bathing purposes. Several methods have been attempted to develop for electricity production of low temperature resources. Most of them have focused on ORC cycles. These small units usually are not very simple and may have maintenance and environmental issues in case of disasters especially in rural areas. If some new idea can help to produce electricity with these low temperature fields and as a bottoming unit with currently operating plants, it will be game changing for geothermal power production and will support its renewability and sustainability.

The idea of wind turbine has been working and currently there are wind farms contributing to power production. Considering exergy loss from geothermal fields and technical progress of wind and solar chimney, it seems that there is good potential of electricity production with hybrid system, which is simple, local and renewable. Figure 1 illustrates the suggested hybrid system. Hot geothermal water comes to pond, and air is being heated above the pond. Since hot air raises, inside chimney air will rotate turbine blade to produce electricity.

This system has 3 main parts including geothermal heat supply system, chimney and wind.

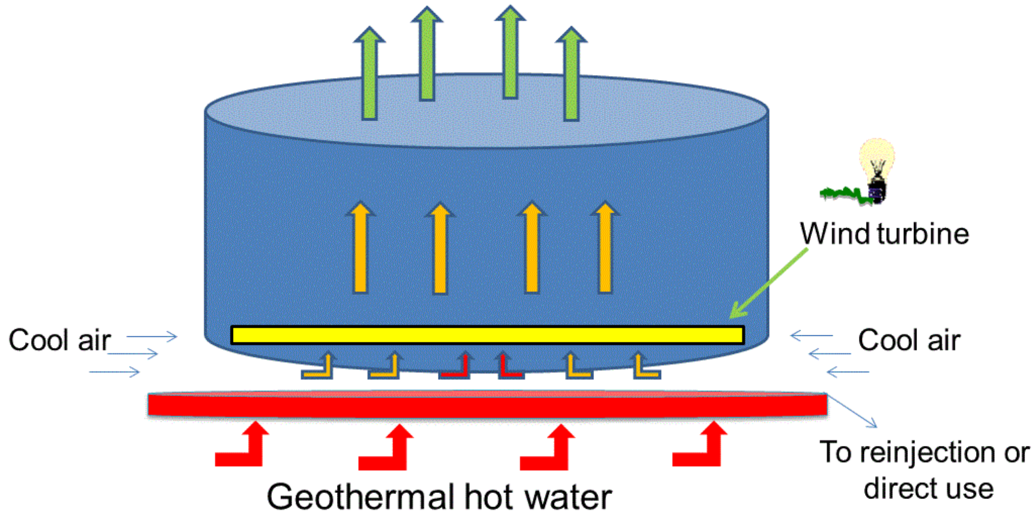


Figure 1: Hybrid geothermal wind system.

2.1 Geothermal heat supply system

Disposed water from a separator or naturally discharged hot water from hot spring at temperature of 60-100°C will be brought to the pond. To calculate heat loss from the pond, heat loss calculation from swimming pool was used, since majority of the pond will be covered by chimney, calculated value of heat loss is predicted to be less. In this part of the paper the heat transfer phenomena between the pond and the chimney and the fluid dynamic are neglected, but for further investigation, it needs to be clearly studied.

2.1.1 Heat loss from the pond

Heat loss from outdoor pools is mainly due to convection, evaporation, radiation, conduction and rain (Svavarsson, 1990). The main heat losses from the swimming pool occur by convection and evaporation. The obtained results from earlier research and analyses showed that heat losses due to the other three factors (radiation, conduction, rain) can be estimated to be equal to 10% of total heat loss due to convection and evaporation. Heat loss due to conduction is small, because of good insulation in the pool building materials. Heat loss by means of rain and radiation is also not very big. In the following calculation, 10% of total heat loss by convection and evaporation will be assumed for these three mentioned factors.

2.1.1.1 Heat loss due to convection

Heat loss due to convection depends strongly on the air temperature around the pool and the wind speed. Equation 1 explains that heat loss through convection will increase with higher wind speed and lower outside temperature:

$$q_c = h_c(T_w - T_a) \quad (1)$$

where q_c is the amount of heat loss by convection (W/m^2), T_w is the water temperature in the pool (°C), T_a is the air temperature in the pool's surrounding (°C) and h_c is the convection heat transfer coefficient (W/m^2°C) which is very dependent on the wind speed.

The relationship between heat transfer coefficient and wind speed is expressed in Equation 2 that is named Rimsha-Doncenko formula:

$$h_c = 4.19(k + 0.45v) \quad (2)$$

where v is the wind speed at 2 meter height from the ground surface (m/s) and k is the empirical coefficient (W/m^2°C) as shown in Equation 3.

$$k = 0.93 + 0.04(T_w - T_a) \quad (3)$$

2.1.1.2 Heat loss due to evaporation

Heat loss due to evaporation takes place when there is different partial pressure of water vapor at the pool's surface and in the air over the pool. This will cause evaporation of water at the pool surface, and this requires energy that is taken from the water. This kind of heat loss in the pool can be calculated with Equation 4 from Rimsha – Doncenko (Svavarsson, 1990):

$$q_E = 4.19(1.56k + 0.70v^2)(e_w - e_a) \quad (4)$$

where q_E is the amount of heat loss by evaporation (W/m^2), e_w is the partial pressure of steam at surface (mbar) and e_a is the partial pressure of steam in the air over pool (mbar).

2.1.2 Energy requirement for heating the pond

The total heat loss from the pond was calculated and the same quantity of heat must be added to the water supplied to the pond. This can be done through a heat exchanger that transfers heat from geothermal water to fresh water that is used as pool water, or geothermal water can be directly fed into the pot:

$$q_T = q_i \quad (5)$$

where q_i is the required quantity of heat for the pool (W/m^2). Equation 6 (wark, 1988) is used for calculation of the amount of geothermal water needed as a heat source and the temperature of pool's heated water by heat exchanger. Equation 6 is known as the energy balance equation in the steady-flow condition:

$$Q_i = mc_p(T_2 - T_1) \quad (6)$$

here m is the amount of water required for circulated in the system (kg/s), c_p is specific heat capacity of water (J/kg°C), T_1 is the temperature of inlet geothermal water (°C), T_2 is the temperature of outlet geothermal water (°C) and Q_i is the amount of required heat for the pool (W). This study set to m = 6.42 kg/s and T_2 = 65°C. The pond diameter was assumed to be 20 m. Figure 2 shows the variation of geothermal fluid mass flow rate with temperature of pond's water leaving the pond. As it can be seen to maintain pond's temperature in higher temperature, higher amount of mass flow rate is needed.

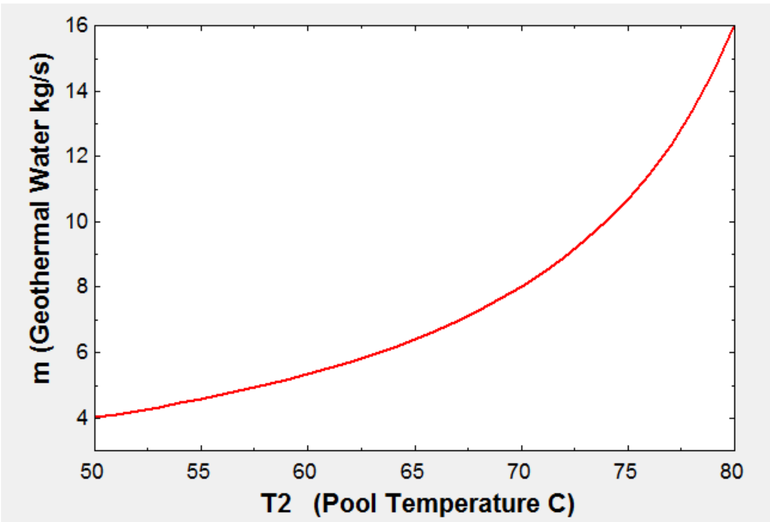


Figure 2: Temperature and mass flow rate variation of geothermal water leaving the pond.

2.2 Chimney

A solar chimney, or thermal chimney, is a form of passive ventilation that can be applied to a structure. It uses the principles of heat transfer and fluid mechanics to naturally ventilate a structure without the need of an outside source of electricity. A solar chimney takes advantage of the fact that as the temperature of air changes, the density of air changes as well. Another application of solar chimney has been applied for electricity production with three essential elements of glass roof collector, chimney and wind turbines. Air is heated by solar radiation under a low circular glass roof open at the periphery. In middle of the roof, there is a vertical chimney with large air inlets at its base. As hot air is lighter than cold air, it rises up the chimney. Thus, solar radiation caused a constant updraught in the chimney. The energy is converted into the mechanical energy by pressure-staged wind turbines at the base of the chimney and into the electrical energy by conventional generation (Bergermann, 2002).

The idea of solar chimney is promising, but constructing tall towers demand high capital investment especially in developing countries. Visual environmental impact could be considered as another major disadvantage of this technology. But combining this idea with geothermal would solve these problems. Electricity produced by a solar chimney is in proportion to the intensity of global solar radiation, collector area and chimney height. By considering geothermal as a heat source, only chimney height will be the most influential parameter, this height will dictate air velocity inside chimney that will rotate wind turbine. Equation 7 was used to estimate wind speed inside chimney:

$$Q = CA\sqrt{2gh\frac{T_i - T_o}{T_i}} \qquad (7)$$

Q	Stack effect draft flow rate (m^3/s)

A	Flow area (m^2)

C	Discharge coefficient (0.65-0.70)

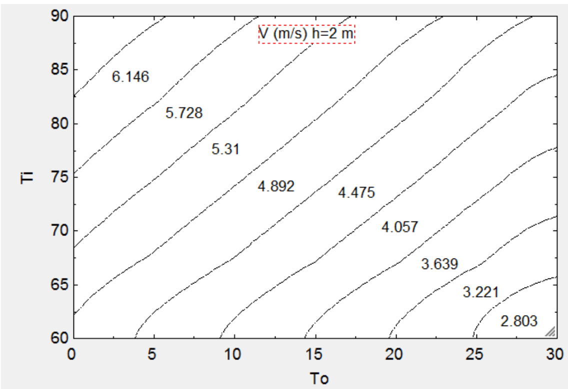
g	Gravitational acceleration (9.81 m/s^2)

h	Height (m)

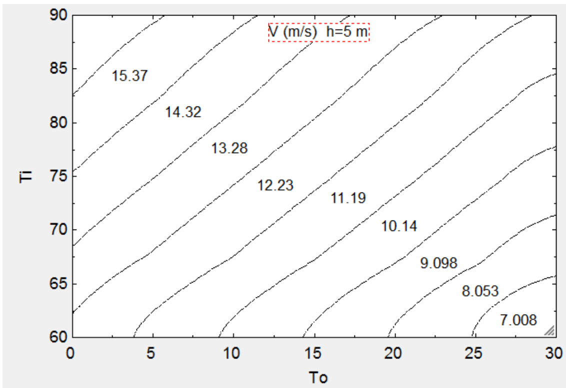
T_i	Average inside temperature (K)

T_0	Outside air temperature (K)

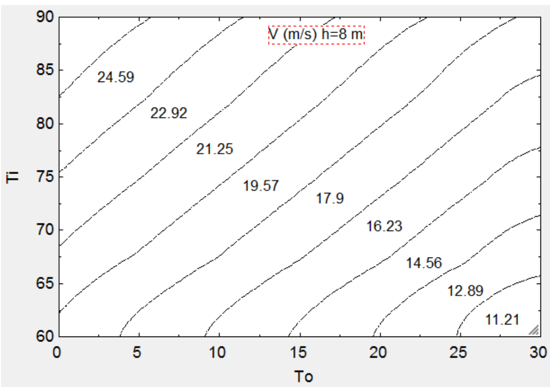
Figure 3 shows variation of velocity with chimney inlet and outlet temperature at height of 2, 5, 8 and 10 m.



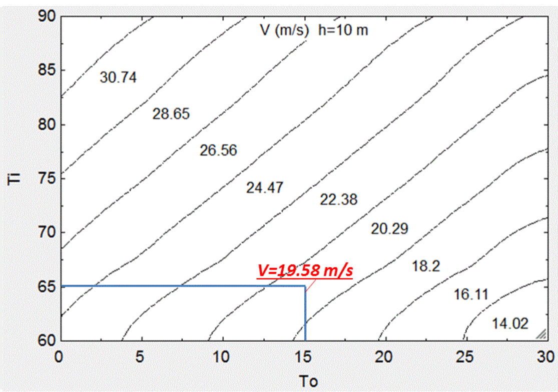
Velocity inside tower with 2 m height



Velocity inside tower with 5 m height



Velocity inside tower with 8 m height



Velocity inside tower with 10 m height

Figure 3: Velocity variation of with chimney inlet and outlet temperature and chimney height of 2, 5, 8 and 10 m.

At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate and generate power is called the cut-in speed and is typically between 3 and 4 m/s. As the wind speed rises above the cut-in speed, the level of electrical output power rises rapidly. However, typically somewhere between 12 and 17 m/s, the power output reaches the limit that the electrical generator is capable of. This limit to the generator output is called the rated power output and the wind speed at which it is reached is called the rated output wind speed. At higher wind speeds, the design of the turbine is arranged to limit the power to this maximum level and there is no further rise in the output power. However, this is done by varying from design to design but typically with large turbines. It is done by adjusting the blade angles so as to keep the power at the constant level. As the speed increases above the rate output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the cut-out speed and is usually around 25 m/s (WINDPOWER PROGRAM, 2013). Considering these explanations for ambient temperature of 15°C and maintaining pond temperature at 65°C wind velocity can be estimated to be 19 m/s with chimney height of 10 m.

2.3 Wind turbine

The available power in a stream of wind of the same cross-sectional area as the wind turbine can be calculated from:

$$W = \frac{1}{8}\eta\rho\pi D^2 U^3 \tag{8}$$

W Power output (W)

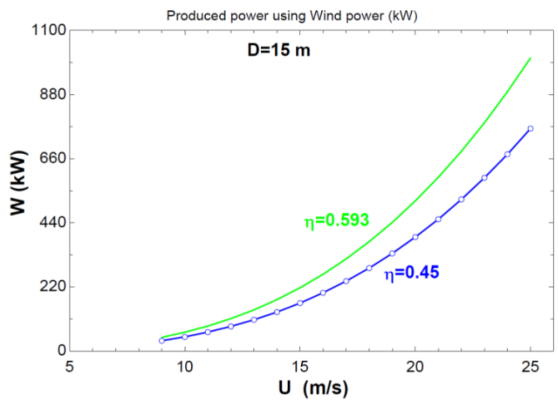
η Betz limit (59% and 0.45)

ρ Density (kg/m^3)

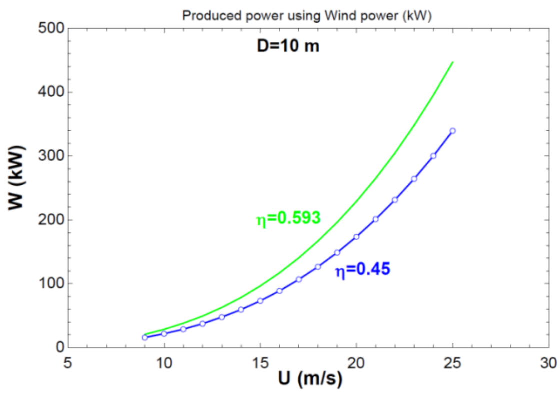
D Rotor diameter (m)

U Wind speed (m/s)

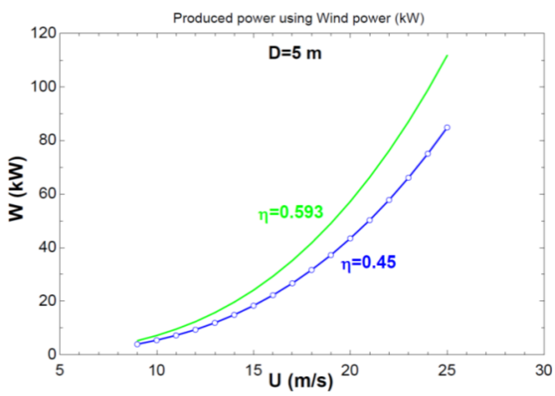
Figure 4 shows variation of produced power with wind speed inside chimney for tower diameters of 1, 5, 10 and 15 m assuming betz limit of 0.59 and 0.45.



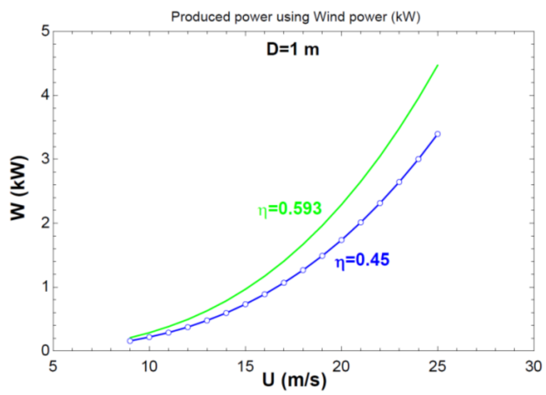
Tower diameter of 15 m



Tower diameter of 10 m



Tower diameter of 5 m



Tower diameter of 1 m

Figure 4: Produced power variation with wind speed inside chimney for tower diameters of 1, 5, 10 and 15 m assuming betz limit of 0.59 and 0.45.

3. DISCUSSION

A novel approach for power production using a hybrid system of geothermal, wind and solar has been proposed. The idea is at its early stage of development and needs further investigation such as numerical simulation, laboratory scale experiment and actual field test. Their results can lead to comprehensive cost benefit analysis and site selection of potential fields worldwide. Its hybrid nature helps each of involved renewable energy sources strength their weakness and cover each other. Places with geothermal potential of almost all classification could benefit from this system due to:

- Development of solar chimney would not be necessary, compare to hybrid system they are expensive due to high capital investment for construction. They also face with serious visual environmental impact criticisms. Applying this idea can solve the problem of solar plant's low efficiency during night time and under soil piping system wouldn't be needed.
- There will be continues stable wind speed to rotate the rotor.
- Exergy loss through geothermal brine will be minimized. Hot springs with low temperature classification could be considered for the power production.
- Each of these renewable energy sources is dependent on location. The hybrid idea will widen their application. Places such as Middle East, Africa, where the direct utilization of geothermal is usually limited to bathing purposes, can use this method to produce electricity.
- Combined efficiencies and power output of hybrid system for different chimney diameters of 1, 5, 10 and 15 m with betz values of 0.45 and 0.59 are shown in Table 1. As it can be seen from Table 1, with 5 m increase in chimney diameter from 10 m to 15 m (rotor diameter), the efficiency of the hybrid system will be increased by 2.25 times. Although clear economic analysis is needed, it seems that constructing chimney with 5 m larger diameter is not a challenging task considering its impact on the efficiency of the plant.

Table 1: Efficiencies and produced power of hybrid system for different chimney diameters of 1, 5, 10 and 15 m with betz values of 0.45 and 0.59.

No.	**Diameter (m)**	**W (kW), η=0.45**	**W (kW), η=0.59**
1	15	335.3	441.8
Plant efficiency		*13.90%*	*18.31%*
2	10	149	196.4
Plant efficiency		*6.18%*	*8.14%*
3	5	37.25	49.09
Plant efficiency		*1.54%*	*2.04%*
4	1	1.49	1.96
Plant efficiency		0.06%	0.08%

As with all new developments, there are several questions to be answered about the new hybrid system considering its environmental issues. Their mitigation methods and operational concerns are:

- Environmental visual impact: Geothermal manifestations are usually located at natural parks and building 10-15 m towers will raise visual impact for the environment, but it seems necessary to mention that chimney will be as tall as vertical separators, so this impact can be justified in the fields that geothermal power plants are already installed and under operation. About other national parks the impact can be mitigated by building in slops, coloring, painting, and etc. However, its visual impact is less than wind farms, solar chimney and sometimes solar farms.
- In operating power plants if there was reinjection difficulties, power companies may hesitate interrupting injection line to avoid any possible surprises.
- In the proposed hybrid system, the pond water temperature can decrease as low as 20°C, which is higher than ambient temperature or less. In case of power plants, brine reinjection with low temperature can be additional challenge to overcome scaling problem. This issue will not be important in case of hot springs, since they are being naturally discharged to the environment.
- Geothermal water in some cases is corrosive; this corrosion can affect turbine blades and may increase maintenance routines of the system. This issue can be managed for every individual project depending on their fluid chemistry. Close loop heat exchanging system can be alternative solution for this problem.

4. CONCLUSIONS

A simple, local and renewable novel design was proposed for power production using the idea from solar chimney which combines three renewable resources of geothermal, wind and solar. Quantitative analysis was carried out using basic equations.

Sample project was defined with ambient temperature of 15 °C, and the circular pond with diameter of 20 m was assumed. According to heat loss calculation with 6.4 kg/s at geothermal water of 90°C, pond's temperature is needed to maintain at 65°C. Chimney with 10 m height and 15 m diameter were assumed to be installed over the pond. With these specifications it was estimated that the velocity inside wind tower will reach to 19.5 m/s and that will produce 441 kW and 335 kW of electricity with betz limit of 0.59 and 0.45, respectively. Discharged water from the pond still has potential for direct use application.

Results promise and it seems that suggested idea is competitive with other renewable energy sources. Further studies are necessary to achieve more realistic results to start actual project.

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