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DESIGN OF SOLAR CHIMNEY WITH SPHERICAL COLLECTOR FOR ELECTRICITY PRODUCTION

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ABSTRACT-*The present paper presents an analytical investigation of spherical collector solar chimney with base diameters of 500, 400, 300, 200 and 150m, collector height of 1.5m and convergent nozzle diameter of 1.5m. Results were obtained for variation of instantaneous power output with (τ) for spherical collector and compared with previous circular collector. It was shown that the output power increases exponentially with (τ). The minimum value of threshold (τ) beyond which appreciable power of (1000w) can be produced by a viable solar chimney power generation is about 3.5. therefore the power increases suddenly after each threshold value of (τ) . Spherical collector gives higher power output than circular collector.*

Keywords: electricity generation, renewable energy, solar chimney, solar radiation.

1.Introduction

Recently, rapid developments of global economy and increase in population and living standards have been posing great pressure on natural resources. Fossil fuels are therefore being exhausted at a quick rate. The utilization of fossil fuels together with net deforestation has induced considerable climate change in warming the environment by releasing greenhouse gases which may produce many negative effects including rise in sea level, extinction of animals, and acidification of oceans [Gullison et al, 2007, Kerr 2007, Stern 2007]. Therefore, it is urgent to develop the technologies utilizing renewable and clean energy sources to solve these problems. Solar chimney power technology is a promising large-scale power technology , which absorbs direct and diffused solar radiation and converts parts of solar energy into electric power which be free from greenhouse gases emissions.
electric power generation by Solar chimney is one of the concepts in renewable energy technology (RET) application. The power station is depend on the principle that warm air rises. Air underneath a glass ceiling is heated by using solar radiation and rises through a collector and then a chimney. The warm air which has just risen is replaced by cold air from the edge of the glass ceiling which flows inward, and will then itself begin to heat up. In this way the Sun's heat radiation is converted into kinetic energy of constant rising air to drive turbine built into the chimney. The turbine then converts the wind power by means of a generator into electrical energy [Frederick 2006].

A technology of power generation using solar chimney is not new in power generation sector, world over. The Sun's radiation heats a large quantity of air, which is then forced by

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buoyancy forces to move as a hot wind through large turbines to generate electrical energy. Solar chimney power plants, with an output of 5-200 MW, require a transparent roof several kilo-meters in diameter, and the tube must be as high as possible to give a large output. With the use of materials of better absorbing radiation, both the base diameter of the solar chimney and its height may be substantially decreased. Therefore, solar chimney plants are appropriate on land with no natural vegetation, such as desert areas [Ketlogetswe et al., 2008].

The concept of solar thermal power plant concept is the process that converts global irradiance into electricity. Since solar chimneys are always associated negatively with exhaust gases, this concept is also named as the solar power tower plant. A solar chimney power plant has a high chimney (tower), with a height of up to 1000 meters or below, and this is covered by a large collector roof, up to 130m in diameter, which consists of glass or resistive plastic supported on a framework. Towards its center, the roof curves upwards to connect the chimney, creating a funnel [Quaschning, 2003].
In this paper an analytical model of power output for spherical collector solar chimney was derived and compared with previous work [Amir et al., 2013].

2. System Descriptions

The solar chimney power station involves of three familiar units: solar collector, chimney, and unit of power conversion which include one or multi- turbine generators. Air flow effect produced by buoyancy resulting from greenhouse effect inside the solar collector drives the turbines as shown in Figure(1). The main purpose of solar chimney systems is converting solar energy into electrical energy. In the solar collector, the solar energy produced from sun will be transformed into heat energy. Solar chimney converts the generated heat energy into kinetic energy, which will be transformed into electric energy by using assembly of wind turbine and generator. Solar collector in solar chimney system involve supporting matrix, structure of column and transparent roof [El-Haroun, 2012].

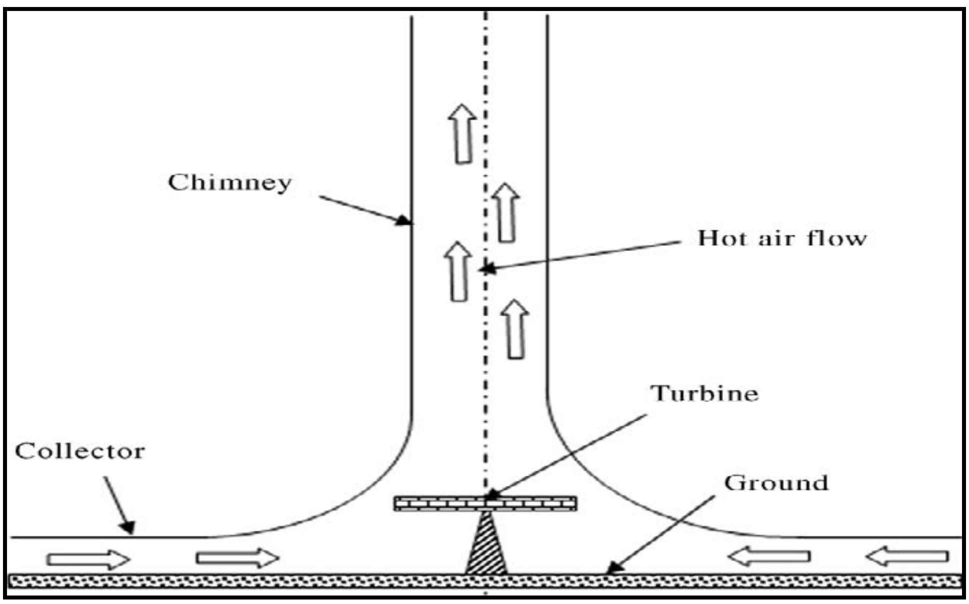

Fig.(1) sketch of a solar chimney power station for electricity generation [El-Haroun, 2012]

ISSN: 2367–7384
Issue 3, pp.101-109, October, 2015

3. Theoretical Analysis

The heat transfer from the patch can be obtained as:

$$W_1 = hA(T_s - T_H) \qquad (1)$$

Where T_s and T_H be the temperatures at glass collector surface and at location H in the area A , and h is the heat transfer coefficient which can be written as:

$$h = h(\mathrm{Re}, \mathrm{Pr}, K, D)$$

For a turbine[Tiwari et al., 1997]:

$$h = 0.036 \frac{K}{D} \mathrm{Pr}^{0.33} . \mathrm{Re}^{0.8} \qquad (2)$$

For semi-spherical collector, the area of the surface is given by:

$$A = 2\pi r^2$$

Where:

$$r = \frac{D}{2}$$

$$W_1 = h 2\pi r^2 (T_s - T_H) \qquad (3)$$

The heat transferred from outlet collector surface area into the interior air can be written as:

ISSN: 2367–7384
Issue 3, pp.101-109, October, 2015

$$W_2 = m^{\cdot} C_P (T_m - T_s) \qquad (4)$$

$$m^{\cdot} = \rho_a u A_p \qquad (5)$$

$A_p = \pi DH$ Substitute into (5)

$$m^{\cdot} = \rho_a u \pi DH \qquad (6)$$

Substitute equation (6) into equation (4):

$$W_2 = \rho_a u \pi DHC_p (T_m - T_s) \qquad (7)$$

For spherical solar chimney of radius R, the velocity V at which air strikes on the rotor blades is given by:

$$\pi R^2 V = \pi DHu$$

$$u = \frac{R^2 V}{DH} \qquad (8)$$

Substitute equation (8) into equation(7):

$$W_2 = \rho_a \frac{R^2 V}{DH} \pi DHC_p (T_m - T_s) \qquad (9)$$

equating equations (3) and (9) to find h :

ISSN: 2367–7384
Issue 3, pp.101-109, October, 2015

$$h = \frac{\rho_a C_p R^2 V (T_m - T_s)}{2r^2 (T_s - T_H)} \qquad (10)$$

or

$$V = \frac{2r^2 h (T_s - T_H)}{\rho_a C_p R^2 (T_m - T_s)} \qquad (11)$$

Substitute equation (2) into (11) and rearrange:

$$V = \frac{3x10^{-5} r^{10} \tau^5}{D^5 R^{7.5}} \beta \qquad (12)$$

Where :

$$\tau = \frac{(T_S - T_H)}{(T_m - T_S)}$$

$$\beta = \frac{K^{3.35}}{\rho_a C_p^{3.35} \mu^{2.35}}$$

For air At 300 K^o and 1 atm :

$$\beta = 3.7x10^{-5}$$

The electric power (instantaneous) P_i which produced by a single turbine is :

$$P_i = \frac{16}{27} \left(\frac{1}{2} \rho_m \pi R^2 V^3\right) \qquad (13)$$

Where ρ_m is the air density at temperature T_m

ISSN: 2367–7384
Issue 3, pp.101-109, October, 2015

Substitute equation (12) into (13) yield:

$$P_i = 5.6x10^{-41} \frac{D^{15}}{R^{20.5}} \tau^{15} \qquad (14)$$

4. Results and Discussions

Figure (2) shows variation of simulated power output with (τ) for spherical collector solar chimney with diameter of 500m . It was shown that the output power increases exponentially with (τ). The minimum value of threshold (τ) beyond which appreciable power (1000w) can be produced by a solar chimney power generating station is about 3.5. Therefore the electric power increases suddenly after each threshold value of (τ) [Amir et al., 2013]. Similarly, figures (3, 4, 5 and 6) show the corresponding simulated power output for collector diameter of (400,300,200 and 150m) respectively. Spherical collector gives higher power output than circular collector.

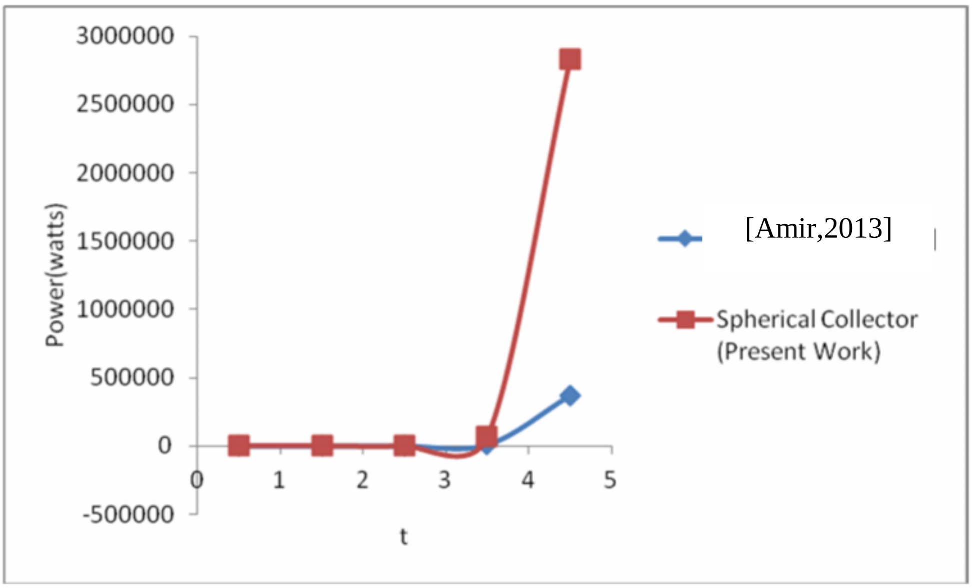

Fig.(2) Variation of Simulated Power Output with (τ) for Collector Length(Diameter) D=500m and H=R=1.5m

ISSN: 2367–7384
Issue 3, pp.101-109, October, 2015

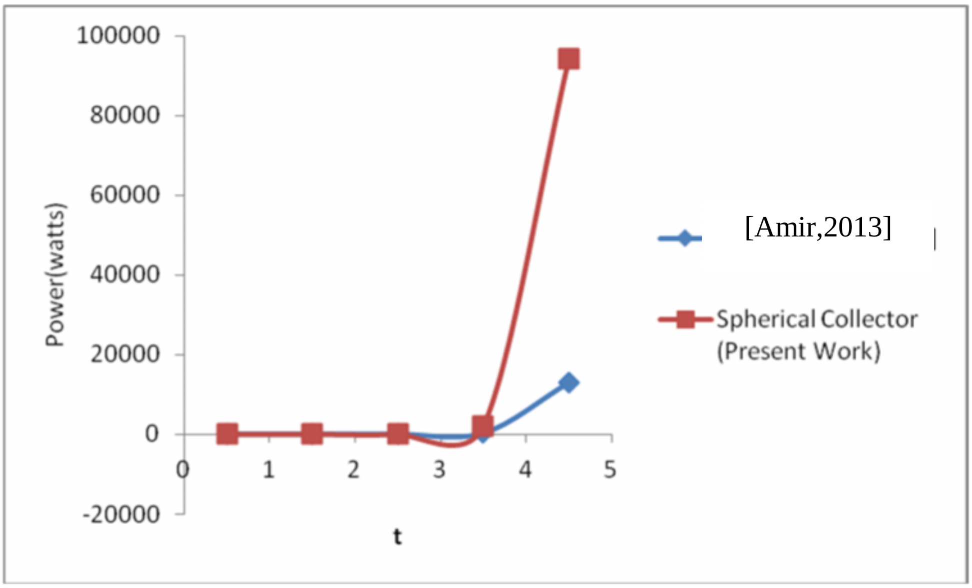

Fig.(3) Variation of Simulated Power Output with (τ) for Collector Length(Diameter) D=400m and H=R=1.5m

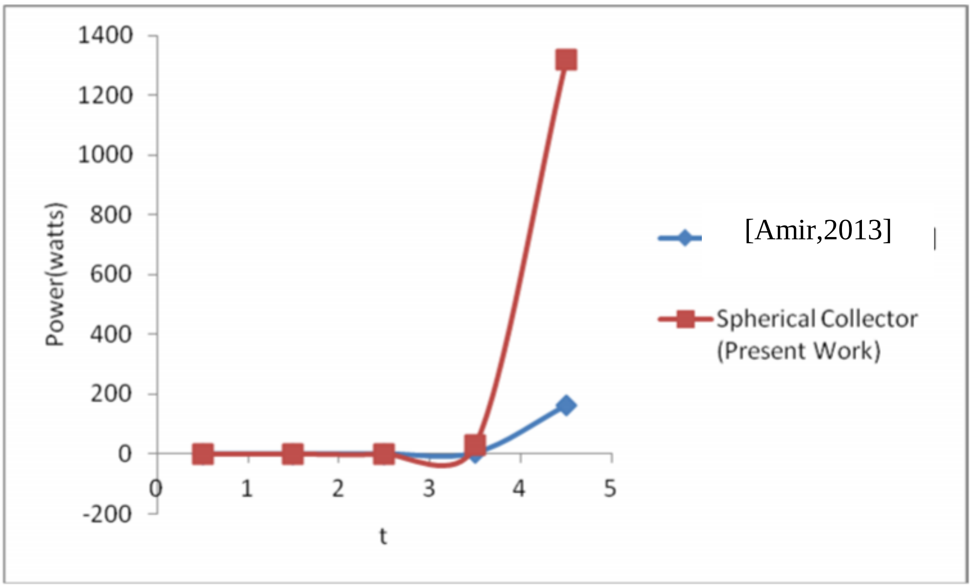

Fig.(4) Variation of Simulated Power Output with (τ) for Collector Length(Diameter) D=300m and H=R=1.5m

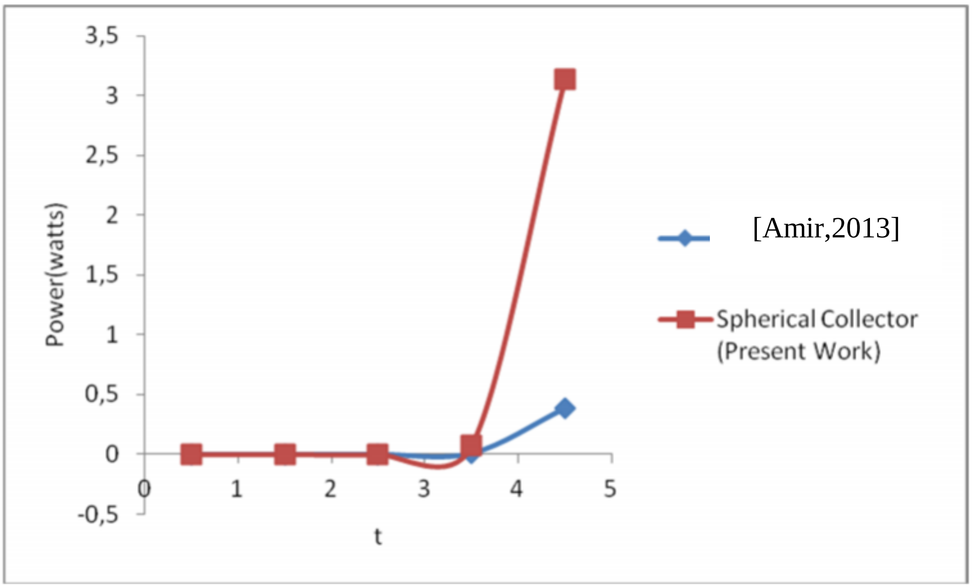

Fig.(5) Variation of Simulated Power Output with (τ) for Collector Length(Diameter) D=200m and H=R=1.5m

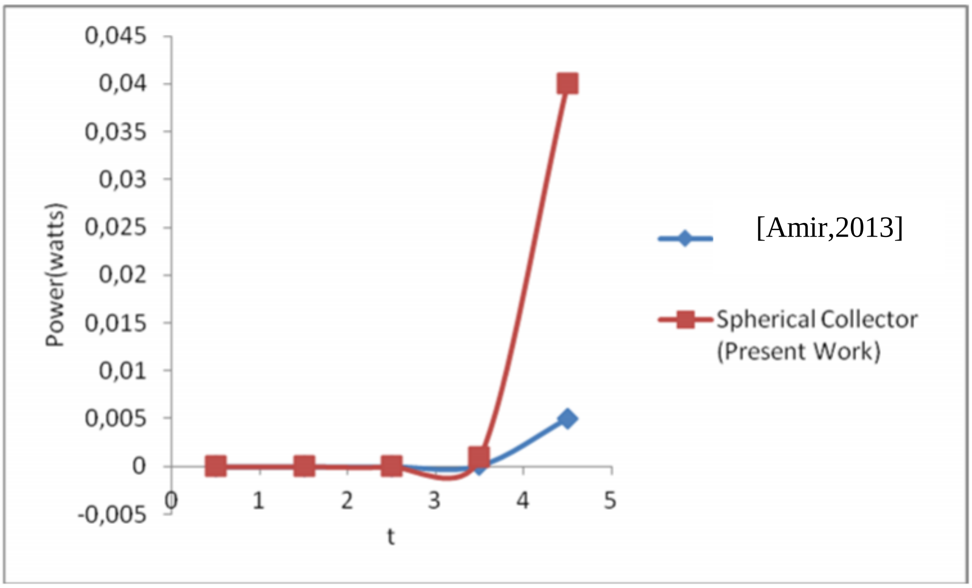

Fig.(6) Variation of Simulated Power Output with (τ) for Collector Length(Diameter) D=150m and H=R=1.5m

ISSN: 2367–7384
Issue 3, pp.101-109, October, 2015

5. Conclusions

Solar chimney power stations are an interesting alternative to centralized electricity generation power stations. It is an ideally adapted technology for regions (countries) that lack a sophisticated technical infrastructure, where simplicity and uncritical operation of the installation is of crucial importance. In this paper, an analytical investigation of spherical collector solar chimney with specific dimensions was achieved. Results show that the minimum value of threshold (τ) beyond which appreciable power (1000w) can be produced by a viable solar chimney power generating station is about 3.5**,** the power increases suddenly after each threshold value(τ) and the spherical collector gives higher power output than circular collector.

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Nomenclature:

A area of collector [m^2]

C_p heat capacity [J/kg K]

D base collector diameter [m]

h heat transfer coefficient [$w/m^2.K^o$]

H collector height[m]

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K thermal conductivity [w/m.K^o]
$\dot{m}$ mass flow rate [kg/s]
Pr Prandtl number [dimensionless]
P_i instantaneous power [w]
Re Reynolds number [dimensioness]
R convergent nozzle diameter [m]
T temperature [K^o]
V Velocity of Air Impinges on the Rotor Blade [m/s]

W heat exchanged [J]
ρ_a air density[kg/m^3]
τ ratio of the temperature difference between the collector surface temperature and the temperature at the turbine ($Ts–T_H$) to the temperature difference between the air mass temperature under the roof and the collector surface temperature (Tm–Ts)
μ dynamic viscosity [pa.s]