EFFECT OF SPIRAL RIB ON SOLAR CHIMNEY COLLECTOR PERFORMANCE

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Abstract

The increased demand for renewable energy calls for increased developments to the techniques of production for such energy. This paper presents a numerical study of conical collector solar chimney with specific dimensions. A glass spiral of square cross section was fitted to the collector to investigate its effects on the velocity distribution of air. Results show that the spiral enhances velocity distribution by (11.57% and 12.82%) corresponding to the inlet air velocity of (Re=99945 and 499729) respectively. This enhancement will reflect to the instantaneous electric power which can be produced by such instrument. The investigation was carried out using CFD program FlUENT14.5, K-ε model.

Keywords: power generation, solar chimney, solar energy, solar radiation.

الخلاصة

ازدياد الطلب على الطاقة المتجددة يدعو الى زيادة التطوير في تقنيات الانتاج لهذه الطاقة. في البحث الحالي تمت دراسة عددية لمجمع مدخنة شمسية بشكل مخروطي وبأبعاد معينة.وضع لولب مصنوع من الزجاج وبمقطع عرضي مربع بتماس مع الجدار الداخلي للمجمع لبحث التأثير على توزيع سرعة الهواء داخل المجمع.تم استحصال النتائج النظرية وقد بينت ان استخدام اللولب يزيد من توزيع السرعة بمقدار(١١,٥٧% و ١٢,٨٢%) لسرع دخول الهواء للمجمع وبقيم رقم رينولد(٩٩٩٤٥ و ٤٩٩٧٢٩) بالمقارنة مع حالة عدم استخدام اللولب وهذه الزيادة سوف تنعكس على زيادة القدرة المنتجة في التوربين المدار بتأثير حركة الهواء الى الاعلى وقد استخدم برنامج فلونت ١٤.٥ لكافة الحسابات باستخدام نموذج K-ε .

Introduction

Renewable energy introduces a significant solution for the pollution and is more important in the socioeconomic aspect. It is able to create thousands of green job opportunities, and can produce a new regional industrial cluster. Solar and wind alternatives are essential for growth, finance, and the political environment. The cost of wind power has reduced from 9.5 cents per kilowatt-hour to 2 cents for wind energy production and to 7.7 cents for solar power production. This is very important for the developing countries which depend on external sources to finance major energy projects. Such countries may be able to finance small scale solar and wind energies projects from their own resources [Mohammed 2011]. Solar chimney is one of the important concepts in the applications of renewable energy technology (RET). The principle of the power station here is based on the continuous rises of warm air. Air underneath a glass ceiling is heated by 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 begin to heat up. In this way the Sun's heat radiation can be converted into kinetic energy through a continuous rising of the hot air inside the collector. A suitable turbine can be fixed inside the chimney to convert wind energy via generator into electrical energy [Frederick and Reccab 2006].

The main physical principles of electricity generation with solar chimney power plants were described by Haaf et al. in 1982 [Terol 1987, Haaf et al 1983]. A pilot plant was built and operated in Manzanares in 1982. First experimental results confirmed the main assumptions of the original physical model [Terol 1987, Haaf 1984]. On the basis of experimental data from 1983 to 1984, a semi-empirical model was proposed for predicting the monthly mean electrical power output of the pilot plant as a function of solar irradiation [Pasumarthi and Sherif 1998]. In this paper a new design of conical collector solar chimney ribbed with glass spiral was suggested and compared with a smooth one (without spiral).

System Descriptions

The solar chimney power plant consists of three familiar units: a solar collector, a solar chimney, and unit of power conversion which include one or several turbine generators. The turbines are driven by air flow effect produced by buoyancy resulting from greenhouse effect inside the solar collector as shown in **Figure (1)**. The main purpose of solar chimney systems is to convert solar energy into electrical energy. In the solar collector, the solar energy produced from sun will be transformed into heat energy. The chimney converts the generated heat energy into kinetic energy, which will be transformed into electric energy by using a combination of a wind turbine and an electric generator. The collector in solar chimney system consists of support matrix, column or truss structure and transparent roof [El-Haroun 2012].

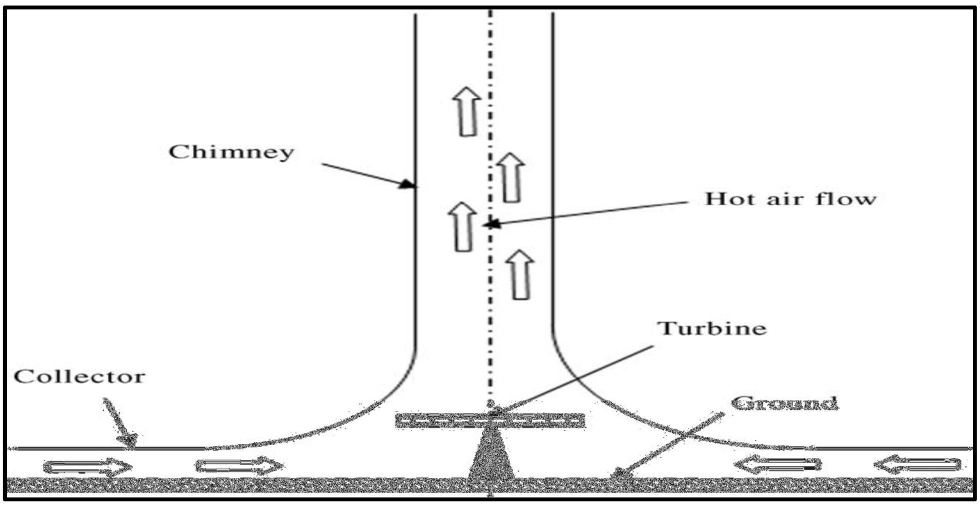
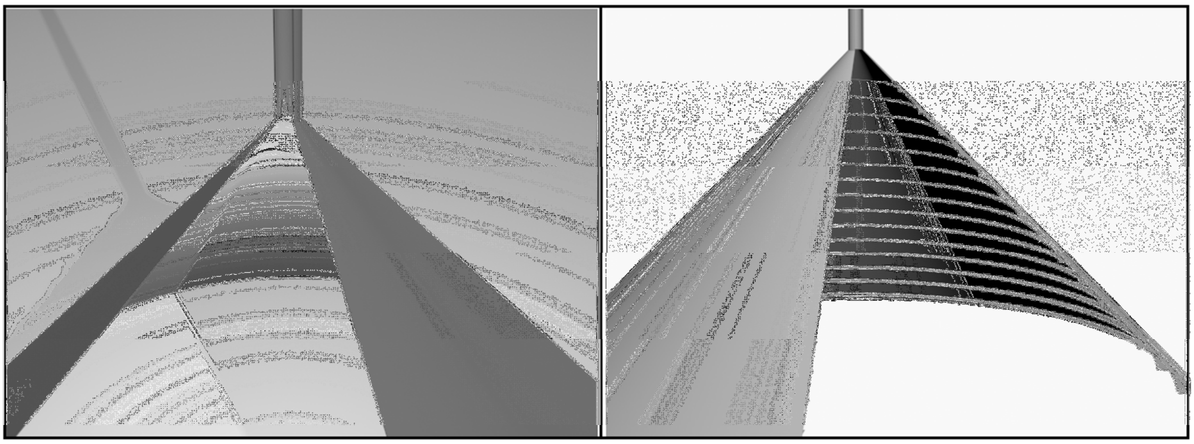


Fig.(1) Schematic diagram of a solar chimney power plant for electricity generation [El-Haroun 2012]

The suggested collector is of a conical shape, 12mm glass thickness, 150 m base diameter and 75 m height. The chimney which connected to the collector is of 150 m height with diameter of 3 m. Another collector was suggested and simulated which contain a glass spiral of square cross section (0.5x0.5 m) and 3 m pitch as shown in **Figure (2)**.



A B

Fig. (2) The simulated conical shape collector (A: smooth collector and B: Spiral collector)

Theoretical Analysis

The output power of the solar chimney depends on parameters such as surrounding conditions and structural dimensions of the system itself. The former includes the solar radiation intensity and ambient temperature, whereas the latter includes the height and radius of both the collector and chimney [Schlaich 1995].

A solar collector converts available solar radiation (G) onto the collector surface A_{coll} into output heat. The efficiency of solar collector can be expressed as a ratio of the collector heat output which is heated air (Q) to the solar radiation (G) times A_{coll} [El-Haroun 2012]:

$$\eta_{coll} = \frac{Q}{A_{coll}.G} \quad (1)$$

The output heat (Q) at the outflow from the collector under steady state conditions can then be expressed as a product of the mass flow $m^{\cdot}$, the specific heat of air C_p and the temperature difference between collector inflow and outflow ΔT :

$$Q = m^{\cdot} C_P \Delta T \quad (2)$$

The mass flow rate of air (kg/s) which is denoted by (m) can be expressed as follows:

$$m^{\cdot} = \rho_{coll}{}^{\cdot} v_c A_c \quad (3)$$

where

ρ_{coll}: the density of air at temperature $T_0 + \Delta T$ at collector outflow-chimney inflow.

$v_{coll} = v_c$ is the air velocity at collector outflow-chimney inflow.

Ac : chimney cross sectional area.

For collector efficiency this gives:

$$\eta_{coll} = \frac{\rho_{coll}.v_c.A_c C_P \Delta T}{A_{coll.}.G} \quad (4)$$

The instantaneous electric power (P_i) produced by a single turbine is [Amir et al. 2013]:

$$P_i = \frac{16}{27}(\frac{1}{2}.\rho_m \pi R^2 V^3) \quad (5)$$

where:

ρ_m :the density of air at temperature T_m

T_m: the temperature of mass of air inside the chimney (K)

R: chimney radius (m)

V: velocity of Air Impinges on the Rotor Blade (m/s)

Equations used in FLUENT are:

- Continuity equation:

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \quad (6)$$

- Momentum equation in 3D:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \quad (7)$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\mu}{\rho}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \quad (8)$$

$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\mu}{\rho}\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \quad (9)$$

- Energy equation:

$$\frac{\partial(\rho u_i T)}{\partial x_j}=\frac{\partial}{\partial x_i}\left[(\Gamma+\Gamma_t)\frac{\partial T}{\partial x_j}\right] \quad (10)$$

where :

Γ = molecular thermal diffusivity = $\frac{\mu}{\Pr}$

Γ_t = turbulent thermal diffusivity = $\frac{\mu_t}{\Pr_t}$

In FLUENT, The (k-ε) model was used**.**

Boundary conditions

At the upstream inlet conical collector surface, the air enters the computational domain is specified to have a uniform velocity with values of (Re=99945 and 499729). The inlet coolant air temperature is (315 K). The outlet boundary conditions were determined using ANSYS Fluent 14.5 package, including: air velocity at conical collector chimney centreline and Instantaneous electric power as a function of air velocity. The conical collector wall is provided with a constant ambient air temperatures of (315 K).

Mesh generation

The mesh should be manipulated and controlled manually to keep smooth mesh transition and maintain proper mesh for a three dimensional model with a minimum computational expense. This is accomplished by applying the size function, **figure(3)** shows mesh generation for the solar chimney (tetrahedrons, 73346 nodes and 70724 elements).

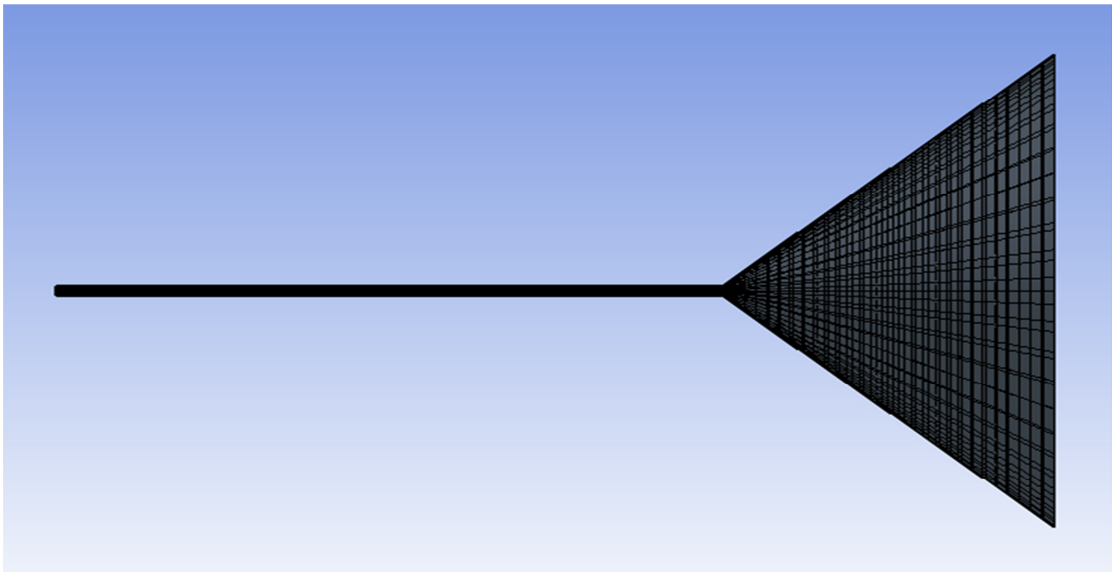


Fig. (3) Mesh generation for solar chimney

Results and Discussions

Figure (4) shows the resulting contour of velocity distribution for smooth collector solar chimney at surrounding air temperature (315 K) and inlet air flow velocity (Re=99945). It was shown that air velocity inside the collector remains unaffected till the collector throat. The unaffected velocity of this part of air flow didn't depend on the inlet air flow velocity (Re). This result was clearly shown in **Figure (5)** which represents the contour of velocity distribution for smooth collector solar chimney at surrounding air temperature (315 K) and inlet air flow velocity (Re=499729).

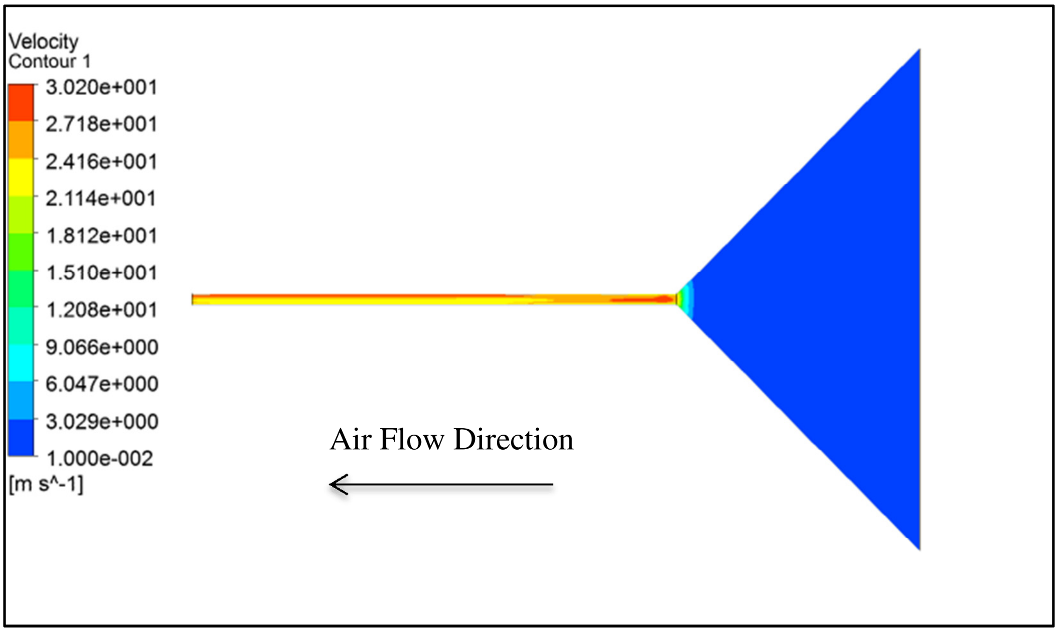


Fig.(4) Velocity distribution contour of smooth solar collector chimney for inlet air velocity (Re=99945)

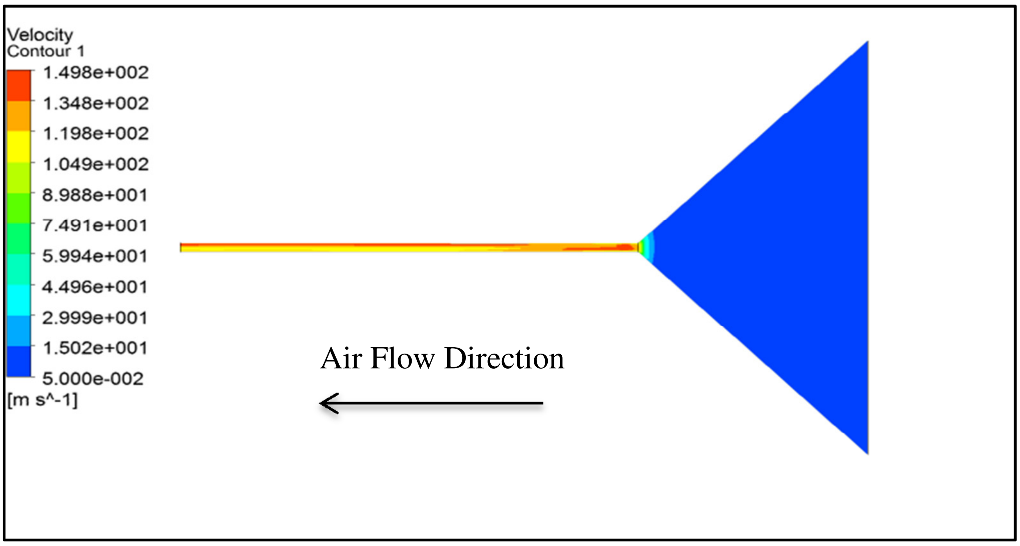


Fig.(5) Velocity distribution contour of smooth solar collector chimney for inlet air velocity (Re=499729)

On the other hand, results showed that the use of a spiral inside the collector was very effective in generating vortex. This vortex will lead to increase the velocity of air flow and, as a result, the generated electric power will be increased. **Figure (6)** shows the behavior of velocity distribution contour for collector solar chimney fitted with a spiral at a surrounding air temperature of (315 K) and an inlet air flow velocity of (Re=99945). Similarly, **figure (7)** show the corresponding velocity distribution contours for air flow velocities of (Re=499729).

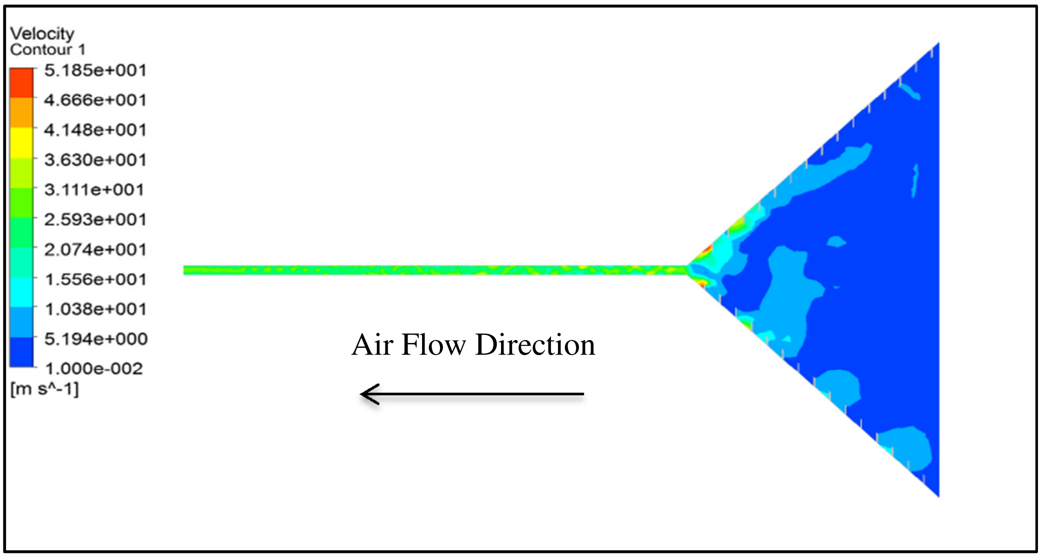


Fig.(6) Velocity distribution contour of spiral solar collector chimney for inlet air velocity (Re=99945)

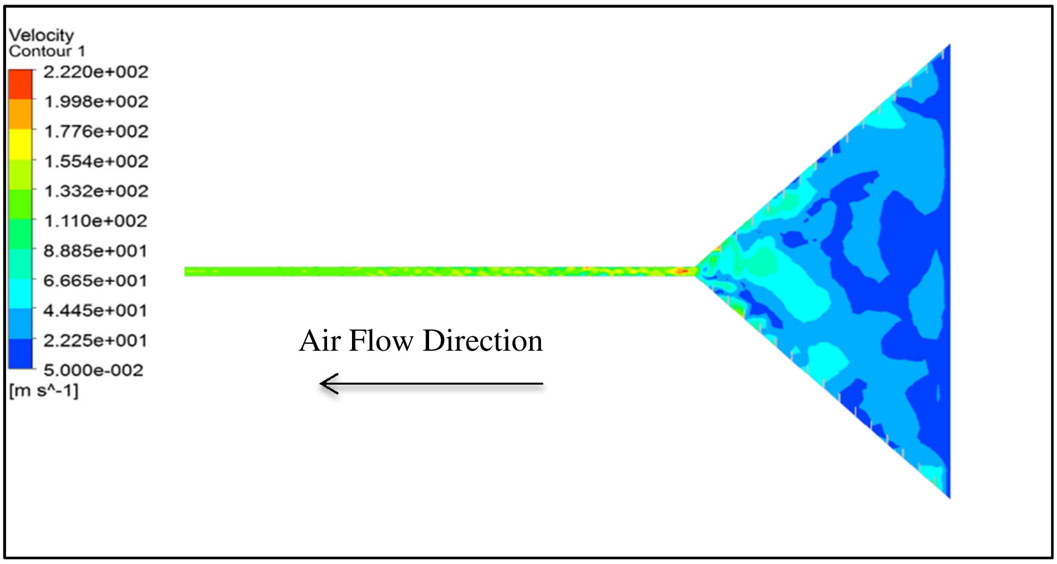


Fig.(7) Velocity distribution contour of spiral solar collector chimney for inlet air velocity (Re=499729)

The velocity distribution along the solar collector of an inlet air velocity (Re=99945) can be noted through **Figure (8)**. The using of a spiral seems to have a greater value of velocity comparing with the case of smooth collector (without spiral). This is due to the configuration of spiral which accelerates the flow along its surfaces (thus air velocity increases at conical collector chimney centerline). The velocity here was increased by (11.57%) at turbine position.

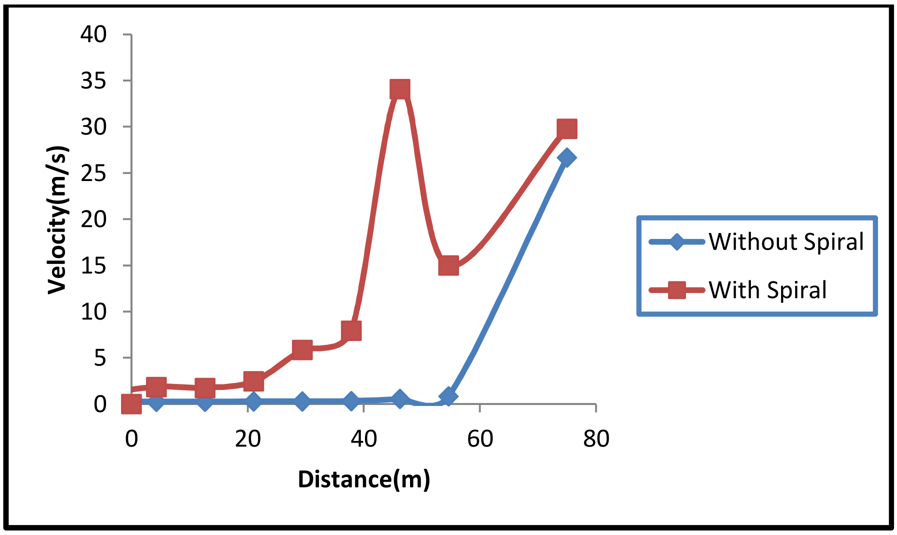


Fig.(8) Velocity distribution in solar collector chimney for inlet air velocity (Re=99945)

Similarly, velocity was increased by (12.82%) at turbine position when using an inlet air velocity (Re=499729) as shown in **Figure (9)**.

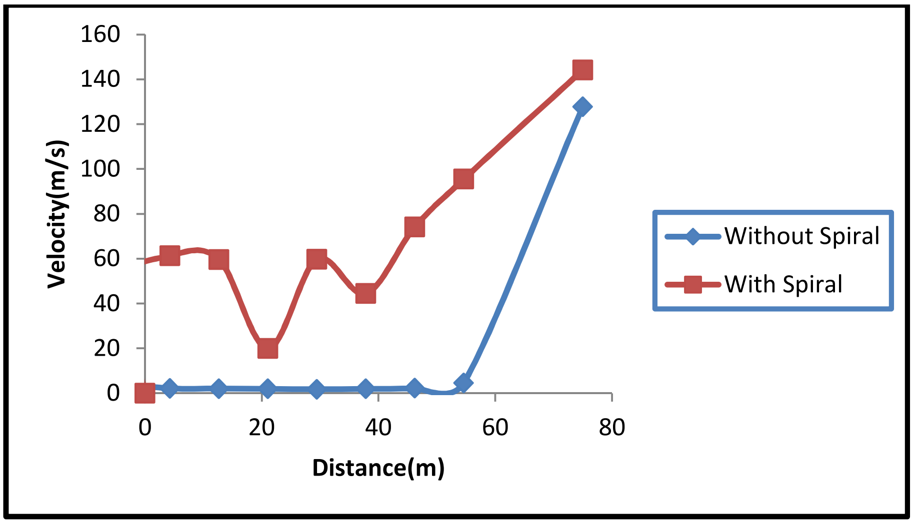


Fig.(9) Velocity distribution in solar collector chimney for inlet air velocity (Re=499729)

Literatures were shown that the output power increases exponentially with air velocity [9]. **Figure (10)** represents the variation of instantaneous electric power with velocity of air impinges on the rotor blade in smooth solar collector chimney . The same relation of an instantaneous electric power with velocity of air impinges on the rotor blade in solar collector chimney with spiral can be noted through **Figure (11).**

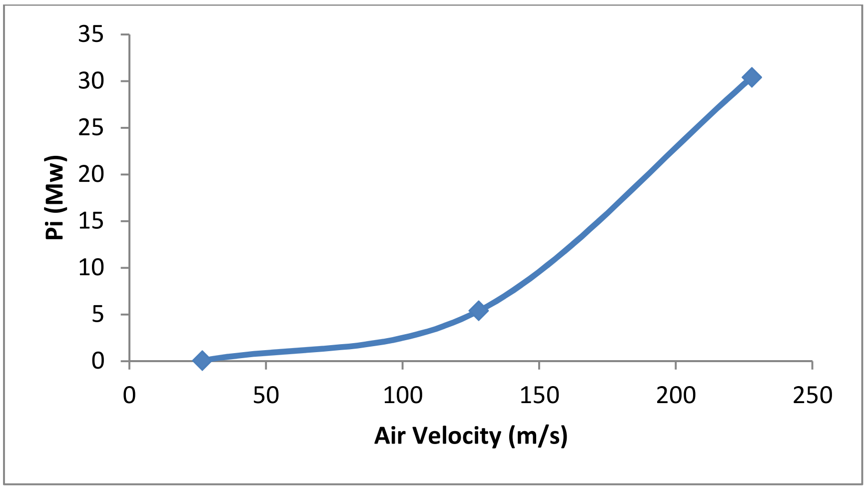


Fig.(10) Variation of instantaneous electric power with velocity of air impinges on the rotor blade in smooth solar collector chimney

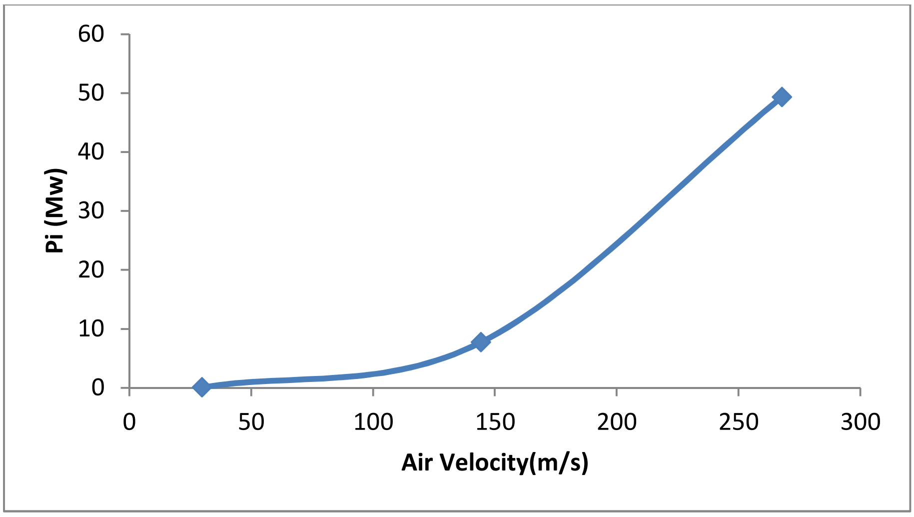


Fig.(11) Variation of instantaneous electric power with velocity of air impinges on the rotor blade in spiral solar collector chimney

Conclusions

Solar chimney power stations are an appropriate alternative to the nowadays known electric power stations. The simplicity of the installation and uncritical operation make them an ideal technology which can be adapted for regions (countries) that suffering from lack of sophisticated technical infrastructure. In this paper, special design of conical collector solar chimney was achieved for two cases one of them is smooth collector (without spiral) and the other case is collector ribbed with spiral. It was concluded that the using of spiral will lead to more air velocity distribution than smooth collector. As a result, the instantaneous electric power generated in turbine using a spiraled collector will be greater.

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