Improvement of collector efficiency of solar chimney power plant using computational fluid dynamic analysis

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Abstract - **The main aim of this work is to explore better efficiency by redesigning solar chimney power plant with using divergent and radial curvature on the roof of SCPP collectors. In this work we did a water dynamic analysis of a solar smoke plant with different height of exhaust space. (such as H2 =1.85m, 3m, 4m & 5m) and radial curvature on collector roof of 10m, 15m & 20m. Roof inclination and curvature radius of collector is vary by changing the outlet collector height and the inlet collector height is fixed as H1= 1.85m of solar chimney powerplant. It have been observed from the result that inclination and curvature radius of collector roof affect the collector efficiency and the collector efficiency is maximum 47.83% when the height of the collector is H2 = 5m and radial curvature on collector roof is 20 m.**

keywords **- solar chimney, collector height, collector efficiency, CFD analysis etc.**

I. INTRODUCTION

The solar power plant is designed to use renewable energy to produce solar energy at low temperatures. Sunshine heats the air under a very broad greenhouse like roofed collector structure surrounding the central base of a very high chimney tower. The solar station has a large chimney surrounded by a large collector roof. Against its center the roof curvature to connect the chimney and create a channel. The principle of the sun is based on the fact that the sun heats the air under the roof of collectors, which releases the chimney and activates the wind turbines.

Parts of the Solar Chimney power plant

The Collector: Collector is the part which is used to absorb hot air. It is usually two-six meters high and covers a very large area about thousands of m².

Turbines: turbine is used to convert air to the mechanical energy.

The chimney: The most important part of the plant is the chimney it acts as a thermal engine.

Working principles of Solar Chimney power plant:

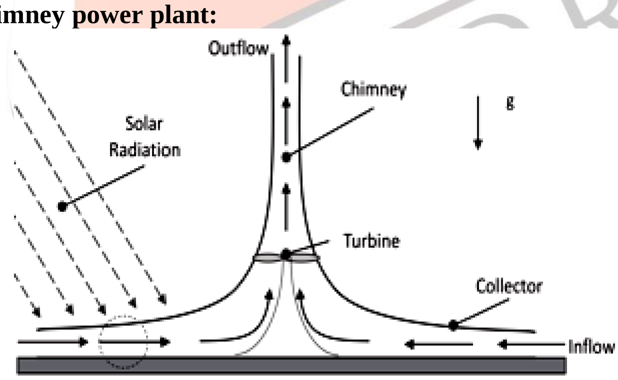

Figure 01: Working principles of Solar Chimney

Solar chimney consists of large area of transparent covers which receive solar radiations. The cold air flows from the bottom of the chimney due to natural draught produced due to density difference of high density surrounding cold air & low density hot air below the transparent covers heated by the solar energy. It is called chimney draught.

Solar chimney consists of a large area of transparent cover that receives solar radiation. Cold air flows from the bottom of the chimney due to the natural draft created by the difference in densities around cold air and low density hot air under transparent covers heated by solar energy. This is called a chimney.

Advantages

- Solar power plants are especially suitable for producing electricity in the desert and sunny deserts.
- It provides electricity 24 hours a day from solar energy.
- No fuel required. It does not need cooling water and is suitable for drying areas.
- This is especially reliable and a little problematic compared to other power plants.
- Concrete, glass and steel materials, necessary for the construction of solar power plants, in sufficient quantities everywhere.
- There is no environmental impact and no consumption of resources.

Disadvantages

- According to some estimates, the cost of producing electricity from a solar pipe is five times higher than that of a gas turbine. Although fuel is not required, solar pipes have very high financial costs.
- The building itself is large and requires a great deal of engineering knowledge and materials for construction.

LITERATURE REVIEW

Aakash Hassan, Majid Ali and Adele Wakas: In this study, a parametric analysis of a three-dimensional solar flux (CFD) solar power plant was performed to demonstrate the impact of the collection and chimney slope on the performance of the Manzanares prototype. Numerical models were included in models of sunset, DO (single coordinates) and R-NG-k-ε turbulence.
Ahmed Ayadi work on SCPP experimental setup was developed at Sfax National School of Engineers, Sfax University, Tunisia in North Africa. Comparison of numerical and experimental results has been demonstrated.
Siyan Hu and Dennis Ya.S. Leung: A mathematical model was created in this paper to analyze the hydraulic functions of a series of different pipes in the SCPP. In this study, the importance of assessing losses due to potential distribution stations in deviated pipes was discussed in particular. It has been found that the efficiency of various SCPPs is determined by the proportion of areas of entry into the chimney over the exit path.
Ehsan Gholamalizadeh & Man-Hoe Kim: This paper presents a computational fluid dynamics study on a solar-chimney power plant with an inclined collector roof. A three-dimensional model using the RNG (Re-Normalisation Group) k_ε turbulence closure is simulated. The discrete ordinates non-gray radiation model is used to implement the radiative-transfer equation.
E. Gholamalizadeh, etc.: Provided comprehensive analysis along with analytical and numerical models designed to predict the performance of solar smoke stations in Kerman, Iran. The numerical model results, as well as the airspeed and performance, were comparable to Manzanares' experimental knowledge.
Xinping Zhou and Yangyang Xu: In this work, it was shown that electricity from solar rising towers is a promising method for the future use of solar radiation to provide energy. The history of solar power plant technology (SUTES, also called solar smoker power) is discussed, its characteristics are presented and its principles are described.
Nima Fathi Seyyed, Sobhan Aleyasin and Peter Vorobye in this article assume the underlying assumptions and suggest that some of the equations obtained, especially the degree equation in this model, may require corrections to be applied in more realistic situations. . The results of the analysis are compared with available experimental data from the Manzanares power plant.
Attig Bahar F el. 3D CFD model of solar power plant (SCPP) was developed and confirmed by comparison with experimental data from a factory in Manzanares. It was then used to study the effectiveness of SCPP for places around Tunisia. Electricity production with the solar cabinet in the southern regions is greater than in other Tunisian regions due to higher solar radiation and sunlight. In particular, Remada and Tozeur show the highest performance with a slight advantage.

II. OBJECTIVE:

There are following objective of the present work.

- The main objective of the present work to perform computational fluid dynamic analysis to enhance the collector efficiency by changing the design of solar chimney power plant.
- To perform the CFD analysis on solar chimney using different collector height of solar chimney power plant.
- To compare the various results obtained from CFD analysis of various design of solar chimney power plant.
- To validate the collector efficiency with base paper and also check the collector efficiency with modified design.

III.METHODOLOGY:

Present work is categories in two parts namely mathematical analysis and Computational fluid dynamics analysis.
Mathematical analysis: in the mathematical analysis some mathematical formulas used such as collector efficiency, chimney efficiency, total efficiency of the system etc. Collector Efficiency

$$\eta_{coll} = \frac{\dot{m} \times c_p \times \Delta T}{G \times A_{coll}}$$

Here $\dot{m}$ is mass flow rate of air

$$\dot{m} = \rho V A C_h$$

$$A_{coll} = \frac{\pi}{4} \times Collector\ Dia^2$$

Chimney efficiency is given by

$$\eta_{ch} = \frac{g \times H_c}{c_p \times T_a}$$

The total efficiency of the system is defined by

$$\eta_{scpp} = \eta_{coll} \times \eta_{ch} \times \eta_t$$

Table 01: Parameters used in present work

Parameter	Value
Chimney height	195 m
Chimney diameter	10 m
Collector diameter	244 m
Distance from ground to the collector roof	1.85, 3,4 & 5 m
Radial curvature on collector roof	10,15 & 20 m
Efficiency of turbine	80%

Specific heat of the air	1.005 kj/kg-k
Solar radiation	850 w/m2
Ambient temperature	300k

Computational fluid dynamics analysis of solar chimney power plant:

The computational fluid dynamics analysis is carried out using ANSYS fluent for solar chimney power plant. The input parameters have been taken from the base paper. The governing equations such as continuity equation, momentum equation, energy equations, K equation and ε equations are used to perform this computational analysis.

Governing Equations

The equation for conservation of mass,

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\, \vec{v}) = S_m$$

Where S_m= mass added to the continuous phase or any user defined sources.

For two dimensional axi-symmetric geometries, the continuity equation is given by

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial r}(\rho v_r) + \frac{\rho v_r}{r} = S_m$$

Here x is the axial coordinate, r is the radial coordinate, v_x is the axial velocity, and v_r is the radial velocity.

Momentum Conservation Equations

Conservation of momentum equation is described by

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla.(\rho\vec{v}\vec{v}) = -\nabla p + \nabla.(\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F}$$

$$\bar{\bar{\tau}} = \mu\left[(\nabla\vec{v} + \nabla\vec{v}^{\mathrm{T}}) - \frac{2}{3}\nabla.\vec{v}I\right]$$

Energy Equation

$$\frac{\partial}{\partial t}\sum_{k=1}^{n}(\alpha_k\rho_k E_k) + \nabla.\sum_{k=1}^{n}\left(\alpha_k\vec{v}_k(\rho_k E_k + p)\right) = \nabla.\left(k_{eff}\nabla T\right) + S_E$$

k*−∈ *model

The turbulence kinetic energy, k, and its rate of dissipation, ∈, are obtained from the following transport equations:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k v_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho \in - Y_M + S_k$$

and

$$\frac{\partial}{\partial t}(\rho \in) + \frac{\partial}{\partial x_i}(\rho \in v_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\in}\right)\frac{\partial \in}{\partial x_j}\right] + C_{1\in}\frac{\in}{k}(G_k + C_{3\in}G_b) - C_{2\in}\rho\frac{\in^2}{k} + S_\in$$

CAD geometry: In the present work a two dimensional CAD model of solar chimney power plant has been created with the help of design modular of ANSYS workbench. In which the chimney height and diameter are 194.6 m and 10 m, respectively, and the solar collector diameter and heights are 244 m and H_1 = 1.85 m, H_2 =1.85 m, 3 m, 4 m & 5 m and radial curvature on collector roof of 10 m, 15 m & 20 m. A two dimensional view of solar chimney power plant is shown in figure no. 02.

Figure 02: CAD geometry solar chimney power plant

Meshing: After completing the CAD geometry of solar chimney power plant is imported in ANSYS workbench for further computational fluid dynamics analysis and the next step is meshing, in this process CAD geometry is divided into large numbers of small pieces called mesh. The total no of nodes generated in the present work is 364923 and total No. of Elements is 119530. Types of elements used are rectangular which is a rectangular in shape with four nodes on each element.

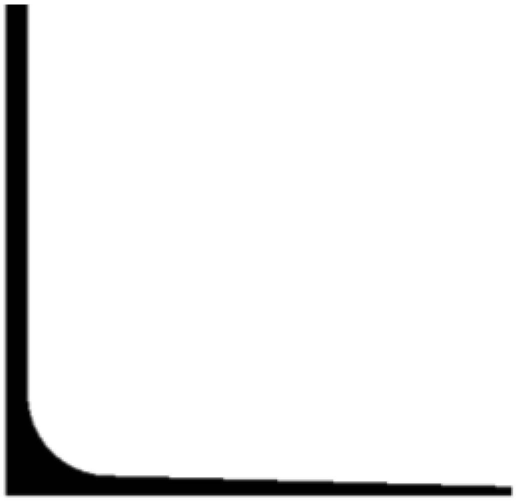

Figure 03: Meshing of solar chimney power plant

Boundary condition:

- To determine the temperature distribution inside the solar chimney power plant need to on energy equation.
- Defining of material property, set working fluid as air and chimney walls is metal sheet with thermal conductivity of 0.6 W/m-K & 16.27 W/m-K, top of collector is covered with transparent glass and the earth surface is considered as soil material.
- For the outlet boundary condition the gauge pressure needs to be set as zero because the flow of air inside the solar chimney is atmospheric.
- Solar radiations were used on collector roof of solar chimney power plant is 850 W/m_2 .
- The Fluent solver is used for CFD analysis.

Temperature distribution inside the solar chimney power plant:

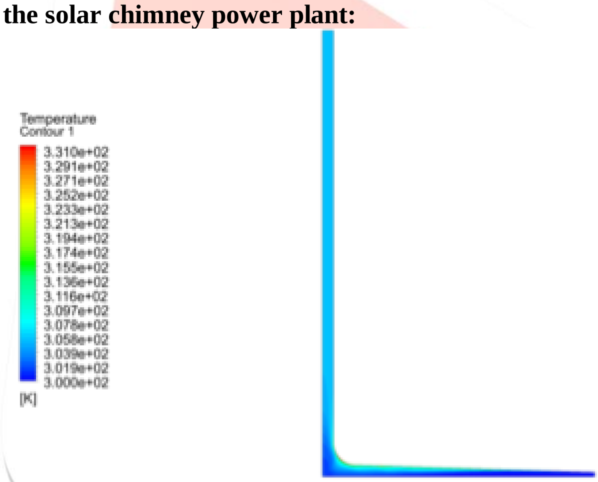

Figure 04: Temperature distribution inside the SCPP for radial curvature of collector roof is 10 m

After performing computational fluid dynamics analysis of solar chimney power plant at collector height H_2 =1.85 m, 3 m, 4 m & 5 m and radial curvature on collector roof of 10 m, at 850 W/m_2 solar radiations. The maximum temperature 331K has been recorded and the temperature difference of 31 degree has been observed.

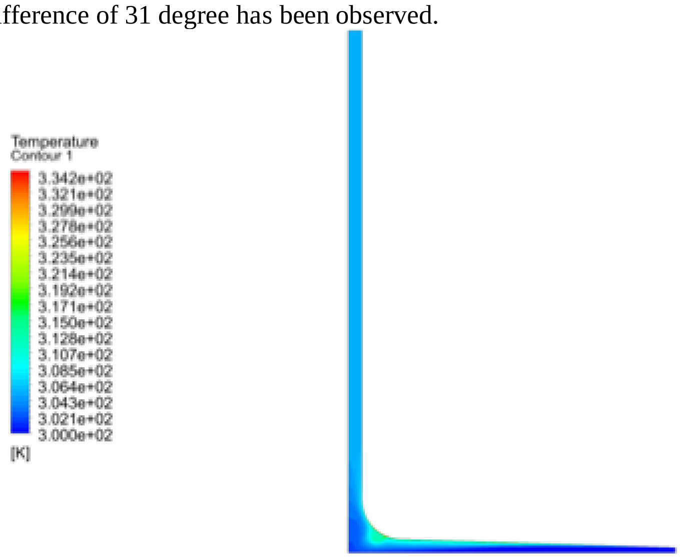

Figure 05: Temperature distribution inside the SCPP for radial curvature of collector roof is 15 m

After performing computational fluid dynamics analysis of solar chimney power plant at collector height H_2 =1.85 m, 3 m, 4 m & 5 m and radial curvature on collector roof of 20 m, at 850 W/m_2 solar radiations. The maximum temperature 334.2K has been recorded and the temperature difference of 34.2 degree has been observed.

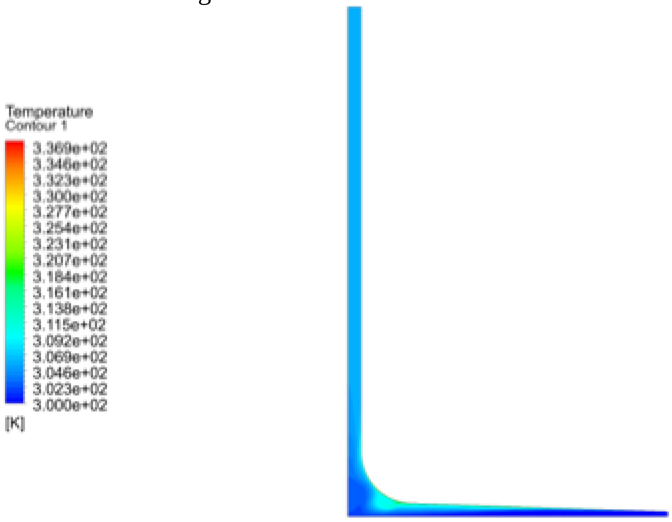

Figure 06: Temperature distribution inside the SCPP for radial curvature of collector roof is 20 m

After performing computational fluid dynamics analysis of solar chimney power plant at collector height H_2 =1.85 m, 3 m, 4 m & 5 m and radial curvature on collector roof of 15 m, at 850 W/m_2 solar radiations. The maximum temperature 336.9K has been recorded and the temperature difference of 36.9 degree has been observed.

IV. RESULT AND DISCUSSION

Validation of work: For the validation of this work the CAD dimensions of the solar chimney power plant is taken from a research paper of Ehsan Gholamalizadeh, Man-Hoe Kim "CFD (computational fluid dynamics) analysis of a solar-chimney power plant with inclined collector roof" international journal of Energy, Vol. 107, year 2016, page from 661-667, contents available at science direct. The compared result of collector efficiency which vary from 32.1% to around 35.8% in base paper and in present work is vary from 31.32% to 38.20% as shown in figure and which show very good agreement with 1% to 6% error. After the validation of base model some other design of solar chimney power plant have been used for computational fluid dynamics analysis to investigate better efficiency.

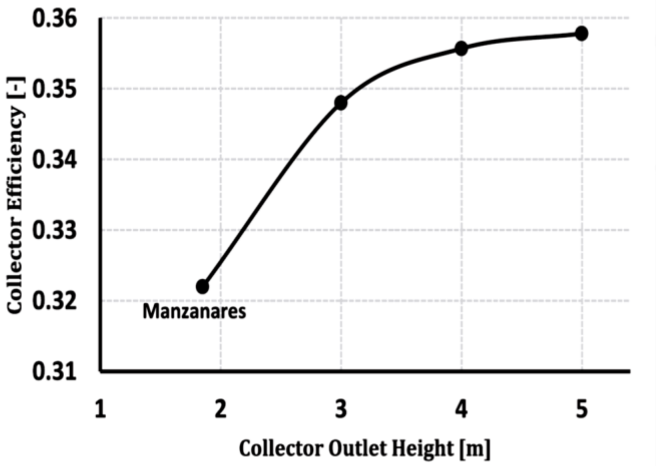

Figure 07: Collector efficiency at different height from base paper

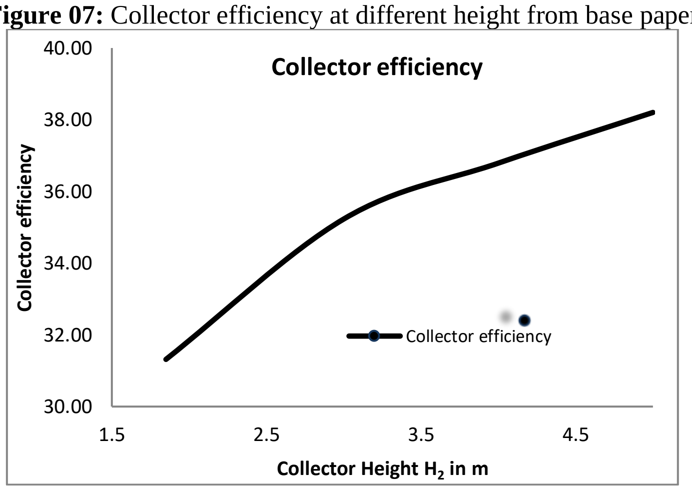

Figure 08: Collector efficiency at different height in present work

Results from Computational fluid dynamics analysis:

After performing computational fluid dynamics analysis of solar chimney power plant at collector height H_2 =1.85 m, 3 m, 4 m & 5 m and radial curvature on collector roof of 10 m, 15 m & 20 m at 850 W/m_2 solar radiation, various result of CFD analysis have been explain using graphical representation.

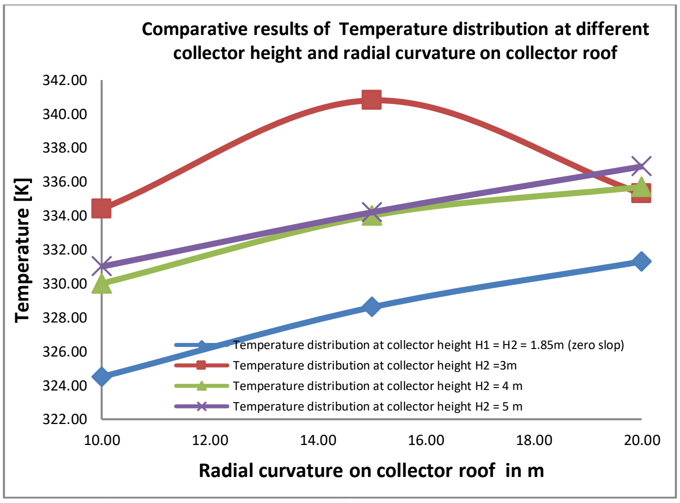

Figure 09: Comparative results of Temperature distribution at different collector height and radial curvature on collector roof

Comparative results of Temperature distribution at different collector height and radial curvature on collector roof is shown in figure no. 09. The temperature distribution inside the solar chimney power plant have been observed range from 324K-340.80K with temperature rise from 24 -40.80 degree,

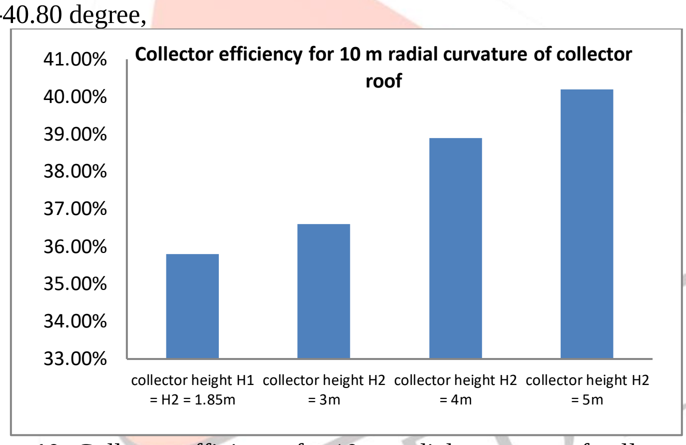

Figure 10: Collector efficiency for 10 m radial curvature of collector roof

It has been observed from figure no. 10 the collector efficiency for 10 m radial curvature of collector roof at different collector heights ranging from 35.80% - 40.20%.

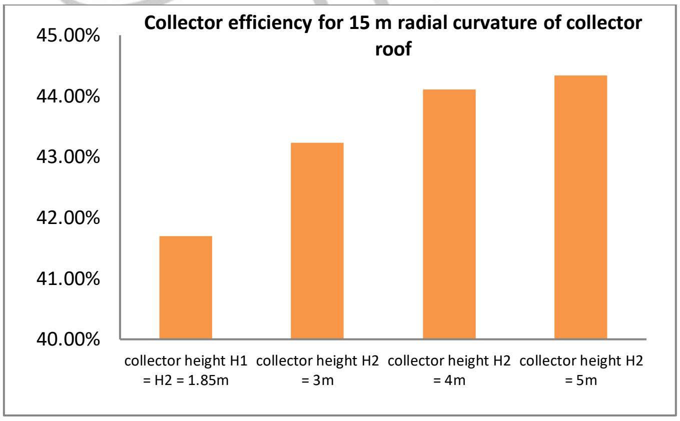

Figure 11: Collector efficiency for 15 m radial curvature of collector roof

It has been observed from figure no. 11 the collector efficiency for 15 m radial curvature of collector roof at different collector heights ranging from 41.70% - 44.34%.

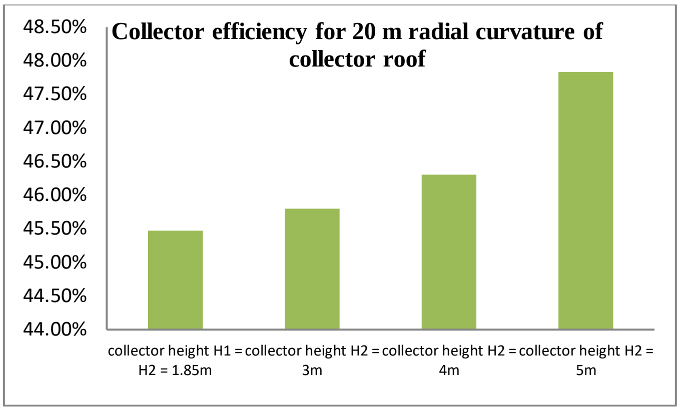

Figure 12: Collector efficiency for 20 m radial curvature of collector roof

It has been observed from figure no. 12 the collector efficiency for 20 m radial curvature of collector roof at different collector heights ranging from 45.47% - 47.83%.

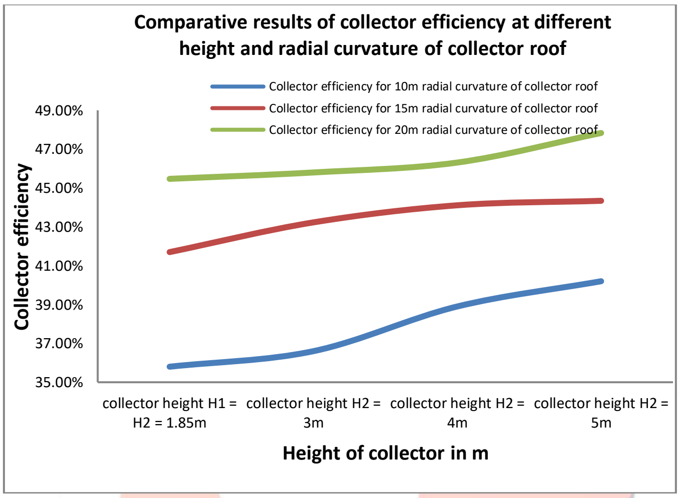

Figure 13: Comparative results of collector efficiency at different height and radial curvature of collector roof

Comparative results of collector efficiency of solar chimney power plant at different collector height and radial curvature on collector roof is shown in figure no. 13. It has been observed that collector efficiency is increasing as outlet height of collector is increasing and vary from 35.80% - 47.83% and maximum at H_2 =5 m when radial curvature of collector roof is 20 m.

V. CONCLUSION

The computational fluid dynamics analysis has been performed on solar chimney power plant for different collector height (such as 1.85m, 3m, 4m & 5m) and radial curvature of collector roof is 10 m at 850 W/m_2 solar radiations. The temperature distribution inside the solar chimney power plant have been observed range from 324K-334K with temperature rise from 24-34 degree and the collector efficiency increased from 35.80% -40.20% have been observed.

The computational fluid dynamics analysis has been performed on solar chimney power plant for different collector height (such as 1.85m, 3m, 4m & 5m) and radial curvature of collector roof is 15m at 850 W/m_2 solar radiations. The temperature distribution inside the solar chimney power plant have been observed range from 328K-340.8K with temperature rise from 28-40.8 degree and the collector efficiency increased from 41.70%-44.34% have been observed.

The computational fluid dynamics analysis has been performed on solar chimney power plant for different collector height (such as 1.85m, 3m, 4m & 5m) and radial curvature of collector roof is 20 m at 850 W/m_2 solar radiations. The temperature distribution inside the solar chimney power plant have been observed range from 331.30K-336.90K with temperature rise from 31.30 - 36.90 degree and the collector efficiency increased from 41.70% -45.47-47.83% have been observed.

It have been observe from the above conclusion that the inclination and curvature radius of collector roof affect the collector efficiency and the collector efficiency is maximum when the height of the collector is H_2 = 5 m with radial curvature of collector roof is 20 m.

VI. REFERENCE

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