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CFD Analysis for Efficiency Evaluation of Solar Chimney with Variation of Height

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Abstract: For large scale application of solar energy, one of the innovative research applications is solar chimney power plant (SCPP). This results in utilization of renewable energy and are pollution free. But effectiveness of solar chimney depends on numerous influencing parameters. In this research work, optimization of solar chimney design is proposed. The variation of height shows impactful result for tracing maximum temperature. The result simulation is performed using computational fluid dynamics (CFD) analysis. In this work, simulation was performed by varying height of collector in range of 2-4m. Different conditions were observed with variable solar radiation ranging between 650-1000W/m2. The simulated result shows improvement of approx. 45% efficiency as compare to existing work.

Keywords: Solar Chimney Power Plant (SCPP), CFD, Efficiency Evaluation.

I. Introduction

Global warming and the pursuit of sustainable development have led engineers to look for new ways to generate electricity from renewable sources, and some "old" methods and techniques, such as the centuries-old solar chimney, are becoming popular again. In fact, the solar chimney is a very old method that has been used for passive ventilation of buildings for thousands of years. The mechanism is very simple, many architects and civil engineers have paid particular attention to it in recent years. Solar chimney can do this naturally and sustainably without using electricity like mechanical HVAC systems for buildings. Today, the solar chimney, the ancient method of building ventilation, is a widely used and popular technology for the production of renewable energy. Solar chimney are intended not only for renewable electricity generation and building ventilation, but also for other purposes such as urban planning, urban air purification, solar drying and desalination, and power generation. fresh water. In this respect, the solar chimney is a very unique concept and very different from other technologies. Despite the simple and well-known mechanism of how solar chimney work, which makes them the preferred technology of many engineers and architects in their sustainable and renewable energy projects, there are still many aspects to be developed to make solar chimney suitable for the home. production of renewable energy or its use. in the construction of air conditioning. Therefore, this very old method, based on increasing hot air, has some uncertainties for power generation and heating or cooling applications in buildings. However, solar chimney still offer great potential for various uses. Therefore, it can be said that solar homes will play an important role in the shift to 100% renewable energy.

Fig.1. Proto-type Solar Tower in Manzanares, Spain

The use of renewable energy sources is today one of the emerging sectors in the world. To minimize the production of greenhouse gases and compensate for the scarcity of traditional energy sources, renewable energies are one of the best alternatives. More and more research is being conducted on the application of solar energy. SCPP consists of three main components such as an absorbent plate, a solar collector and a chimney. A turbine is placed to generate electricity. The basic and fundamental method behind the work of SUT is the buoyancy effect. When the solar flux falls on the collector cover (clear glass), the flux is absorbed by the absorbent plate. Then the air in the SUT heats up, its density decreases and becomes lighter; then it goes up. The heated air circulates through the chimney and comes out from the system outlet. A wind turbine is located at the bottom. The development and maintenance of SUT systems are very cost-effective due to their robust construction. This power plant can be installed in both rural and urban areas, and desert and mountainous areas can also be preferred for installing structures. Other applications of solar chimney are in agriculture for food drying, for desalination and in buildings for ventilation purposes.

A 50 kW, 200 m high prototype solar chimney was built in Manzanares, Spain, since 1981. The plant operated from 1982 to 1989 and was connected to the municipal electricity grid between 1986 and 1989 (figure 1). There was a 4-blade wind turbine in the chimney, which is located at the bottom of the chimney to use energy from the floating air. Conversely, many types of renewable energy sources such as wind and solar energy are constantly being renewed. The most common methods of solar energy harvesting are reflector collectors and photovoltaic solar planes, both of which are expensive and require expensive maintenance. Solar chimneys can be used to generate electricity with the added benefit of not wasting land as the soil under the greenhouse component can also be used for agricultural purposes.

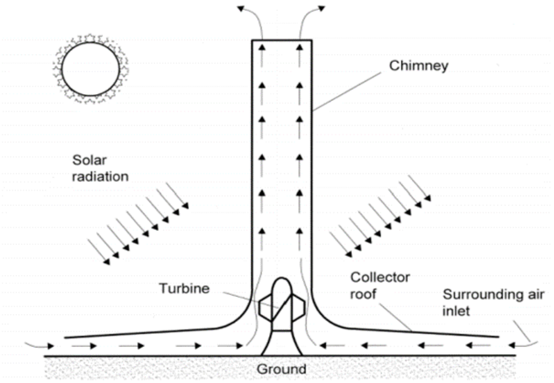


Figure 2: Solar chimney power configuration

The first solar chimney was designed by Schlaich in the 1970s and his practical test on a primary model showed the potential of this tool to generate electricity and clean energy. An SCPP is made up of three main parts: a manifold, a turbine and a chimney. A collector is a glass or plastic cylinder through which solar radiation can pass and store its heat. The chimney is a highly cylindrical structure placed in the center of a collector with the turbine at the inlet (Fig. 2). The greehouse impact in the authority warms the air entering from beneath. The hot air ascends because of its lower thickness and drives the turbine in the stack through the gatherer [1]. Force and effectiveness rely upon the size of the stack and the authority.

II. Basics of SCPP

The solar chimney is a technology that has been shown to be capable of generating electricity from the sun [9]. It contains the collector whose function is to heat up the air near the ground and conveys it into the ground of a large chimney. Floating air ascends in the chimney, and power is produced by hot air moving through at least one turbines at the lower part of the stack. Accordingly, the sun powered radiation is changed over into heat energy in the retaining medium, the heat energy is changed over into dynamic energy in the gathering channel, motor energy is changed over into mechanical energy in the breeze rotor, lastly mechanical energy is changed over into energy power through the generator.

Open solar-air collector

The collector is installed outside or on the rooftop whose main function is to collect the heat from the solar energy. It acts as heat exchanger. The radiations are received in form of solar energy which is ultimately converted into thermal energy.

The chimney

The chimney is used to create hot air pressure for generation of power. Many researchers focused their work on design of chimney especially height and diameter of the chimney inlet as well outlet. It was observed that with increase in height or diameter frictional losses gets minimized and efficiency increases.

Turbine

The power conversion unit (PCU) of a large-scale SCPP consists of one or more turbines whose dimensions depend on mass flow rate and its design. Turbine installation locations, configurations and arrangements have been suggested by various researchers for the chimney outlet or conventional chimney inlet.

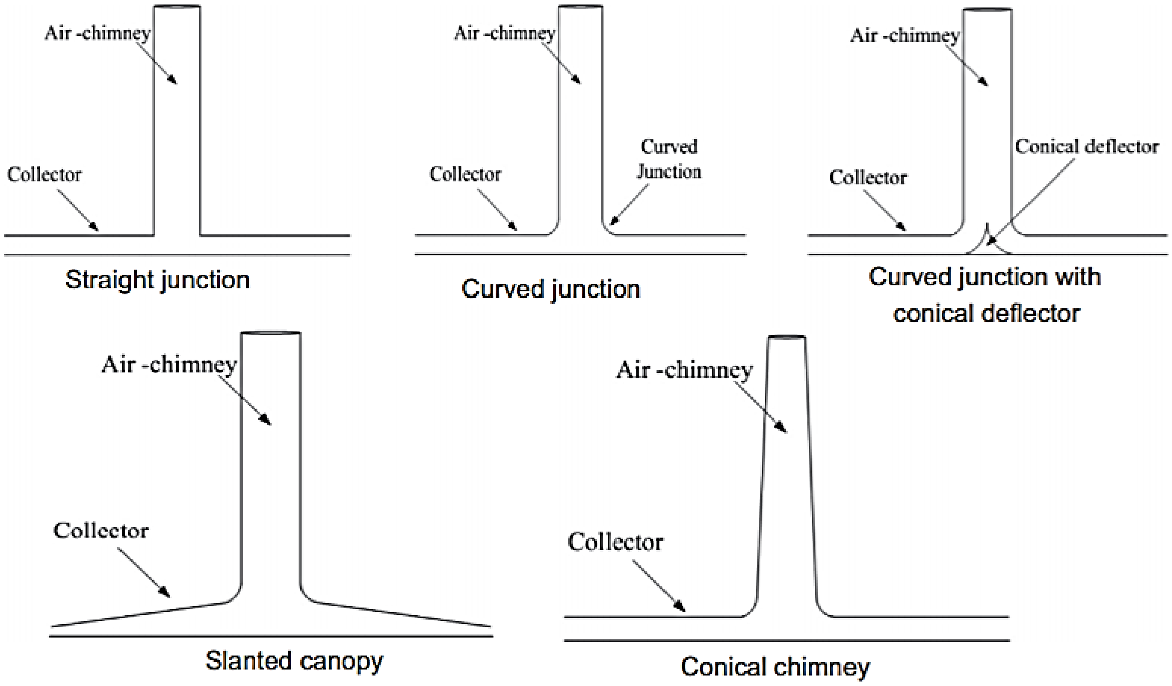


Figure 3: Different Chimney Configurations

The pressure of rising hot air is given as:

$$\Delta Pressure_{air} = G\int_{o}^{h} (density_{out} - density_{chimney})dz$$

Where,
$Density_{out}$= air density of outdoor
$Density_{chimney}$ = air density of chimney
H= height of chimney
G= gravity (9.81 m/s^2)

Potential difference of pressure is created between static as well as dynamic components in order to remove negligible losses due to friction such that:

$$\Delta Pressure_{out} = \Delta Pressure_{static} + \Delta Pressure_{dynamic}$$

Where, maximum power is extracted as:

$$Power_{max} = \frac{2}{3}V_c A_c \Delta Pressure_{out}$$

Where,
V_c = Air velocity of chimney in (kg/m^3).
A_c = Area of chimney
Then efficiency of chimney is evaluated as:

$$Efficiency = \frac{Gh}{cT_o}$$

Most of the research has focused on the structural design of the chimney, while some numerical studies have been carried out on different shapes of chimney.

III. Proposed Methodology

Assumptions

1. It was assumed that heat inside collector due to air and floor is negligible. The parameter considered was the heat switch between the surroundings and the collector.
2. In actual conditions, solar radiations are transient, hence a steady state is assumed to exist.
3. Air flow is assumed to be incompressible.
4. The parameters like construction Labour costs and land costs are not considered in the economic model.

Mathematical analysis

Efficiency of the collector

$$A_{ch} = \frac{\pi}{4} \times ChimneyDai^2$$

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

Total efficiency can be given by the following relation:

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

In terms of enthalpy it is evaluated as:

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

$\dot{m}$=$\rho V A_{ch}$
$\dot{m}$= air mass flow rate
V_2 =Velocity of the air at the outlet of the collector.
ΔT= Difference of temperature between the outlet of the solar collector and the ambient.
$\Delta T = T_2 - T_a$
T_a= Temperature of the ambient
T_2= Collector temperature at the outlet
Power output is given by:

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

Chimney

The outlet of the collector provides heated air which then passes through solar turbine. After this the air enters the chimney. Air at a high temperature obtained from the collector provides kinetic energy available within it due to pressure drop of convection current in chimney. Hence, the density difference then provides the necessary driving force. Air at high temperature has low density and hence rises against the gravitational force.

Efficiency of the chimney is thus given by:

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

Turbine

The kinetic energy of the air is converted into rotary mechanical work in a device within SCPP known as turbine. Efficiency related to a turbine is given by:

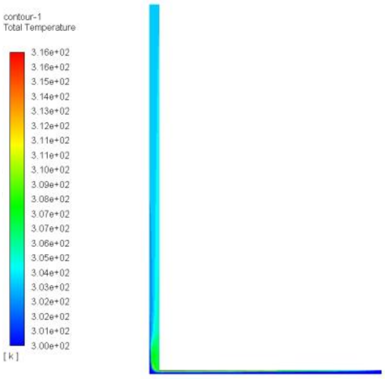
$$\eta_t = 1 - \frac{V_2}{2C_p \Delta T \eta_{ch}}$$

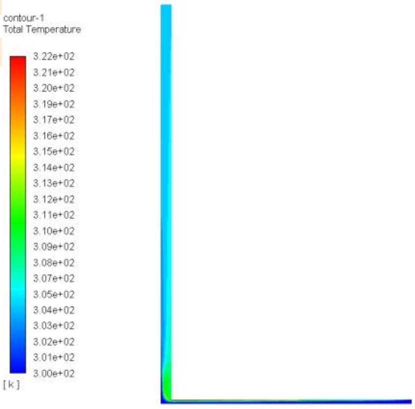
Generated power:

$$P_{el} = \eta_{scpp} \times G \times A_{coll}$$

CFD Analysis

At height 2m and solar radiation 650, 850, 1000 W/M^2.





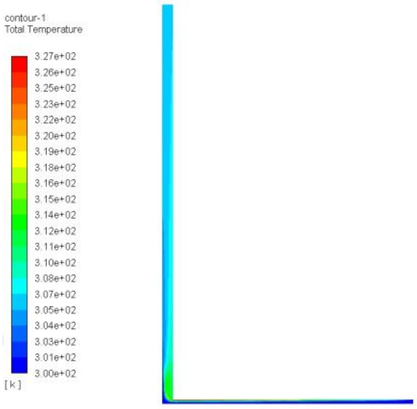


Figure 4: Temperature distribution of collector at 2 m height

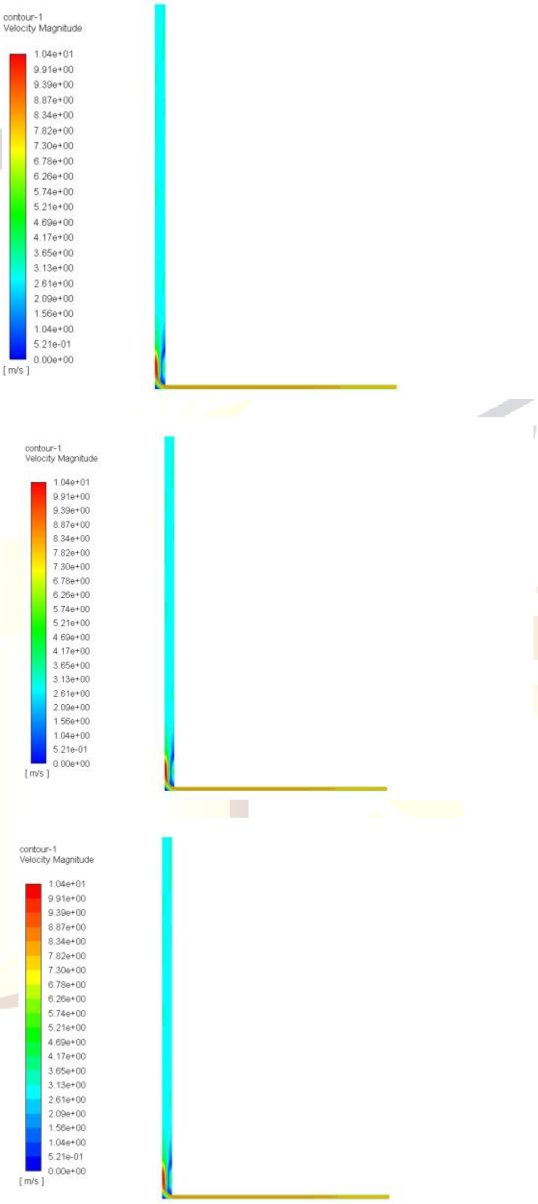


Figure 5: Velocity distribution of collector at 2 m

At height 3m and solar radiation 650, 850, 1000 W/M^2.

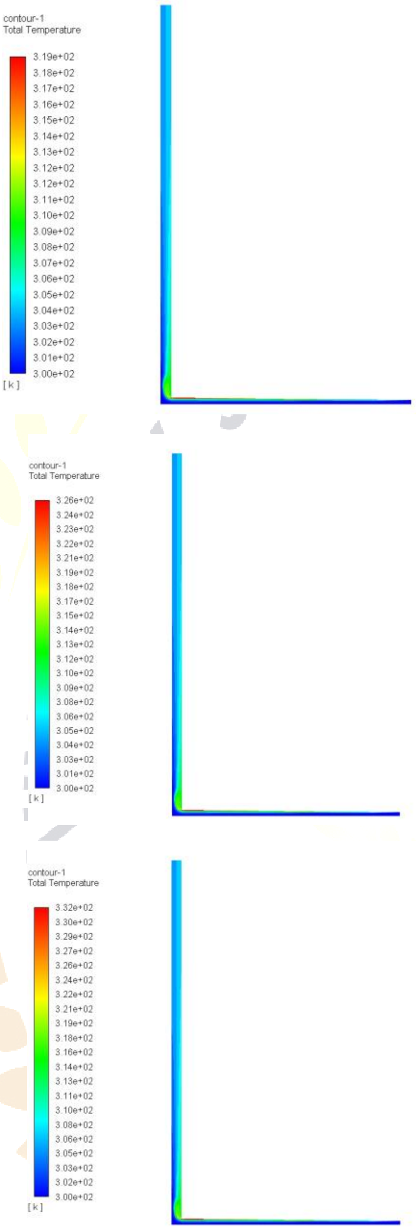
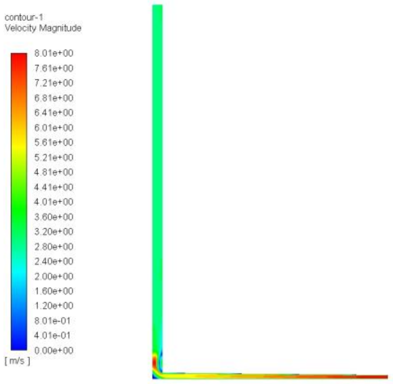


Figure 6: Temperature distribution of collector at 3 m height



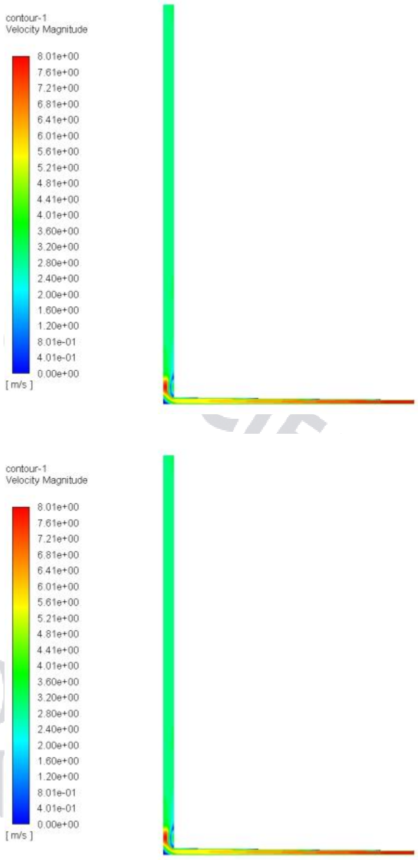
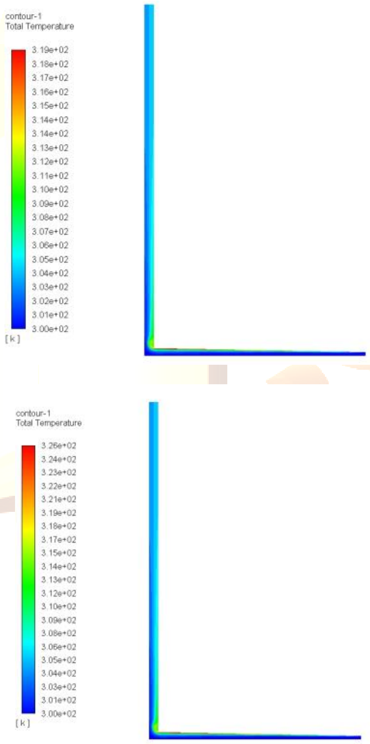


Figure 7: Velocity distribution of collector at 3 m

At height 4m and solar radiation 650, 850, 1000 W/M^2.



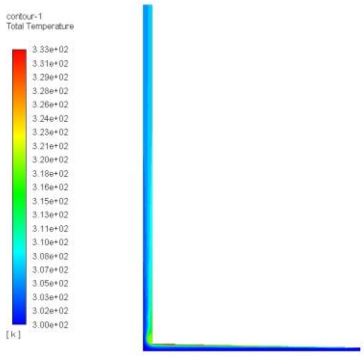
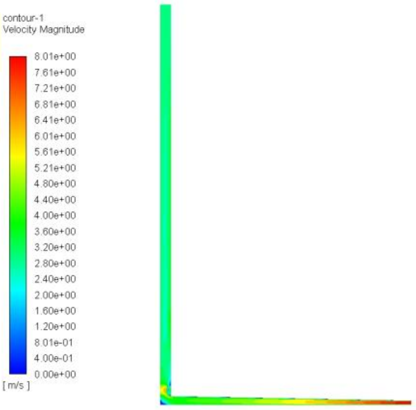
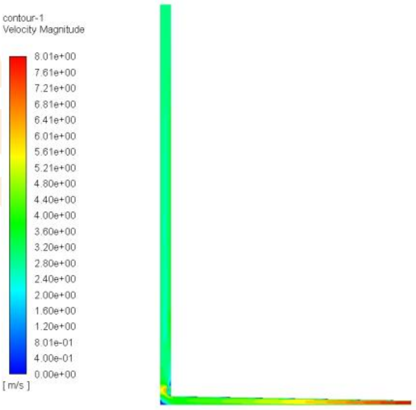


Figure 8: Temperature distribution of collector at 4 m height





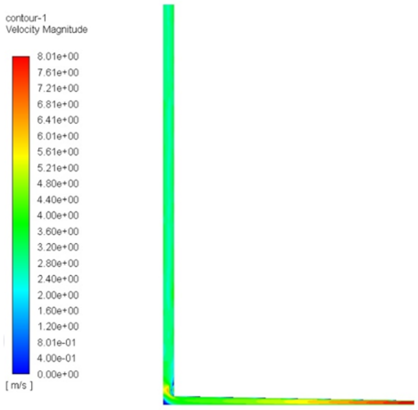


Figure 9: Velocity distribution of collector at 4 m

IV. Result Analysis

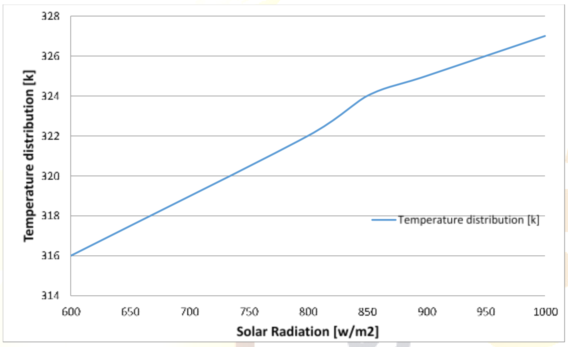


Figure 10: Temperature distribution of collector at 2 m height

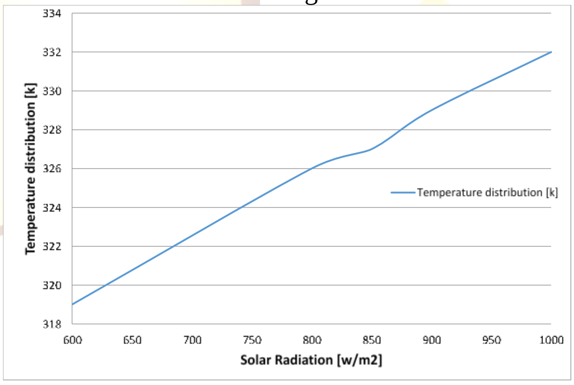


Figure 11: Temperature distribution of collector at 3 m height

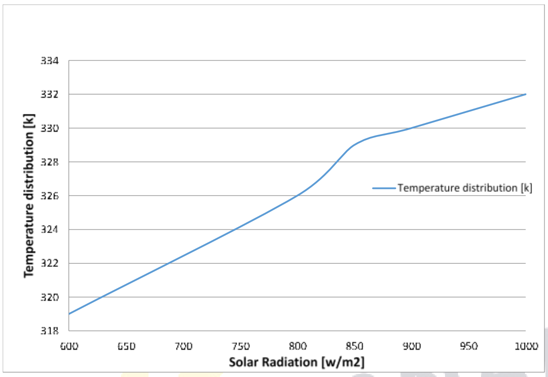


Figure 12: Temperature distribution of collector at 4 m height

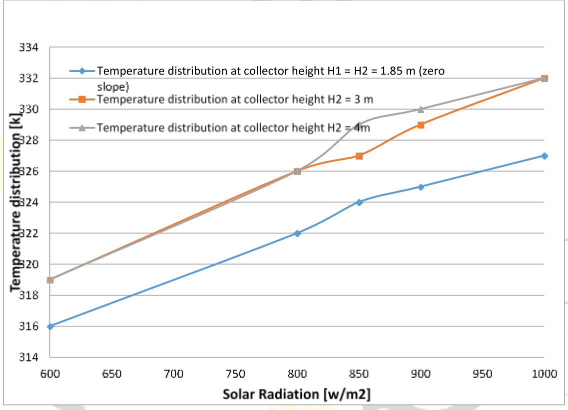


Figure 13: Comparative Analysis

V. Conclusion

In the present work the performance of SCPP is evaluated on height difference using CFD analysis. The simulation is performed on temperature distribution in the solar system, for varying height was observed between 317K and 335K with a temperature increase of 16-25 degrees and the sensor efficiency increased from approximately 29%-38%.

From the above conclusion, it can be seen the efficiency is maximal when the height of the sensor H2 = 4 m. The present work is concentrated to improve the efficiency by changing its design. Though the study is performed with an utmost care then also there is scope for further improvement. Some of the suggestions for future study might be possible. In the present work there is fixed size of chimney that can be further improved in future on variable height. In the future work CFD on some other collector height with other radiation may be used.

References

[1] Ehsan Gholamalizadeh, Man-Hoe Kim "CFD (computational fluid dynamics) analysis of a solar-chimney power plant with inclined collector roof" Volume 107, 15 July 2016, Pages 661-667.

[2] H. Huang, G. Li and H. Zhang, "Experimental Performance of a Solar Collector in Solar Chimney Power Plant System," 2010 International Conference on Electrical and Control Engineering, Wuhan, 2010, pp. 3718-3721, doi: 10.1109/iCECE.2010.907.

[3] Mohammed A., Aurybi S.I. Gilani, Hussain H.A, Kayiem Ali, A. Ismaeel, "Mathematical evaluation of solar chimney power plant collector, integrated with external heat source for non-interrupted power generation", Sustainable Energy Technologies and Assessments, Volume 30, December 2018, Pages 59-67.

[4] T. A. Yassen, F. M. Abed, M. S. Kassim and I. S. Farhan, "Experimental investigation of the performance of a multi-purpose solar chimney power plant," 2018 2nd International Conference for Engineering, Technology and Sciences of Al-Kitab (ICETS), Karkuk, Iraq, 2018, pp. 88-92.

[5] A. Cervone, D. Zaccagnini Romito and E. Santini, "Design of solar chimney power plant for Mediterranean countries," 2011 International Conference on Clean Electrical Power (ICCEP), Ischia, 2011, pp. 480-484, doi: 10.1109/ICCEP.2011.6036295.

[6] Xinping Zhou & Yangyang Xu "Review Solar updraft tower power generation" Solar Energy 128 (2016) 95–125.

[7] Z. Akhtar and K. V. S. Rao, "Effect of collector efficiency on levelized electricity cost of 200 MW solar chimney power plant in India," 2015 International Conference on Technologies for Sustainable Development (ICTSD), Mumbai, 2015, pp. 1-6, doi: 10.1109/ICTSD.2015.7095908.

[8] A. A. Bidgoli and S. Rahnamayan, "An Innovization-based Model to Approximate Geometric Parameters of Solar Chimney Power Plant for Desired Efficiency and Output Power," 2019 International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), Istanbul, Turkey, 2019, pp. 1-8.

[9] Vieira RS, Petry AP, Rocha LAO, Isoldi LA, dos Santos ED. Numerical evaluation of a solar chimney geometry for different ground temperatures by means of constructal design. Renew Energy 2017;109:222–34.

[10] E. Gholamalizadeh and J. D. Chung, "A Parametric Study of a Pilot Solar Chimney Power Plant Using CFD," in IEEE Access, vol. 6, pp. 63366-63374, 2018, doi: 10.1109/ACCESS.2018.2875411.