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CFD Assessment of Circular and Spiral Recipients in CSP Plants

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***Abstract*: The primary goal of this research is to create a new billboard-style central spherical solar receiver with varying header and tube diameter, for which two spiral central receiver designs and a new circular central solar receiver with varying pipe radius and varying mass circulation are utilized. The exhaust temperature of the water was determined employing a computational fluid dynamics assessment employing ANSYS Fluent. Following the verification of the standards models, a novel central solar receiver project was made that accomplishes computational fluid dynamics assessment with almost the same boundary condition.The heat export fluid is water, and the spiral coil tube is copper. The mass circulation rate varies among 0.1 LPM, 0.2 LPM, and 0.3 LPM, with the inlet temperature of water being 299K at continuous solar irradiation. The findings demonstrate that at 0.1 LPM, the redesign of the central solar receiver produces a temperature of 383.9 K, which is 28.39 percent higher than the inlet temperature and 7.32 percent higher than the spiral central receiver. As a consequence, the circular central solar recipient to varying pipe radius is suggested and considered in upcoming usages.**

***Keywords*:** Solar energy, solar thermal energy, concentrating solar power, Linear Fresnel Reflector and Parabolic Trough.

I. INTRODUCTION

Solar thermal technologies, in overall, are founded on the idea of concentrating solar radiation to convert water into steam or hot air, that can then be used to generate electricity employing traditional thermal - dynamic power cycles. Among the most difficult technical tasks in the implementation of solar thermal power plants is accumulating low-density solar energy. Reflectors concave geometry, visually affiliated mirrors, and parabolic shaped devices are used to concentrate uniform solar irradiation. Due to various their high reflectivity, most processes employ glass mirrors for concentration. To coincide the beam radiation on the recipient, a sun monitoring system is also necessary.

CSP relying systems focus the sun's uniform solar irradiance on a recipient, which would be intended to minimize the highest amount of radiation dropping on it. The assimilated heat is conducted to a thermo-dynamic power cycle's operating fluid, where it then motivates the power block to initial electricity.

The receiver's highest absorption of incoming radiation is favoured for heating the HTF, that can then increase the temperature of the operating fluid injected into the turbines, leading to greater productive output. CSP technologies are divided into two categories depending on the concentration geometry: point focus concentrators and line focus concentrators.

The concentration configuration of a CSP system is determined by the geometrical and layout of the reflectors mirrors. Owing to the increase concentration ratio (3000), juncture start concentrating relying technologies reach greater temperatures (700–1000 °C) at the recipient, so although line focus techniques attained lower temperatures (700–1000 °C) excessive heat losses in HTF mass transit. A CSP depending power plant's general layout includes a solar field, storage facility, and power block.

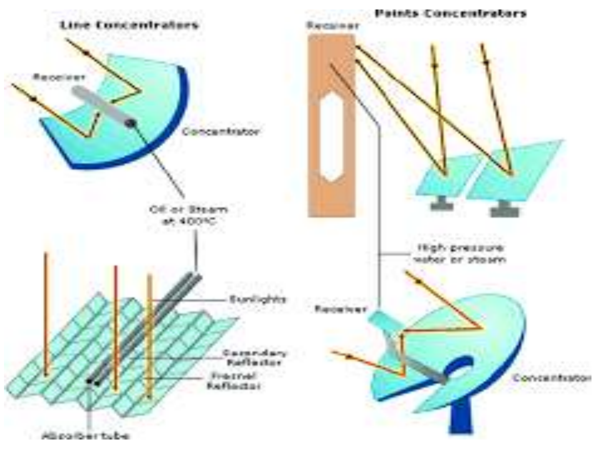


Figure 1 Concept of CSP technologies

The centralized receiver framework, known as a heliostat, just at top of a tower is used to concentrate on sunlight to a received signal in a sun-tracking mirror system. The transceiver is used to produce steam in a heating medium warmed to about 600 degrees Celsius, which is then used to generate electricity in a traditional turbine.

There are four main CSP systems

1. Parabolic trough collector
2. Linear fresnel collector
3. Parabolic dish collector, and
4. Solar Tower

Linear concentrating systems

Large, rectangle, curved (U-shaped) reflectors are used in linear focusing systems to capture the energy of the sun. Sunlight is focused on recipients (tubes) that runs through the middle of the lenses. A fluid running through the pipes is heated by the focused sunlight. Through generate power, the fluid is transferred to a heat transfer, which boils water in a traditional steam generators. Parabolic trough mechanisms, in which transceiver tubes are situated along the optical axis of every spherical mirror, as well as linear Fresnel reflector mechanisms, in which one transceiver tube is situated above numerous mirrors to enable the mirrors larger survivability in solar tracking, are indeed the two major categories of linear concentrator frameworks.

To maximise solar energy gathering, a linear concentrating collecting power plant comprises a huge numbers, or area, of collects in parallel lines that are typically placed in a north-south direction. The mirrors may track the sun from east to west throughout the daytime and concentrated sunlight onto the receiving tubes in this arrangement.

Parabolic troughs

A wide parabolic-shaped reflection in a concentrator collector concentrates the amount of solar radiation on a receiving tube at the parabola's centre. As the sun rises and sets from east to west throughout the day, the collection nudges with it to maintain sunlight concentrated on the receivers.

A trough's parabolic design allows it to concentrate light from the sun between 30 to 100 times its typical brightness (concentration proportion) on the recipient pipes, which is situated all along trough's central axis, resulting in operation conditions of over 750°F.

Linear Fresnel reflectors

Mirrored (reflectors) focus sunlight onto a receivers situated well above reflections in linear Fresnel reflector (LFR) devices, which are identical to parabolic trough processes. These mirrors make use of the Fresnel lens impact, that allows for a big apertures with small focal length focusing mirror. These systems have the ability to concentrate the sun's energy to 30 times its regular brightness. Compact linear Fresnel reflectors (CLFR), also known as concentrating linear Fresnel reflections, are a form of LFR technologies has enabled several absorption near the lenses. Several receptions enable the reflectors to vary their slant to reduce the amount of sunlight that they obstruct for nearby reflectors. This location enhances system performance while lowering material and expense needs.

II. LITERATURE REVIEW

M. Karvinkoppa, S. Sanap, and S. P. Digole (2020) [1] The current study uses an analytical model to calculate the spiral receiver's outlet temperature for nine different mirrors. In investigating the change in thermal performance of fluid and temperature inside the recipient, a focusing attention central receiver system designed, assembled, and report findings an exterior receiver. The outlet temperature of water was determined using a steady-state numerical simulation using ANSYS Fluent. Obtained measurements are used to validate CFD results. The fluid temperature relies on the amount of heliostats and the mass circulate rate. At solar noon, nine heliostats with a mass circulation rate of 0.0016 Kg/sec achieve a highest temperature of 92.4 C, with a mean temperature of 84.4 C for the entire day. The spiral coil tube's heat transfer coefficient and pressure loss are 1.44 and 1.97 times greater than the straight tube's, respectively.

Maytorena, V.M., et al (2021 [2]) A numerical investigation of direct steam initiation, excessive heat, and overall deflections on a delegate tube of an exterior solar receiver is introduced in this report. On the recipient, a non-uniform allocation of solar heat flux was regarded. The temperature field, volumetric vapour fraction allocation, and steam performance of sub-cooled boiling and direct steam initiated were studied. The system can achieve steam with a quality of 0.113 percent in this arrangement. The internally and externally temperature areas of the tube's walls were used as boundary conditions to develop the computer modeling. Experimental results was used to validate mathematical methods and techniques for straightforward steam generation, temperature levels, and deflections. Through use of clips was suggested because the base case had a high deformation (78.63 cm). Aside from that, the amount, dimensions, and placement of the clips were all put to the test. It was discovered that by placing clips at various locations all along tube, deflections can be whittled down by 99.1%.

Zhenghua Rao et al. (2021) [3] The permitted energy heat flux of a supercritical Carbon dioxide coiled tube recipient is guesstimated using a receiver's service life model depending on simulations of temperature, stress, and creep-fatigue malfunction. The permitted flux concentrations are 138.8 and 172.5 kW/m2 once solar energy lands on the coiled tube with an absorption spectrum of 1.0 and 0.6, in both, whereas the permitted energy flux density is 163.80 kW/m2 when constantly exposed to a uniform flux distribution. As a result, receivers can handle a higher energy density. This research provides design guidelines for the safe operation of evolving supercritical CO2 solar recipients at high temperatures.

Meige Zheng et al (2020) [4] Utilizing energy and exergy assessment, this paper compares a variety of heat transfer fluids while varying tube diameter, tube wall thickness, and tube-bank flow configuration. The model optimises exergy efficiency by ignoring the thermal stresses, circumferential tube temperature variations, and cost while assuming uniform flux. Based on a realistic configuration of an applicable thermal energy storage and power block, suitable pressure and temperature conditions are chosen for each fluid (PB). Molten salt (60 percent NaNO3, 40 percent KNO3), liquid sodium, supercritical carbon dioxide (sCO2), air, and water/steam are the heat transfer fluids studied. The liquid sodium at an elevated temperature range (540–740 C) performed best, with a solar-to-fluid exergy efficiency of 61 percent.

MessaoudHazmoune et al (2020) [5] The impact of several 3D geometric notions on the temperature evolution and acceleration of the operating fluid at the recipient is explored in depth in order to gain a more efficient design. A new receiver tube to helical fins is suggested, with the goal of improving heat transfer exterior and thermal capacity. To evaluate the results of the designed solar tower transceiver, numerical simulations calculations were carried out in ANSYS CFX (CFD). In this case, an unstructured mesh engendered by a computation machine and a (k-") turbulence model are used. The findings demonstrate that tubes with helical fins for solar tower recipients start increasing the outlet temperature significantly, reaching up to 1050 K.

Madjid Sarvghad 2018 [6] In order to generate power at competitively reduced costs, the next generation of CSP plants require increased efficiency. A key factor to achieve this goal is to increase the operational temperature of the system to the thermodynamically optimum temperature of around 700 °C. In this paper, an overview of the main sections of a suggested CSP plant designed to operate at temperatures from 550 to 700 °C has been provided and discussed with a focus on the compatibility of the structural materials used to construct the plant. A review of the degradation mechanisms that threaten structural alloys at elevated temperatures was discussed in detail. Fig. 5 shows a summary of the mentioned issues that are likely to arise in receiver, storage and power generator sections of the plant. Thermal fatigue and creep are quite common for materials at high temperatures and expected to potentially occur in this system..

U. Pelay et al. (2017) [7] A review of TES (thermal energy storage) systems used in Concentrated Solar Power plants is presented in this work. The state-of-the-art on CSP facilities across the world, as well as the pattern of advancement, are mentioned, as are technological solutions of TES systems for applications requiring high temperature (200–1000°C), with something like a concentrate on thermo - chemical storage, and battery conceptual frameworks for their assimilation in Concentrated Solar Power plants. For further over 70% of innovative CSP plants, TES systems are a must-have option. Thermal energy storage innovation is the most widely used in operational CSP plants due to its reliability, low cost, ease of implementation, and large availability of adequate exploratory feedback. The energy content of latent and thermo - chemical stockpiling innovations is much higher, so they may well have a bright depth of field. Innovative TES interoperability notions, such as coupled advanced technologies for increased operating temperatures and cascade Thermal Energy Storage of modular design storage containers for intellectual control of temperature, are also suggested. This overview paper's major contributions are a thorough examination of CSP plants, their TES systems, options to boost heat and/or mass transactions, and various new ideas for TES systems development.

Ya-Ling He et.al (2019) [8] The non-uniform flux characteristics in multiple CSP advancements, such as the parabolic-trough collector, linear Fresnel collector, solar power tower, and parabolic-dish collector, are described in this article. The obstacles of material degeneration, thermal stress and deflection, and overburning are discussed. The suggestions to tackle these problems are thoroughly examined, and a suggestion for solar collector enhancement is made based on this examination, which is that the solar flux distribution and the heat exchange capacity of the heat exchanger (HEF) should be just as close as possible. Existing approaches are categorized into two parts from this perspective. The passive method includes optimising the heat transfer capability of the HTF to match the flux distribution. The effective process, on the other hand, involves homogenising the flux distribution to complement the HTF's equivalent heat transfer ability. This overview can assist in gaining a greater understanding of the non-uniform solar flux characteristics in CSPs, as well as providing guidance on how to overcome the difficulties associated with them.

III. METHODOLOGY

The single centimeter billboard, which uses a particular panel of relatively homogenous radius, concurrent pipelines, is the simplest advertisements layout. In this design, the circulation rate across each pipe is uniform. Because all of the fluids have combined, the HTF (Heat transfer fluid) resignation temperature in the pivotal piping systems must be much higher than that of the exterior tubes in order to attain a significantly increased intensity and temperature. Heat strains occur when the recipient's surface temperature is higher than the water temperature. Employing circulation control gadgets or changing pipe geometry to supplement heat transfer on each pipe could serve to minimize this.

For the recipient's body, the overall energy maintained equation

$$Q_{receiver} = Q_{abs} + Q_{loss}$$

$$Q_{loss} = Q_{conv} + Q_{radiation} + Q_{reflection} + Q_{conduction}$$

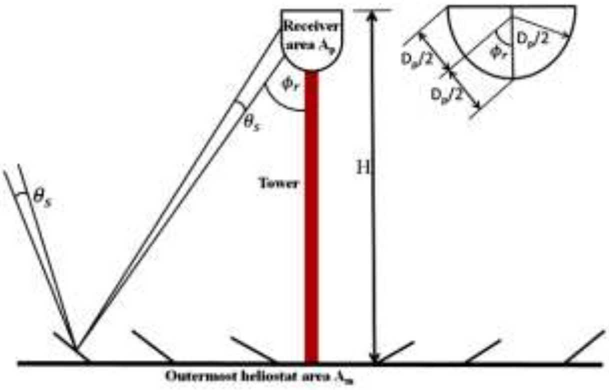


Figure 2 Central Power receiver System

Taking the energy balance on the absorber, the useful het gain rate:

$$q_u = I_b\left[\sum_{j=1}^{N} r_{bj}\right]\rho.\tau.\alpha.A_m - U_l.A_p\left(T_{pm} - T_a\right)$$

Average tilt factor,

$$(r_b)_{av} = \frac{1}{N}\sum_{j=1}^{N} r_{bj}$$

For the receiver tube of the linearly polarized via concentrator, the computational fluid dynamics assessment is conducted utilisingAnsys fluent. This same variables for the input have indeed been begun taking from the assignment. This algorithmic assessment is carried out using continuity equation such as the following equations, constant acceleration, energy calculations, K equation, and symmetries. In most cases, CFD doesn't really replace traditional measured data, but it can substantially decrease the amount of experimenting and total cost. Although it is hard to manage equipment and resources, CFD software is mobile, simple for using, and alter. It can be beneficial to be using CFD placed above a white conventional experimental-based assessments because insents have such an expenditure straightforwardly dependent on the quantity of combinations preferred ring, with exception of CFD, which can generate large quantities of findings for validation at no additional cost. Even before contrasted to experimentations, numerical simulations to optimise machinery are navnensive including CFD..

Flow Velocity: At an intake manifold, mass transfer conditions is often choose to start providing a specified flow rate as well as flux allocation. As a result of the mass flux, the overall force can change in responding to the internal solution. The mass transfer inlet, on the other hand, works for both immiscible and pliable flows. Convergence is more challenging in this case than in the case of the pneumatically inlet boundary circumstance. In incompressible fluid, mass flow inlets are unnecessary because velocity inlet boundary conditions will fix the mass flow if the concentration remains unchanged. By clarifying the streamlines aside from the solution space, a mass flow nozzle contour could also be utilised as an outflow.

The fundamental (low only) mass flow demarcation line for single stream ow border trying to operate as an outfall has the following constraints: this is only obtainable in the pneumatically simulation with both the combination and Eulerian mu designs. This is not accessible with both the Wet Sienm prototype in the concentration solution..

Acceleration inlet: To tasks can be completed the velocity distribution, speed inlet initial conditions are being used. n0t stream inlet and outlet, including all pertinent parameter characteristics of the stream. Therefore in scenario, the total area is not repaired, but it will start rising to whatever value is required to provide all the given a prescription velocity profile (in reaction to the calculating static pressure). Immiscible and pliable lows are both affected by this Parameter. A speed inlet could be used to reduce zero acceleration at low exit points in a variety of situations (The scalar inputs are not utilised in such instances.) In those kind of instances, you should guarantee that now the website domain as a whole consistency is sustained.

Force Inlet: The pressure difference at flow inlet and outlet, as well as all other scalar characteristics of the stream, are defined by pneumatically inlet boundary layer. This criterion necessitates the use of Pressure Gauge insight. The Static Pressure as well as Inlet Speed will be calculated by Fluent. Contingent on the interior remedy and the stipulated flow direction, the mass flux through the edge will fluctuate. They can be used to calculate both immiscible and moldable flows. Whenever the flow rates isrecognised however the flow velocity and/or acceleration are unknown, pneumatically inlet constraints can be utilised. This scenario can occur in a variety of circumstances, which include neutrally buoyant flows. In an exterior or unreinforced flow, pressure inlet boundary conditions can also be utilised to describe a "free" border. For an incompressible viscous fluid, the overall pressure is

$$P = P_s + \frac{1}{2}\rho|\bar{v}|^2$$

$$P_o = P_s\left[1 + \frac{\gamma - 1}{2}M^2\right]^{\frac{\gamma}{\gamma-1}}$$

The configuration of a static pressure at the exhaust boundary is required by pressure outlet boundary conditions. While the flow is subsonic, the value of the specific static pressure is Ju. If the circulation becomes supersonic locally, the pressure will no longer be used; instead, pressure will be extrapolated from the flow specified pressure. The interior is used to extrapolate all other flow quantities. Should the flow opposite direction at the pressure backflow" condition Boundary during the solution process, a collection of "conditions" is also clarified. If users explicitly state if we specify realistic values for the backflow quantities, convergence difficulties will be minimized.

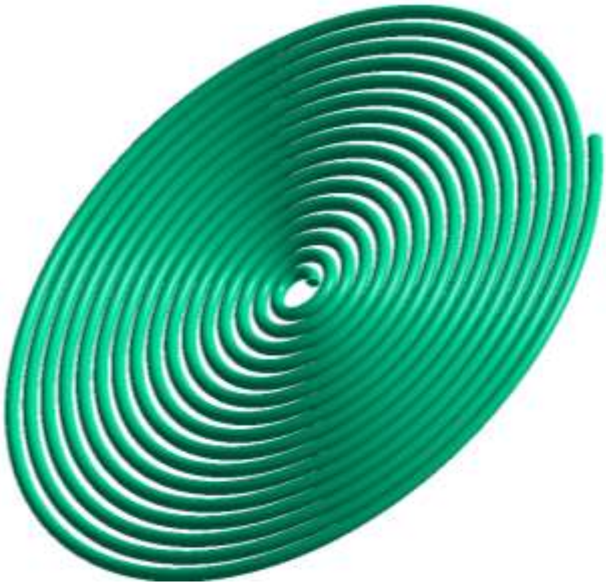


Figure 3 CAD model of the spiral solar receiver system

Mesh is a significant function wherein CAD configuration is divided into large nodes and elements and the process to convert into small pieces or elements is called mesh. That after three-dimensional CAD configuration of the circular central solar receiver system is completed, it is shipped for meshing. The total number of elements in the current work is 564408. The shapes of the elements used are hexahedral.

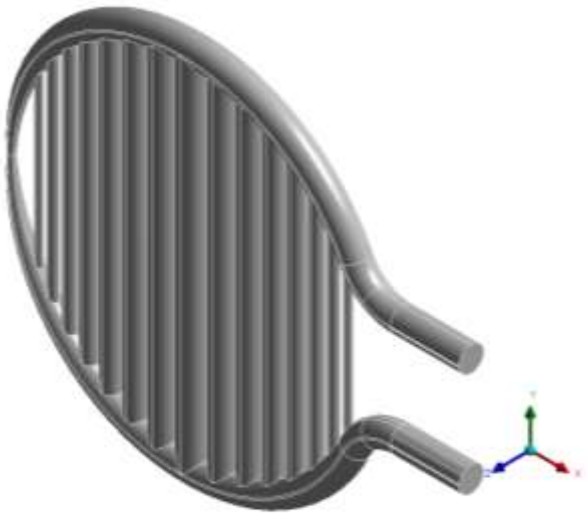


Figure 4 CAD model of the circular central solar receiver system

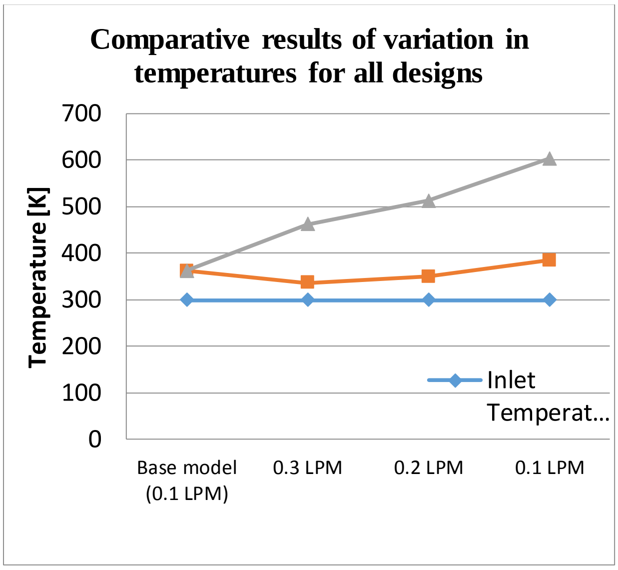
Mesh is a significant function wherein CAD configuration is partitioned into large nodes in the network and aspects and the methodology to transform into small pieces or elements is called mesh. After the three-dimensional CAD geometry of the circular central solar receiver system is completed, it is imported for meshing. The total number of elements in the current work is 1644769. Tetrahedral elements are the ones that are used.

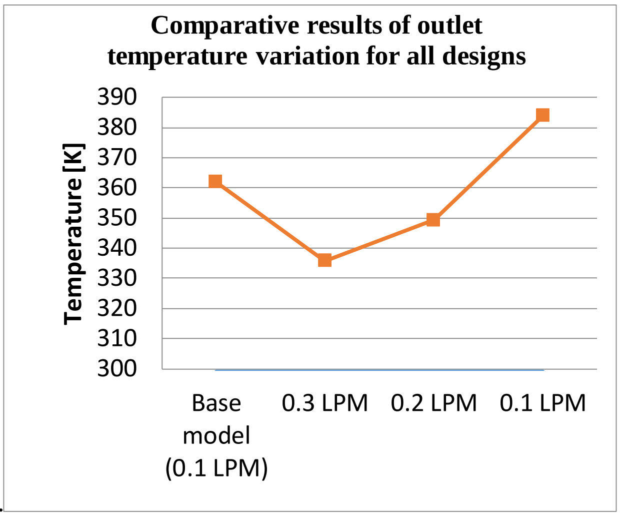
IV. Result And Discussion

The main goal of this project is to create a new billboard-style central circular solar receiver with variable header and tube diameter. The current study uses an analytical model to calculate the spiral receiver's outlet temperature for nine different mirrors. To determine the water's outlet temperature, a steady-state numerical simulation was performed using ANSYS Fluent. After the base models were validated, a new design of central solar receiver was created that performs CFD analysis with the same boundary conditions.

The flow rate is variable in all different pipes of the central solar receiver, which caused an increase in temperature and is strongly dependent on the flow rate of the heat transfer fluid, as shown in the above figure of Stream function at 0.1 LPM for the new design of the central solar receiver. Figure depicts a stream function with a maximum fluid velocity of 0.0148 m/sec.

S. No.	Mass flow rate	Inlet Temperature	Outlet Temperature	Maximum Temperature	Temperature Increases at outlet	% Variation
1	Base model (0.1 LPM)	299 K	362 K	362 K	63.0	21.07
2	0.3 LPM	299 K	335.8 K	461.2 K	36.8	12.31
3	0.2 LPM	299 K	349.3 K	512 K	50.3	16.82
	0.1 LPM	299 K	383.9 K	603.3 K	84.9	28.39





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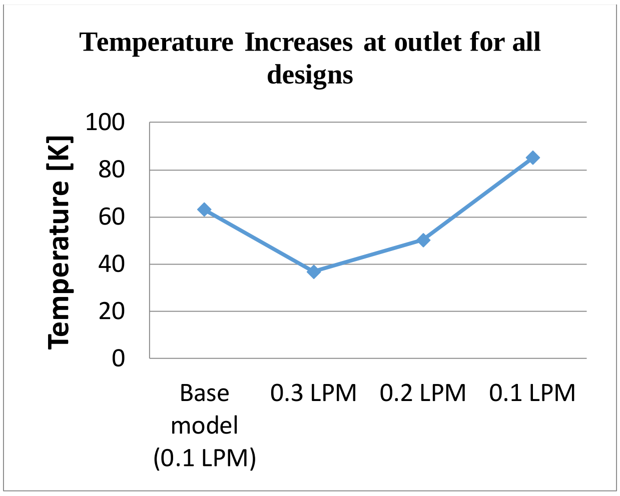

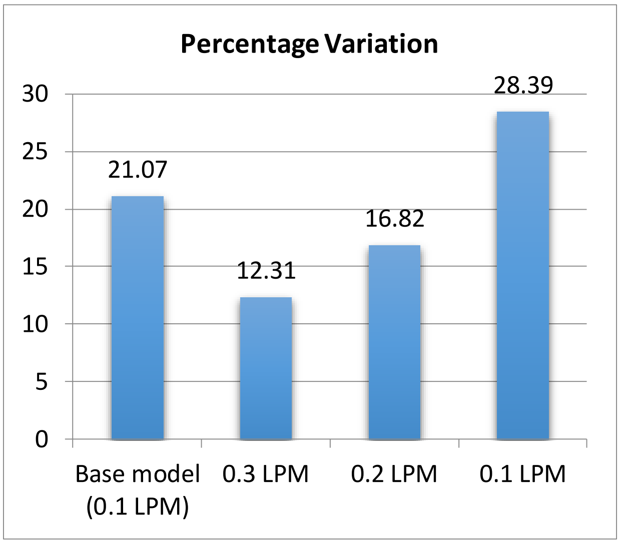

V. Conclusion

The variation of the fluid temperature in spiral central receiver and proposed new design of circular central solar receiver with variable pipe diameter have been simulated using computational fluid dynamics analysis using ANSYS fluent. There are following conclusion having been drawn from the above analysis.

- ❖ After performing computational fluid dynamics analysis on base design as spiral central receiver at 0.1 LPM, The maximum temperature of 362K is achieved at the outlet where temperature increases at outlet 63.0 degree from inlet temperature of 299 K with variation of 21.07% and the velocity of heat transfer fluid is 0.153 m/sec.
- ❖ After performing computational fluid dynamics analysis on new design of the central solar receiver at 0.3 LPM, The maximum temperature of 335.8 K is achieved at the outlet where temperature increases at outlet 36.8 degree from inlet temperature of 299 K with variation of 12.31%.
- ❖ After performing computational fluid dynamics analysis on new design of the central solar receiver at 0.2 LPM, The maximum temperature of 349.3 K is achieved at the outlet where temperature increases at outlet 50.3 degree from inlet temperature of 299 K with variation of 16.82%.
- ❖ After performing computational fluid dynamics analysis on new design of the central solar receiver at 0.1 LPM, The maximum temperature of 383.9 K is achieved at the outlet where temperature increases at outlet 84.9 degree from inlet temperature of 299 K with variation of 28.39%.

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