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# Modeling, simulation and performance analysis of porous disc receiver for solar parabolic trough collector

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**Abstract:** This paper presents and discusses the enhancement of heat transfer through a porous disc receiver for parabolic trough concentrator. To evaluate the performance of the receiver, a three dimensional numerical model of the porous disc line receiver has been developed for parabolic trough collector. The influence of important parameters like the concentration of solar radiation and thermic fluid properties on overall heat collection rate has been analysed. The analysis of this model is carried out based on renormalization-group (RNG) k-ε turbulent model associated with standard wall function by using Therminol-VP1 as working fluid. The performance of the receiver is investigated under various heat flux conditions. The heat transfer analysis of the receiver is carried out for the different orientation of the porous disc for different heat flux conditions and the results compared with that of the receiver without porous disc. It is observed that the receiver showed better heat transfer characteristics than that of the receiver without porous disc. The percentage increase in Nusselt number for the receiver is about 70% at Reynolds number of 31,845 as compared to tubular receiver. The experiment has revealed that the use of porous medium in tubular receiver enhances the system performance significantly.

***Keywords:*** *Solar Parabolic Trough Collector, Porous Disc Receiver, Modeling and Simulation*

## Introduction

A solar collector absorbs the solar energy, converts into useful thermal energy and transfers to the fluid which flows through the tubes. The solar collectors may be classified as follows:

Non-concentrating type

- Flat plate collector
- Evacuated tube collector Concentrating type
- Solar parabolic trough collector
- Linear fresnel reflector
- Parabolic dish system

In the non-concentrating type the collector area is same as that of the absorber area. On the other hand in the concentrating collectors the area intercepting the solar radiations is greater, sometimes even hundred times greater than the absorber area.

The solar parabolic trough collector (SPTC) consists of a parabolic-shaped reflector, which focuses the solar radiation on the line receiver located at its focal point. The collector tracks the sun to ensure that the solar radiation exactly focuses on to the receiver. The fluid which is to be heated is made flow through the receiver to collect the heat. The parabolic trough focuses the sun at 30 to 100 times its normal intensity on receiver pipe located along the focal line of the trough and the operating temperature of the system is about 400ºC. The SPTC system performance is mainly dependent on internal heat gain characteristics, heat loss from the surface, velocity of the fluid, and geometrical concentration ratio. The solar parabolic trough receiver influences the overall performance of the system.

Barra and Franceschi [1] analyzed the parabolic trough plant using black body receivers and concluded that the value of heat transfer coefficients increase when the flow rate increases. Clark JA. [2] has carried out the performance of a parabolic trough concentrator and observed that the factors such as spectral-directional reflectivity of the mirror system, mirror receiver tube intercept factor, the incident angle modifier and product of absorptivity-transmissivity of the receiver tube and cover tube. It has been concluded that these parameters play a major role in the design and manufacturing of solar parabolic trough concentrator. Tandiroglu [3] has investigated the effect of flow geometry parameters on transient entropy generation for turbulent flow in a circular tube with baffle inserts and concluded that the time averaged entropy generation is a function of Reynolds number and the other flow geometry parameters such as pitch to diameter ratio (H/D), baffle orientation angle (β), ratio of smooth to baffled cross-section area (So/Sa) and ratio of tube length to baffle spacing (L/H). Reddy[4] has analyzed the energy efficient receiver for solar parabolic trough concentrator and carried out the performance analysis of the receiver for different fin aspect ratio and fin thickness for porosity 0.37 at different heat flux conditions.

Kang-Hoon Ko and N.K.Anand [5] have experimentally investigated the use of porous baffles to enhance the heat transfer and found that the heat transfer enhancement was as high as 300% compared to that of in straight channels with no baffles. G.J.Hwang and C.H.Chao [6] have carried out the heat transfer measurement and analysis and found that the predicted fully developed Nusselt numbers are in good agreement with the measured values. K. Ravi Kumar and K.S. Reddy [7] have carried out three dimensional numerical analysis of the porous disc line receiver for solar parabolic trough collector. It has been observed that the enhancement of heat transfer characteristic about 64.3% in terms of Nusselt number with a pressure drop of 457 Pa against the tubular receiver and conluded that The use of porous medium in tubular solar receiver enhances the system performance significantly. Seyed Ebrahim Ghasemi et al.[9] have carried out three dimensional numerical analysis of heat transfer characteristics of solar parabolic collector with two segmental rings and found that the use of segmental rings in tubular solar absorber enhances the heat transfer characteristics of solar parabolic collector and also the heat transfer coefficient can be increased by decreasing the distance between two segmental rings.

Fig. 1: Solar parabolic trough with porous receiver

TABLE I. PROPERTIES OF WORKING FLUID AND POROUS DISC RECEIVER

| **Property** | **Heat Transfer Fluid** ***Therminol VP 1*** | **Porous Disc Receiver** ***Silicon Carbide*** |
|---|---|---|
| Density (kg/m$^3$) | 938 | 3210 |
| Specific heat (J/kg-K) | 1970 | 750 |
| Viscosity (N-s/m$^2$) | 0.000486 | - |
| Thermal conductivity (W/m-K) | 0.118 | 120 |

TABLE II. GEOMETRICAL PARAMETERS OF THE POROUS DISC RECEIVER

| **Parameter** | **Porous Disc Receiver** |
|---|---|
| Length of the receiver (mm) | 2000 |
| Thickness of the porous disc (mm) | 4 |
| Inside diameter of the receiver (mm) | 66 |
| Outside diameter of the receiver (mm) | 70 |
| Glass cover diameter (mm) | 100 |
| Distance between two consecutive porous discs (mm) | 1di |
| Reflectivity of the mirror | 0.95 |
| Transmissivity of the glass cover | 0.95 |
| Absorptivity of the receiver | 0.9 |
| Intercept factor | 0.9 |

## Modeling and Analysis of Porous Disc Receiver

A thermal model is proposed of a porous disc receiver for solar parabolic trough collector as shown in Fig. 1. The solar radiation falling on the parabolic concentrator is focused on to a line receiver by parabolic. The concentrated solar radiation is then transmitted to the working fluid which flows through the tubular receiver. The high boiling working fluid of Therminol oil VP1is used as the heat transfer fluid. The receiver is made of silicon-carbide and enclosed by a glass envelope to reduce the heat losses to the surroundings. The performance of the circular line receiver can be improved by increasing internal area and heat transfer rate. This can be achieved by incorporating porous disc inside the circular line receiver. The solid or porous surfaces/inserts in the receiver pipe can be installed by casting, gluing with thermal epoxy, joining, etc., The porous discs are placed in two halves of the circular tubes by gluing with thermal epoxy separately and welded together to give the shape of the circular receiver.

The solar gain and heat loss characteristic of the receiver were analysed under steady state condition. The porous medium is a matrix permeated by a porous medium network of pores filled with a fluid. The heat transfer co-efficient of the receiver is increased by inserting porous medium. The increase in convective heat transfer co-efficient due to the porous medium is caused by (i) producing a thinner hydrodynamic boundary layer, which produces low thermal resistance, (ii) enhancing the mixing of the fluid and (iii) increasing the fluid effective thermal conductivity. However, inserting the porous medium increases the pressure drop within the receiver that in turn increase the operating cost of the pump.

For the numerical simulation, the flow is considered as hydro dynamically developed and thermally developing flow. The properties of the working fluid and absorber material are assumed constant. The thermo-physical properties and geometrical parameters of the receiver are illustrated in tables 1 and 2 respectively.

The governing equations were solved using finite volume method by segregated implicit solver with first order formulation with CFD commercial software FLUENT - 6.3. The segregated solver solves conservation governing equations independently, and it is applicable for the incompressible flow. The geometrical model is created using commercial software PRO-E and meshed using ICEM-CFD with a quadrilateral cell. The triangular mesh is used for the inlet and outlet faces, whereas the hybrid/tetragonal mesh are used for volume mesh.

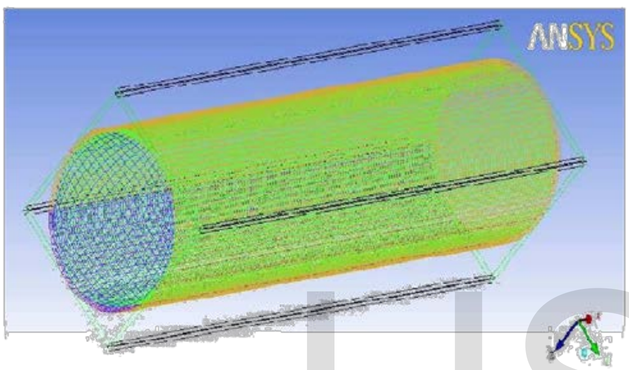

Fig. 1. Meshed Receiver without Disc

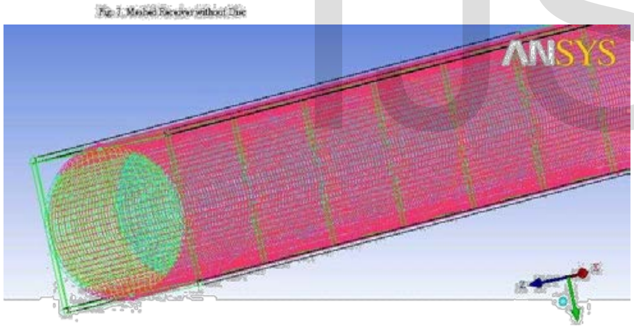

Fig. [illegible]: Meshed Receiver with Porous Disc

A 3-D steady state turbulent RNG k-ε model with standard wall functions was used for simulation of forced convection of the receiver .This RNG model is expected to yield improved prediction of near wall flows, separated flows and in curved geometries such as tubular and intricate surfaces. The RNG turbulent model is more responsive to the effects of rapid strain and streamlines curvature, flow separation, reattachment and recirculation than the standard k-ε model .The RNG k-ε model gives the best predictions of all the two-equation models as far as the velocity field. The turbulence kinetic energy and the recirculation length are concerned. The RNG derived k-ε model gave very good predictions for a pipe with sudden expansion especially when non-equilibrium wall-functions were implemented. Therefore RNG k-ε turbulent model is adapted for the parabolic trough receiver system.

## Results & Discussion

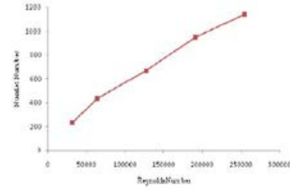
Fig 2 Variation of Nusslet Number with Reynolds Number for Tubular Receiver

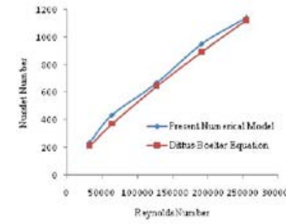

Fig. 3: Comparison of the present model with the Dittus-Boelter Correlation for Tubular Receiver

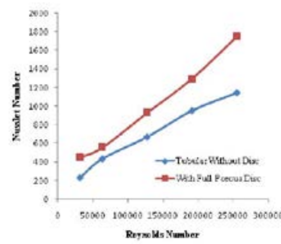

Fig 4: Effect of Porous discs on Nusslet number in the receiver

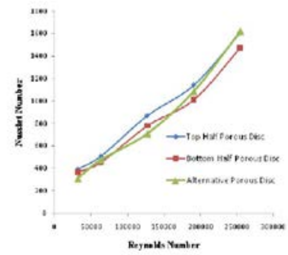

Fig. 5: Effect of orientation of Porous discs on Nusslet number

Numerical simulation was carried out for a solar parabolic trough tubular receiver with uniform heat flux which is applied over the entire surface of the receiver. The Nusslet number obtained from the present numerical code has been validated with the standard empirical correlations for steady state, fully developed, turbulent flow convection heat transfer in circular tubes and the following parameters have been analysed:

(a) Variation of Nusslet number with respect to the Reynolds number.

(b) Effect of orientation of porous disc on Nusslet number.

The data obtained from the numerical simulation has been validated with the well-known model, the Dittus-Boelter correlation, and is given as:

Nusselt number, Nu = 0.023 Re0.8 ×Pr 0.4

Reynolds number, R e = ρ u di/μ
Prandtl number, Pr = μCp/λe

Where, □ is the density of the fluid in kg/ m3; u is the velocity of fluid in m/s; di is the internal diameter in m; □ is the d ynamic viscosity in N-s/m2; Cp is the specific heat of fluid in kJ/kg K.

The variation of Nusslet number with respect to Reynolds number is shown in Fig. 2. The Nusslet number increases almost linearly with the Reynolds number. The comparison of the present numerical model with the Dittus-Boelter model in terms of Nu is shown in Fig.3. The model is in reasonable agreement with Dittus-Boelter equation and deviates only 7.5% for all velocities. The heat transfer is augmented in porous disc receiver compared to that of the tubular receiver.

## Conclusion

A numerical model was proposed to evaluate the heat transfer characteristics of a solar parabolic trough receiver by introducing porous discs. The porous disc in the receiver improves the receiver heat transfer characteristics with a pressure drop as penalty. The heat transfer was augmented in all receivers due to increase in heat transfer area, thermal conductivity and turbulence. The maximum heat transfer coefficient is achieved in top half porous disc receiver with reasonable drag. The percentage increase in Nusslet number for the receiver is about 70% at Reynolds number of 31,845 as compared to tubular receiver

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