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Thermal Performance enhancement of absorber tube of Parabolic Trough in direct steam generation using passive methods

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ABSTRACT:

Harnessing the solar energy has been widely accepted and been more popular amongst all the available renewable energy sources. Different collectors operate in different range of temperatures such as Low temperature: flat plate 30–80 °C, evacuated tube 50–200 °C & compound parabolic collector 60–240 °C, Medium temperature: cylindrical trough 60–300 °C, linear Fresnel reflector 60–250 °C, parabolic trough 60–400 °C and high temperature collectors: parabolic dish reflector 100–1500 °C, heliostat field collector 150–2000 °C. The direct steam generation technology based on Parabolic trough is most economical, environmentally friendly, suitable for vide temperature and pressure range, medium temperature application worldwide. It is being widely used for 50°C to 400°C. The optical efficiency greatly depends on the material property such as absorptance-emittance of receiver, reflectance of mirror, intercept factor, transmittance of glass cover, geometry factor and angle of incidence. The thermal efficiency is majorly depending on overall loss coefficient which encompasses all conduction, convection, and radiation losses. Conduction losses depend on the structure of the element. Convection and radiation losses can be reduced using glass evacuated tubes and selective surface coatings on the receiver. The Heat Collection Element (HCE) is the prime important component of the system. Non-Uniform heat flux around the perimeter poses uneven thermal stress and operational challenges. In order to reduce the instability and temperature induced stress, here has been tremendous efforts, by way of testing the different types material for of HCE, different designs of HCE , heat transfer enhancements used within the HCE, such as inserts, rings, springs, metal foam, porous disc , indentation on HCE, vortex on the HCE, internal threading or grooving on the HCE, external fins with HCE, different coating materials, are rapidly taking place in this technology, to make it more economical , viable, stress free and improve heat transfer efficiency. The work here discusses the advances in the passive methods with varying heat flux across perimeter in Direct steam Generation in Concentrated solar thermal Power for last two decades.

Keywords:*Direct Steam Generation, Heat collection element, parabolic trough, heat transfer enhancement.*

I. INTRODUCTION

Concentrating solar power (CSP) systems utilize direct beam radiation and combinations of mirrors or lenses to concentrate it. Useful energy is produced in the form of Hot water for process application, steam for process and turbine input to convert it to electricity. Concentrating Solar Power include both concentrating solar thermal (CST) and concentrating photovoltaic (CPV) energy conversion. The CSP consists of three sub systems, solar radiation Concentrator, receiver and power conversion systems.

There are four CSP families depending on the method of concentration and configuration as follows,

1. Parabolic trough collector (PTC)
2. Linear Fresnel lenses (LFR)
3. Paraboloidal dish
4. Central receiver tower (Heliostat)

The temperature and process requirements, availability of area and application are key factors selecting the technology.

Table 1 Comparison of the four CSP families(1)

CSP technology	**Parabolic trough**	**Central receiver**	**Linear Fresnel**	**Dish**
Solar collector Focus	Line	Point	Line	Point
Solar receiver	Mobile	Fixed	Fixed	Mobile
Power conversion cycle	RC , CC	RC , CC , BC	RC	RC , SC
Concentration ratio	70–80	> 1000	> 60	> 1300
Solar field slope (%)	<1-2	<2-4	<4	10 or more
Working temperature(°C)	Medium	Higher	Relatively lower	Highest
Current efficiency (%)	15–16	16-17	8-10	20-25
Plant peak efficiency (%)	14-20	23-35	18	30
Typical capacity (MW)	10-300	10-200	10-200	0.01-0.025
Annual capacity factor (%)	25–28 (without storage)	55(with 10 h storage)	22–24 (without storage)	25–28 (without storage)

As per

Fig.1, in the Parabolic trough collector (PTC) the incoming solar radiation is concentrated on the bottom periphery of the tube receiver placed on the focus of the collector, and then the concentrated solar radiation is converted to heat by the heat transfer fluid (HTF) flowing through the tube receiver. The tube receiver is enclosed by a glass envelope to reduce the heat losses to the surroundings.

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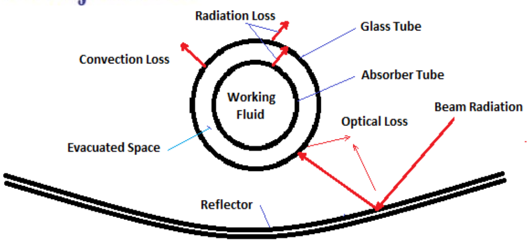

Fig.1 Solar Parabolic trough collector configuration with different types of losses.

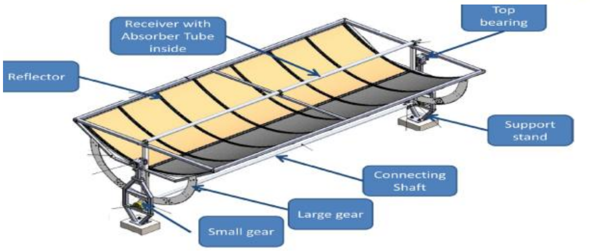

Fig.2 Schematic Diagram of Parabolic Trough Collector (PTC) (3)

Parabolic trough collector: General Parameters affecting the performance

1. Solar field Location:
2. Wind load, tracking and structure
3. Parabolic trough optics: Rim angle
4. The glass tube size and vacuum type.

Geographic location of the parabolic trough installation in the equator region or closed to tropic of cancer and Capricorn will receive higher direct beam radiation. (1) The convective losses in the high wind speed region will be more. The

Fig.2 indicates all the parts of the parabolic trough collector. The absorber tube is supported to provide it a Structural stability from the PTC torque to prevent sagging of it due to mass of fluid, wind load and self-weight. East-west direction tracking of collector by aligning the trough in north-south axis will yield maximum energy in summer than winter and the opposite happens while E-W axis alignment and tracking in N-S direction. The primary reflecting surface is either the mirror oraluminum sheet. Rim angle is the angle between the centerline and rim of the collector. Larger the rim angle (90º) lesser the mean focal to reflector distance and vice a versa. The optimal angle suggested by researcher is 65º(2)

The glass tube geometry and the vacuum are affecting the performance of the parabolic trough. The Convection losses are in the range of 8-10%.(1)

System Efficiency:

The system efficiency is the product of optical and thermal efficiency.

Thermal Efficiency is the ratio of energy incident on the absorber to the energy carried away by the working fluid (excluding conduction, convection and radiation losses)several techniques are used to enhance the thermal efficiency by way of reducing the losses. Use of evacuated tubeto reduce convection losses and use of selective surface coating on receiver to reduce radiation losses by reducing emissivity. Researchers have carried out several experiments and numerical studies for enhancement of heat transfer inside the HCE are carried out.

In this paper critical analysis of the different passivemethods for effective heat absorption and dissipation

Using various inserts and surface modificationstheheat transfer is enhanced. Energy losses from the receiver component affect the output of parabolic trough solar collectors. It is important toexamine the impact of such losses on heat transfer andcollector thermal efficiency. Compared to previously published review articles the present work varies in objective, content and description.

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Table 2 Summary of passive enhancement techniques (S. Karsli a 2002) (3)

Passive techniques	Single phase	Two phase
Treated surfaces	C	A
Rough surfaces	A	A
Extended surfaces	A	B
Displaced enhancement devices	A	A
Swirl flow devices	A	A
Surface tension devices	N/A	A
Additives	B	B

A: Most significant; B: significant; C: somewhat significant

In passive methods no additional power is being used but the internal surface is modified or inserts are placed to disturb the flow. It includes the inserts inside the tube, modified tube profile.

Metal Inserts: Different types of twisted tapes, porous media, springs, hinges, fins, discs, foam have been used to investigate the heat transfer performance enhancement, and the results found are encouraging.

Twisted tape: The twisted tape is a metal strip which is twisted to form helix. The twisted tape is always slightly smaller in diameter then the diameter of the tube. (WOLVORINE TUBE n.d.) Numerousstudies have been taken up on the pressure drop and heat transfer enhancement due to twisted tape inserts in a single phase flow. (M.A. Akhavan-Behabadi 2009) There are very few studies on twisted tape inserts used in tubes having two phase flow, some literature available for the use of inserts with the refrigerants like R134a (Fabio Toshio Kanizawa 2012) The counter twisted tape performance is found to be better than co twisted tape. In general the heat transfer rates of both the inserts are 17.8–50% higher than singleAbsorber with twisted tapes (4) , twisted tape inserts (5), Louvered twisted tape,(6) helical inserts (7)and wavy inserts (8). No literature for the use of twisted tape inserts with the solar parabolic trough HCE is available.

Fig.3,

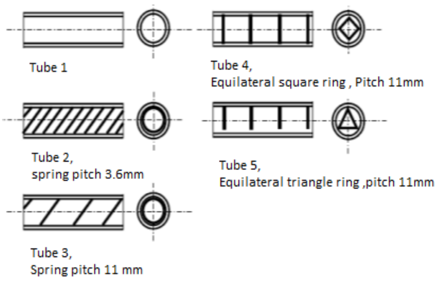

Fig.4, Fig.5are schematic view of twisted tape inside tube. As the twisted tapes are smaller than the tube diameter, they are in rather poor contact with the tube wall. In fact, there is a possibility that the large two-phase pressure drop may drive the insert out of the tube if it is not firmly fixed

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at the entrance. For two-phase flows in tubes with twisted tape inserts, the two-phase pressure drops are typically much larger than those of plain tubes and micro fin tubes and similar to those of corrugated tubes. No general method is available for predicting two-phase pressure drops in tubes with twisted tape inserts. This typically results in two-phase pressure drops twice as large as in the same tube without the tape. (WOLVORINE TUBE n.d.)

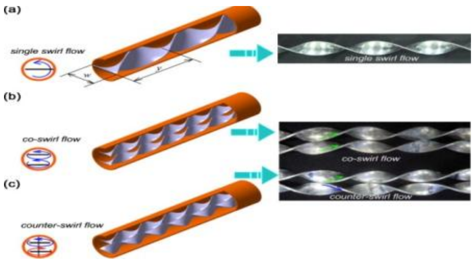

Fig.3 Twin twisted tapes (S. Eiamsa-ard 2010)

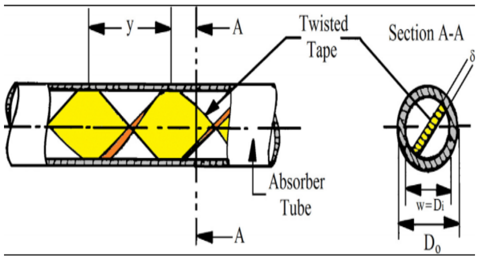

Fig.4 Twisted tape configuration (Ravi Kumar 2012)

Orifice plates or capillary structure

M. Eck has investigated heat transfer enhancement by capillary structures at the inner surface of the absorber tubes or displacers to improve the operation performance of the DSG process in PTC. Significant improvement in heat transfer in two phase flow has been proved using Lab-scale experiments especially for low mass fluxes.(9)(10)(11)(12)

Metal springs: Karsli(13)(Fig. 5)in his study has used springs or the equilateral rings of different cross section and pitch and its effects as internal surface modificationin forced convection boiling in a horizontal tube. Though this study is not done specific for the solar applications, but the results can be extended for the parabolic trough collector absorber tube heat transfer enhancement.

Porous Media: Kumar Reddy studied the effect of use of porous discs (
Fig.3) in the receiver; it shows that it improves the heat transfer characteristics of the receiver but 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 HTF used is Therminol VP1 (Kumar 2009). The use of porous disc with water is not studied.

But as known to all, the pressure drops always increased largely while the heat transfer is enhanced. Then the cost becomes the most important factor to determine whether the enhancement technology is adopted. (Z.D. Cheng 2012)

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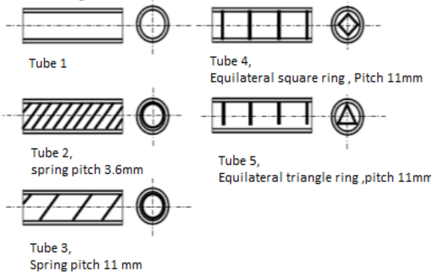

Fig.5 Longitudinal cross-section of the test tubes used in the experiments (13)

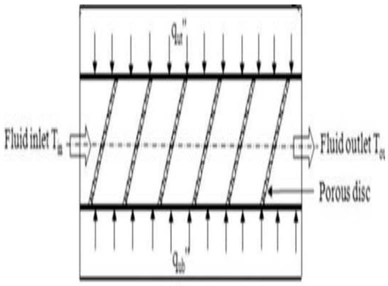

Fig.6 solar parabolic dish with porous receiver

Fig.7 porous media. (14)

Metal foam: Increase in Nusselt number is found in the investigation of placing metal foams in the absorber tube. Wang (P. Wang 2013) studied the application of porous media on enhancing heat transfer by (1) disturbing the boundary layer to decrease the thermal resistance; (2) increasing the intensity of turbulence to augment mixing of fluid; and (3) increasing the effective thermal conductivity of fluid due to the high area density and thermal conductivity of porous media. Wang has done Numerical study of heat transfer enhancement in the receiver tube of direct steam generation with parabolic trough by inserting metal foams in the absorber tubes in superheated section of DSG system. The use of metal foam which occupies different sections of the HCE is studied, 14% increase in efficiency is noted.

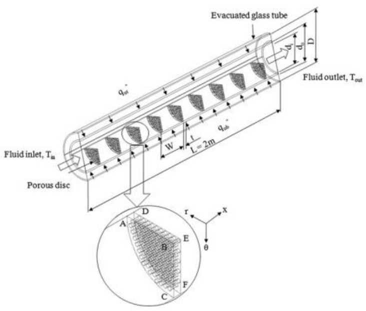

Fig. 8 Porous disc

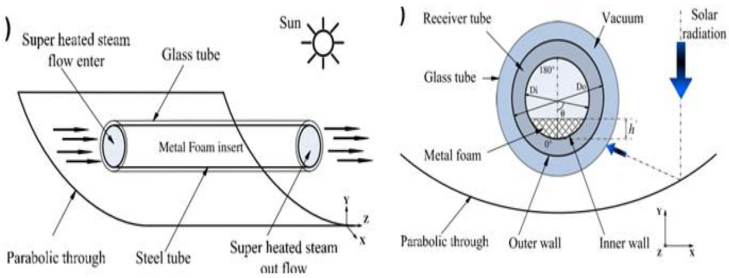

Fig. 9Absorber tube with internal hinged blades for solar parabolic trough collector. (15)

Angle of inclination: According to the theory and the results of lab scale experiments it is seen that the slight tilt of HCE has a positive influence on the thermo hydraulic behavior of the DSG process. Already a slight tilt of 4° as realized at the ninth collector of the DISS test facility will reduce the region of stratified flow in the flow pattern map considerably compared to a horizontal absorber tube. On the other hand the tilting causes a higher investment. The test procedure has been performed at a working pressure of 30, 60 and 100 bar (E. Z. M. Eck 2003).

Tube Geometry alterations: The regular circular HCE of the PTC is replaced by asymmetric outward convexcorrugated tube(16), internally finned tube, dimpled tubes, dimple - converging – divergingtubes and modified receiver with hinged blades and investigatedexperimentally or numerically for the performance. The altered geometry has shown increase in plant efficiency.

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Finned receiver tube: Munoz (Javier Muñoz 2011) analyzed internal helically finned tubes for parabolic trough design by CFD tools, The application of finned tubes to the design of parabolic trough collectors must take into account changes in the pressure losses, thermal losses and thermo- mechanical stress and thermal fatigue. It is a tradeoff between the increases in the pressure drop, parasitic power losses due to use of fins and helix angle vs. the increased heat transfer efficiency and the cost.

Patil and Reddy (Kumar 2009) investigated the solid finned receiver for solar parabolic trough collector to improve the performance of the receiver. Analysis was carried out to determine the heat transfer rate and pressure drop for different concentration ratio, fin aspect ratio.

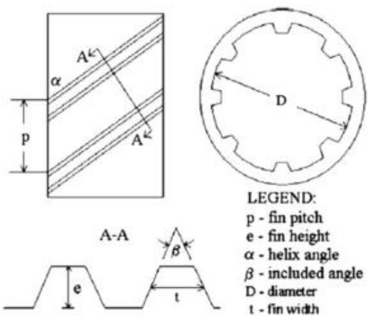

Fig.10 Geometric variables of the helical fin (17)

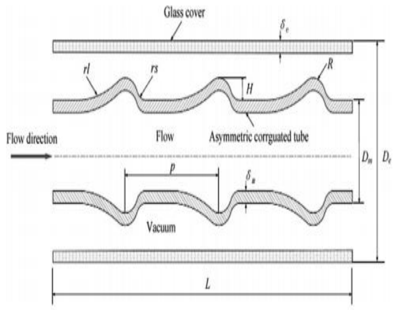

Fig.11 Schematic view of corrugated tube used (18)

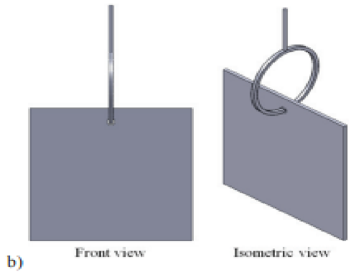

Fig.12 Absorber tube with internal Hinged Blades for solar PTC (Kalidasana B 2016)

Significant heat transfer is increased using the corrugated tubes. Configuration as per Fig.11.

Hinged bladesreceiver (Fig.13) Experiments demonstrated an increase of thermal efficiency by 9% more than conventional receiver.

Dimpled Tube or Longitudinal vortex generators

Investigation on dimpled tubes reveals that deep dimples perform better than shallow ones. Cheng (Z.D. Cheng 2012) have studied unilateral milt-longitudinal vortexes enhanced parabolic trough solar receiver (UMLVE-PTR) where LVGs are only located on the side of absorber tube with concentrated solar radiation and the longitudinal vortices are produced by the original heat transfer surface of the tube wall itself . The LVGs could be stamped by different discrete double-inclined stamping moulds, such as hemi-prism, semi-cylinder, semi-cylinder with hemispheroidal ends. The HTF used is Syltherm 800 oil can be extended to Water but the results are not available.

Dimpled -converging – diverging tubes were tested with water. An increase in thermal efficiency of just 4.5% was observed. (19)

Eccentricity of the tube receiver: Thermal stress analysis of eccentric tube receiver using concentrated solar radiation has been done by Fuqiang wang. It is found that the eccentric receiver whose center has been shifted upwards by 3mm the thermal stress has been reduced (Y. S. Fuqiang Wang 2010)

Fig.14 unilateral milt-longitudinal vortexes enhanced parabolic trough solar receiver (Z.D. Cheng 2012)

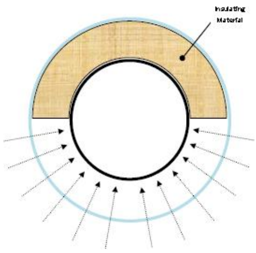

Fig.15 The HCE with the insulation (20)

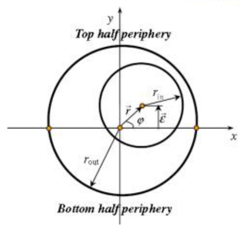

Fig.16 Schematic diagram of physical domain and coordinate system for the eccentric tube receiver

Use of insulation in the HCE annuli: Modified HCE with partial insulation inside the glass tube envelope and the HCE have been suggested by Hency and Obida (Al-ansary 2011).The system is non-evacuated type. The radiation losses from the insulated side arereduced, the presence of the insulating material prevents the natural convention currents developing from the other portion of the HCE. But use of insulation restricts some of the solar radiation reaching the collector , thermal conductivity of the insulation increases with the increase in the temperature reducing heat loss reduction benefit,

Use of Cavity Receiver: Black body cavityreceiver replaced regular tubular receiver to reduce the heat loss and enhance the optical & thermal efficiency. The 89.23%. Optical efficiency achieved by a triangular cavity receiverwith fins. Furtherinvestigations scope is there in Cavity receiver domain.

Use of Nano Fluids: Thermo physical heat transfer properties of the fluid are enhanced by adding the additives in Nano size. Here only water based Nano particle additions are considered. Extensive research using Nano fluids such as CuO/H_2O, TiO_2/H_2O, and Fe_3O_4/H_2O have been carried out.(21). Manikandan et. al. (22)in his study observed the hybrid nanofluid containing 1 wt% paraffin wax and 1 vol% sand nanoparticles resulted in enhancement in thermal conductivity by 9.6% and viscosity reduction by 18%.In the study for using the SWCHNs, there has been no significant variation in thermal efficiency has been observed for the first two hours of exposure to concentrated solar radiation and later 87%.(23). With the use of TiO_2 as additive the maximum overall efficiency is57% which is 9% higher than the base fluid(24)

II. CONCLUSION

This work briefs on all the techniques used in thermal performance enhancement of heat collection element of parabolic trough in direct steam generation. Summary of the review is given below.

It in an economical trade off while selecting the HCE material, coating material. The use of various passive methods for heat enhancement includes,porous discs, internal helical fins the metal foam, internal grooving, inserts, springs,threading,and longitudinalvortex. Adding any enhancers inside the tube certainly causes the uniformity in thermal gradient around HCE the circumference however it also increases the pressure drop and the pump power requirement to overcome the same. These methods improves and gives better performance, improved heat transfer efficiency, stability in the operation , lesser thermal stresses as the near uniform heat flux is possible. There are lots of opportunities in terms of material for HCE but the options are tried only on labscale models, no commercial direct steam generation power plant is based on any of these methods. The use of insulation in the annuli is improving the performance but blocking the sun radiation reaching the collector.

Nano fluids as HTF:Though the cost is the hindrance in penetration of the usage of it, it has an appreciable increase in thermal efficiency.

Cavity Receivers: Advantage is that these are far less prone to the Thermal distortion. Its performance is better than circular absorber with selective surface coating andvacuum enclosure.

Inserts:very few Passive inserts have been investigated for theirperformance PTC in DSG. This have shown promising results. Heat transfer performance using inserts the use of internal helically finned and internal finned tube, corrugated tube, dimple protrusion, convergent divergent tubes, have also been investigated for their heat transfer performance.

The research work review has shown the dominance of the cavity receiver and passive inserts in use for enhancementof thermal efficiency, over the use of Nano fluids as the cost is high. However there is a lot of scope in all the three domains for further work.

Future prospects for research in PTC models

This section e forth coming section high lights the gap highlights the scope for future research work in the Thermal performance improvement of the of PTC.

- Research in the field of cheaper, effective and high thermalconductivity nanofluids.
- Investigation of an optimal combination of nanofluids and inserts
- Feasibility of cavity receivers particularly with absorbers withoutselective surface coatings
- Inserts not yet analyzed for DSG but analyzed in heat exchangers can be investigated in absorbertube
- Modification of receiver surface area and profile such as dimpled tubes, internally finned tubes with different geometry of fins, convergent and divergent tubes and performance investigation
- Researching the possibility of multiple passive inserts in receiver tube.
- Investigation of nano HTF with cavity receivers and Performance investigation of inserts with cavity receivers.

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