Passive heat transfer augmentation techniques to enhance the performance of solar collectors.

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***Abstract*— Solar energy is the most promising, environmental friendly energy source and renewable to sustain the growing energy demand. Parabolic trough collector is a concentrating collector which concentrates the solar radiations to the focal axis of parabolic reflector where a receiver is placed. Concentrated solar radiation heat the HTF flowing through the receiver. In order to have better performance of the solar collector it is necessary that maximum amount of heat transferred to the heat transfer fluid. Hence heat transfer augmentation is one of the major domain in enhancing the performance of solar collector. The present paper gives a comprehensive literature on various heat augmentation techniques to enhance the performance of solar collectors.**

***Index Terms*— Heat transfer augmentation, solar collector, twisted tape, wire coil.**

I. INTRODUCTION

The demand of energy is increasing day by day and at the same time there is need of environment protection. Thus the attention of the researchers is to explore use of renewable sources of energy. [1] Solar energy is one of the most promising source that has great potential in future. Traditionally, non-concentrating collectors have good thermal performance at low temperatures but at higher temperatures it is difficult to achieve good thermal performance due to thermal losses from large dissipating area. Therefore concentrating collectors are used which has a small absorbing area and thus low heat losses. Presently parabolic trough collectors are successfully used in many countries worldwide. Primarily the performance of receiver of parabolic trough solar collector is mainly governed by the thermal losses and the heat transfer from the absorber to the heat transfer fluid. In order to have better performance of the solar collector it is necessary that maximum amount of heat is transferred to the heat transfer fluid which is passing through it. Hence heat transfer augmentation in parabolic trough collectors is one of the major concern. [2]. The present paper reviews various heat transfer augmentation techniques for performance improvement of the solar collector.

II. HEAT TRANSFER ENHANCEMENT BY USING TURBULATOR

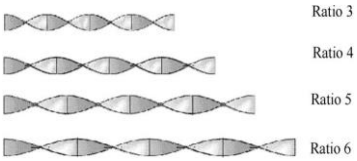
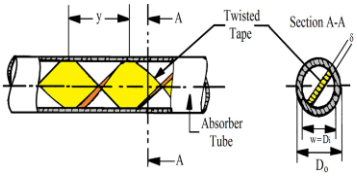
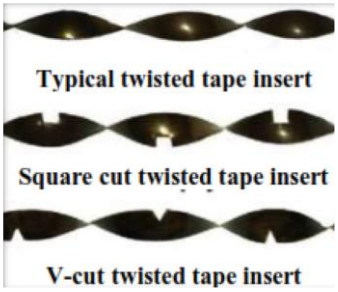
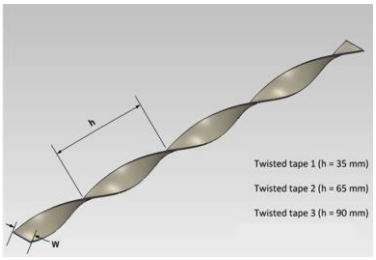
Heat transfer between a fluid and a solid surface can be increased by increasing the contact area by the use of extended surfaces which increases the heat transfer area and by creating turbulence in the fluid which is flowing through the conduit. The swirl flow devices create secondary recirculating flow causing betterment in radial and tangential turbulent fluctuations. The turbulence reduces the development of boundary layer thereby forming of secondary or swirl flow [3]. The usage of swirl causes a pressure drop which is largely due to the interaction between inertial and pressure forces within boundary layer. Due to the simple design and economic advantage as well as ease of use, some researchers have employed this method in solar thermal systems to achieve a higher thermal efficiency in comparison with conventional systems. [4] The type of working fluid also governs the type of geometrical modification to be made in the absorber assembly. If the working fluid is air or gas, which has very low convective heat transfer coefficient, the extended surfaces such as fins, corrugations are provided on the absorber plate. For water or liquid as the working fluid, twisted tapes, perforated tapes, wire coils inserts, dimples, baffle plates, metal foams, porous discs and internally finned tubes are provided to generate turbulence, which eventually increase heat transfer coefficient. However, the use of surface modifications and turbulence promoters results in an increased pressure drop, which ultimately increases the consumption of pumping power [5]. The various experimental and numerical analysis carried out for heat transfer enhancement by placing turbulators inside the receiver tube are discussed below. Main

emphasis is given to the most widely used turbulators such as twisted tape inserts, wire coil inserts, porous rings, dimpled tube, porous metal foam and internal fins.

II. TWISTED TAPE INSERT

Studies under taken by various researchers who have considered different forms of twisted tape turbulators are summarized in **Error! Reference source not found.**. Jaisankar et al. [6] investigated the heat transfer and friction factor characteristics for a thermosiphon solar collector .with helical twisted tapes and it was found out that heat transfer enhancement was better with twisted tape insert than the plain tube collector. It was observed that decreasing value of twist ratio led to increase in the heat transfer rate and pressure drop. From the study, it was concluded that the thermal performance of twisted tape collector with twist ratio (Y = 3) was better as compared to the other twist ratios. Experimental study was carried out by Saravanan et al.[7] to assess performance of solar water heater with V-trough and V-cut twisted tape inserts. The use of Square and V-cut twisted tape provided additional disturbances in the fluid flow to enhance the thermal performance. This was due to the combined action of swirl flow and the secondary fluid flow that created the mixing of fluid flow with the core and the tube surface . Experiments were conducted at laminar flow conditions with twist ratios 3 and 5. Average Nusselt number and frictional factor for the solar collector was found out to be 5.765 and 0.0354 respectively. Jaramillo et al. [8] carried out analysis of the efficiency for enhancement by using twisted tape inserts. The simulation results showed that in the presence of a twisted tape insert, the Nusselt number, the removal factor, the friction factor and the thermal efficiency increased with respect to the ones associated to an empty tube. On the contrary, the results showed that these quantities did not present an enhancement when the twist ratio (y/w) was increased. Experimental study was carried out by Sandhu et al. [9] to analyze the performance of the collector to with the combined effect of inclination angle and twisted tape insert. The working fluid was water and the Reynolds number range and Prandtl number range were 200 to 8000 and 5 to 8 respectively. The results indicated the enhancement of the Nusselt number by the use of inserts in the tube.

Table 1 Twisted tape inserts

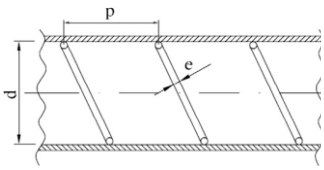
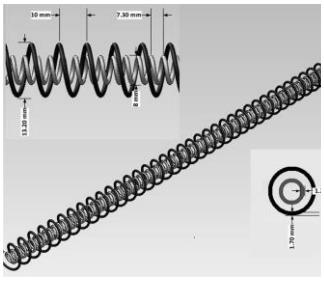
Author / Year	Shape of turbulator	Test fluid
Jaisankar et al. [6] 2009	Helical twisted tape 	Water
Jaramillo et al. [8] 2016	Twisted tape inserts 	Water
Saravanan et al.[7] 2016	V cut and square cut twisted tape 	Water
Sandhu et al.[9] 2014	Twisted-tape inserts 	Water

III. WIRE COIL INSERT

Studies under taken by various researchers who have considered different wire coil turbulators are summarized in Table 2 Martın et al. [10] carried out simulation study by TRNSYS to analyze performance

enhancement of solar liquid collector with wire coil insert. A parametric study was performed to relate the fluid and flow characteristics with the heat transfer enhancement by wire-coil inserts. It was observed that the thermal efficiency of the collector increased by 4.5% due to enhancement by wire coil insert. The simulations were performed for different working fluids such as water and propylene glycol/water mixtures in a mass flow rate range from 15 to 120l/hm^2. Experimental investigation was carried out by Sandhu et al.[11] using concentric wire coil insert in solar collector. Water was used as working fluid over a Reynolds number range of 200 to 8000 and a Prandtl number range of 5 to 8. A clear indication of enhancement of Nusselt number was observed after using the wire coil insert. Nusselt number enhancement of 110% and 460% in low Reynolds number range and high Reynolds number range respectively.

Table 2 Wire coil inserts

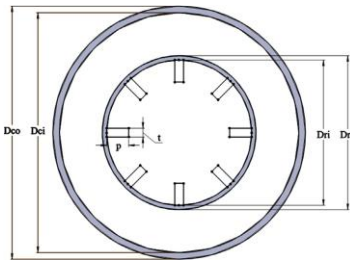
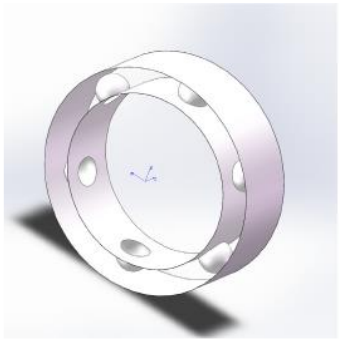
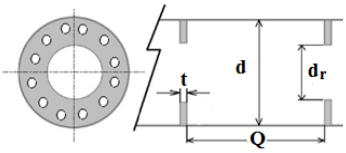
Author	Shape of turbulator	Test fluid
Martın et al.[10] 2011	Wire coil insert 	propylene glycol - water mixture
Sandhu et al.[11] 2014	Concentric wire coil insert 	Water

IV. OTHER INSERTS

Studies under taken by various researchers who have considered other different forms of turbulators are summarized in Table 3. Bellos et al.[12] Investigated the thermal performance of internally finned absorbers. Twelve different fin geometries were examined and compared with the smooth absorber for various operating scenarios. The increase in the thermal efficiency and the thermal enhancement index were found to be 1.27% and 1.483 respectively for 600 K inlet temperature, while the Nusselt number was 2.65 times greater than in the smooth case. Syltherm 800 was used as working fluid. A three-dimensional numerical study was carried out by Haung et al. [13] on mixed convection in the dimpled tube of parabolic trough solar collector. The numerical study was carried out at Reynolds number of 2x10^4 and different Grashof numbers ranging from 0 to 3.2x10^{10} to produce substantial surface heat transfer augmentations with relatively small pressure drop penalties. Boussinesq approximation was applied and a k-ε two-equation turbulence model with enhancement wall treatment was adopted. The results indicated that the average friction factor and Nusselt number in dimpled receiver tubes under non-uniform heat flux were larger than those under uniform heat flux. Moreover deep dimples (d/Di = 0.875) were superior to the shallow dimples (d/Di = 0.125) at a same Grashof number. Therminol VP1 was considered as working fluid. Jamal-Abad et al [14] carried out experimental investigation to evaluate efficiency of parabolic trough collector filled with copper foam porous media. The porosity of copper foam was 0.9 and the pore density was 30 PPI (pores per inch). It was found that by increasing the mass flow rate, the efficiency of the collector was enhanced when absorber was filled with copper foam. Moreover the overall loss coefficient UL decreases by 45% which caused the efficiency to increase because less energy was lost. Experiments were performed with different volume flow rates from 0.5 to 1.5 Lit/min and ASHRAE 93 standard was used to test the solar collector's performance. Performance investigation of Solar Parabolic Trough Collector was carried out by Ghasemi et al [15] numerically. Thermal Study was carried out to analyze the effect of porous rings on performance of solar collector. A three dimensional turbulent flow analysis was carried out using Computational Fluid Dynamics (CFD) based on Re-Normalization-Group (RNG) k–ε turbulent model. It was found that the heat transfer characteristics of solar parabolic trough collector enhances by inserting the porous rings in tubular solar absorber. Also, by decreasing the distance between porous rings, the heat

transfer characteristic increased but by increasing the inner diameter of the porous rings, the Nusselt number reduced.

Table 3 Other inserts

Author	Shape of turbulator	Test fluid
Bellos et al.[12] 2017	Internally finned absorber 	Syltherm 800
Haung et al. [13] 2016	Dimpled receiver tube 	Therminol VP1
Jamal-Abad et al [14] 2017	Porous foam 	Water / Liquid
Ghasemi et al.[15] 2017	Porous ring insert 	Syltherm 800

V. CONCLUSION

Research investigations carried out by various researchers to increase the performance of the solar collector by the use of various turbulator inserts have been reviewed and presented. The outcome of the review is summarized below.

- Twisted tapes are generally made up of metallic strips twisted in some special form and dimension which are placed across the flow that act as turbulators to impart swirl flow which causes an enhancement in heat transfer rate. The usage of cut type twisted tape insert can lead to the production of the secondary motion apart from the swirl motion in the fluid flow and accordingly, improves the mixing fluid between the center and wall regions of the tube.
- Wire coils are made by firmly wrapping a coil of spring wire on a rod. Wires create a helical roughness as the coil spring is pulled up. Wire coil pitch and shapes of their cross section are two parameters, which affect the performances of these devices. Studies show that the wire coils are more appropriate for improving the heat transfer rate in low turbulent or laminar regimes.
- Porous Foam of metal is low density permeable material and has excellent thermal and electrical conductivities and good corrosion resistance. Thus it allows heat to pass through it quickly and hence improves the thermal performance of the collector.
- Various other forms of turbulators such as internal fins, dimpled receiver tube also augment the heat transfer due to breakage of the boundary layer.

Depending upon the temperature application, pressure drop permissible, type of flow and fluid, appropriate turbulator can be chosen to enhance the thermal performance of the solar collector for industry application.

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