A Review on Heat Transfer Augmentation in Parabolic Trough Collector Receiver Tube by Twisted Tape Inserts

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Abstract

In Parabolic Trough Collectors (PTCs) the major heat losses occur due to convection and radiation because of many reasons. One of them is non-evacuated receiver used in earlier PTC delivered lower thermal efficiency even they are used with reflectors having best optical characteristics. PTC with evacuated receivers has thermal-efficiency in the range of 65–70% which is about 10% higher than PTC with non-evacuated receiver. Therefore heat transfer augmentation in PTC became essential to transfer maximum heat to heat transfer fluid (HTF). Heat transfer augmentation techniques are of two types: Active techniques and Passive techniques. The present study is focused on review and feasibility of passive heat transfer augmentation technique, especially twisted tape inserts inside PTC receiver. It can be seen that, for PTC application use of twisted tape insert with base fluid is beneficial in the laminar region and nanofluid with twist tape insert is justified for turbulent regime. The base fluids with twisted tape insert augmented heat transfer by 10–200% in turbulent region compared to its flow in plane receiver. The heat transfer augmentation by twisted tape inserts is due to increased effective heat transfer area, swirl generation and increase in flow turbulence with interruption to the growth of boundary layer.

Keywords: Enter Parabolic Trough Collector, Heat Transfer Fluid, Twisted Tape, Twist Ratio, Width Ratio

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I. INTRODUCTION

In recent years many countries started running behind renewable energy due to reduction of non-renewable energy, for various applications such as air heating, desalination, refrigeration, small scale and large scale industries and electric power generation. Although many developments done to extract maximum energy from various renewable sources. Renewable energy sources like solar, wind, biomass, hydropower and tidal energy are CO_2 free alternatives. By applying renewable energy scenario the global consumption of renewable sources by 2050 reach up to 318 exa joules. Solar energy is the most useful source of energy which has been readily available in earth for thermal power generation, and for industrial heating applications. Some developing countries have high level of solar radiation like India, Egypt, Morocco and Mexico are moving to concentrating solar power for electricity.

An environmental analysis has been conducted in 58 places in India for viability analysis of parabolic solar trough power plants. In India, on an average 3000 to 3200 h/year solar radiation receives, which delivers approximately 2000 kWh/m^2 per year of solar radiation on the horizontal surface. According to a National Renewable Energy Laboratory survey, Gujarat received an average of above 6.7 kWh/m^2 of solar radiation per day. According to the Central Energy Authority of India on November 2016 the total installed capacity for electricity generation was 308,834MW and the various sources are shown in Figure 1. India requires a peak demand of 153,824MW whereas peak met is 152,295MW. Also, specifically, the state of Gujarat has a peak demand of 14,134MW electricity.

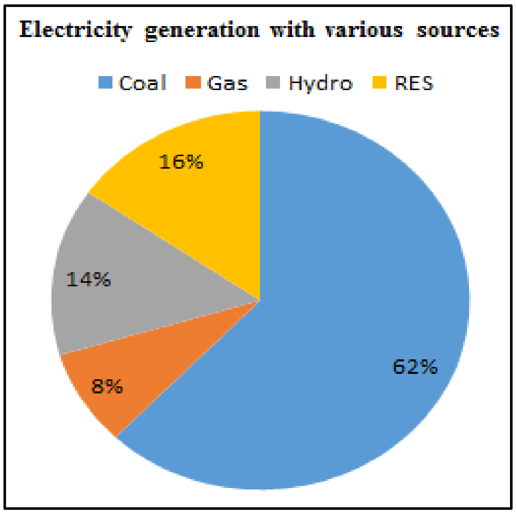

Fig.1(a) All India power installed capacity(MW)

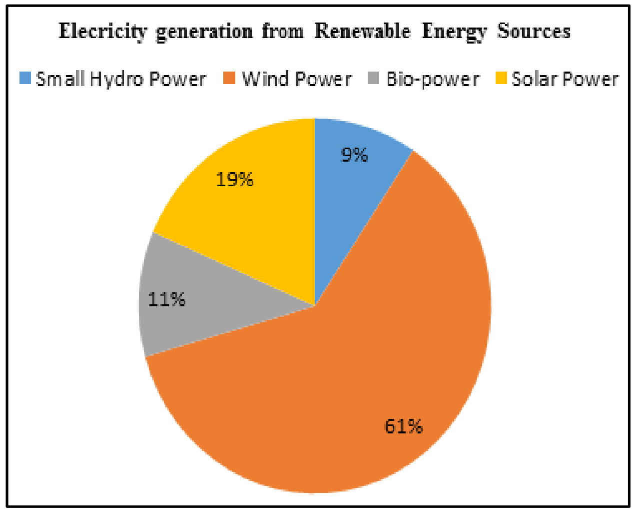

Fig.1(b)All India renewable power capacity (MW)

All the processes temperature required is less than 260°C. The heat required for all the industrial processes is obtained from solar energy. The solar PTC has the ability to capture temperature of about 400 °C. Solar energy is being used for industrial processes in various developing countries. Each square meter of collector surface can reduce 250-400 kg CO_2 emission per year.

The solar collectors absorb the solar radiation and convert it into heat, and transfer it to the working fluid. The working fluid may be air, water, oil or any organic solvents. The heat energy which is in the form of thermal energy in the working fluid of the solar collector can directly be utilized for different applications. Solar collectors are of various types as shown in Table 1.

Table – 1
different solar collector

Name of Collector	*Type*	*Operating Temperature(℃)*	*Heat transfer medium*	*Application Area*
Flat plate	*Non concentrating*	*30-80*	*Water or air*	*Air heating and water heating*
Evacuated tube	*Non concentrating*	*50-200*	*Water or air*	*Water, oil and air heating*
Parabolic trough	*Line focusing*	*60-300*	*Air, thermal oil*	*Power generation, water and air heating*
Linear Fresnel reflector	*Line focusing*	*60-250*	*Water, air, thermal oil*	*Water and air heating*
Dish type	*Point focusing*	*100-500*	*Water, thermal oil*	*Steam generation, parabolic dish engine*
Power tower	*Point focusing*	*150-2000*	*Thermal oil*	*Power generation*

The advantages of PTCs over other solar collectors used in water heating facilities are their lower thermal losses and, therefore, higher efficiency at higher working temperatures reached, smaller collecting surface for a given power requirement, and no risk of reaching dangerous stagnation temperatures, since in that case, a control system sends the collectors into off-focus position and reduce risk.

Today factories are usually located in industrial areas where land is limited and expensive; there for installing the solar field on roofs should be a real possibility. PTCs should therefore be modular to cover the wide range of thermal power required for many different applications. Differences between PTCs used for industrial applications and for power generation are that they are smaller, have fewer absorber tube selective coating requirements due to the lower working temperature, and use first surface reflectors instead of silvered glass mirrors, which are only marketed for PTCs developed for power generation applications.

In many solar thermal applications, flat plate collectors are not capable of producing required higher temperature as concentrating collectors. Concentrating collectors which can focus the incoming solar radiation on an evacuated receiver having smaller area compared to the flat plate collectors. One of such concentrating collector is Parabolic Trough Collectors (PTC), which concentrates the solar isolation on the focal axis of a parabolic reflector where receiver is located. The receiver absorbs the thermal energy from incoming solar radiation and transfers the same to the Heat Transfer Fluid (HTF). The PTCs can effectively produce heat at high temperatures up to 400 °C. It is necessary to transfer maximum amount of heat to the HTF at high receiver temperatures otherwise radiation heat loss from the receiver surface increases due to the increased emissivity of the receiver selective coating, resulting in a lower thermal efficiency of the system. Moreover it is possibility of the failure of the tube or even damage the outer glass envelope if receiver tube is subjected to excessive thermal stress at high temperatures. On the other side, the optimum utilization of solar radiation can cut down the overall size of the system. Hence, heat transfer enhancement in PTC is of major concern. Enhancement techniques are also adopted in other solar thermal systems such as solar cooker, using integrated evacuated heat pipes and flat plate collectors, in which refrigerants are used in vacuum heat pipes. In-depth research in this field has proved the effective applications of various heat transfer augmentation techniques are necessary. The present study is focused on review of one of these techniques of twisted tape inserts with the interest of its practicability in case of PTC.

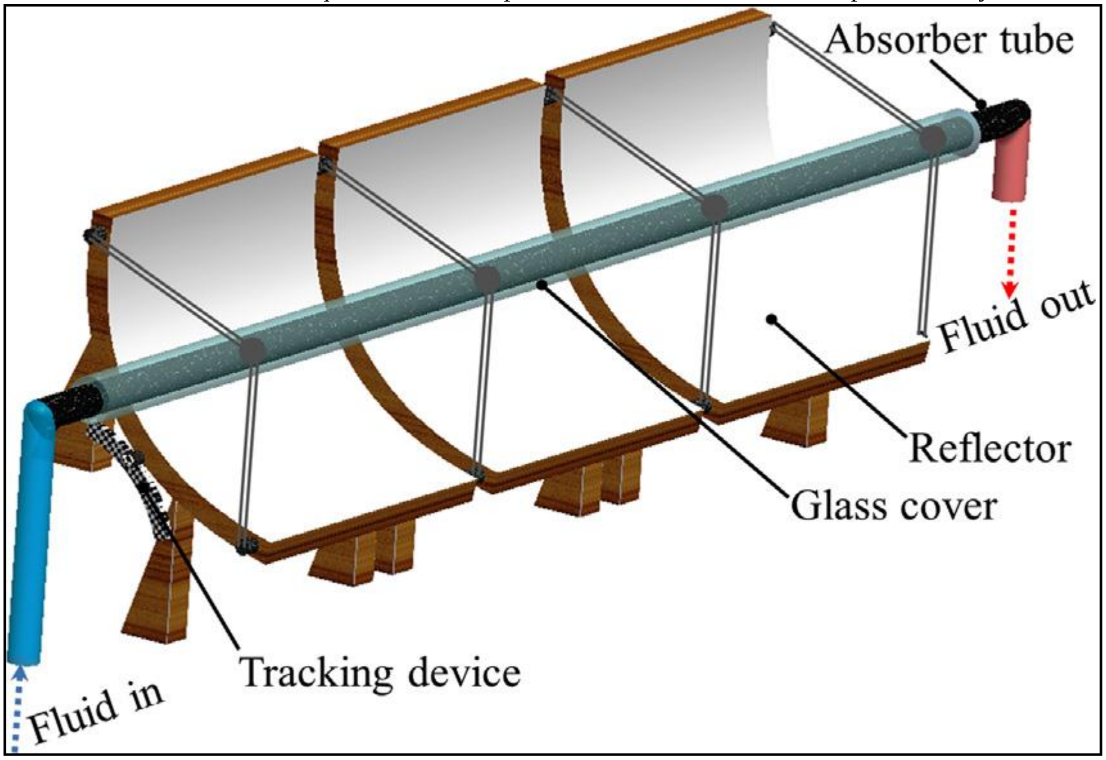

Fig. 2: Parabolic Trough Collector

II. CLASSIFICATION OF AUGMENTATION TECHNIQUES

A. Active Method

This method involves some external power input for the enhancement of heat transfer and has not shown much potential owing to complexity in design. Furthermore, external power is not easy to provide in several applications. Some examples of active methods are induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, etc.

B. Passive Method

This method does not need any external power input and the additional power needed to enhance the heat transfer is taken from the available power in the system, which ultimately leads to a fluid pressure drop. The heat exchanger industry has been striving for improved thermal contact (enhanced heat transfer coefficient) and reduced pumping power in order to improve the thermo hydraulic efficiency of heat exchangers. A good heat exchanger design should have an efficient thermodynamic performance, i.e. minimum generation of entropy or minimum destruction of available work (exergy) in a system incorporating a heat exchanger. It is almost impossible to stop exergy loss completely, but it can be minimized through an efficient design.

C. Compound Method

It is the combination of above two methods.

III. HEAT TRANSFER AUGMENTATION USING TWISTED TAPES

Heat transfer augmentation is always an important matter of concern since the enhancement of heat transfer rate leads to increase the performance of system which is quite important in various heat transfer applications. Twisted tapes are well known heat transfer enhancement devices and several correlations of heat transfer and pressure drop have been developed for different types of twisted tapes. The enhancement of heat transfer is obtained by developing swirl flow of the tube side fluid, which gives high velocities near boundary and fluid mixing and consequently high heat transfer coefficient. In heat transfer systems equipped with twisted tapes, the heat transfer and pressure drop characteristics are governed by twist ratio of the twisted tapes. Also, small clearances between twisted tape and tube boundary are important factor while selecting the width of the twisted tapes. Clearance between twisted tape and tube boundary should be acceptable because greater clearances can produces bypass flow which lead to performance drop.

Use of twisted tapes and other inserts causes flow blockage, flow portioning and induction of secondary flow. Free flow area is reduced due to flow blockage and pressure drop and viscous effects are considerably reduced. In addition to this, flow velocity also increases and in many cases secondary flow is induced. This secondary flow produces swirl and gives effective mixing of fluid flow which improves temperature gradient and thus heat transfer coefficient.

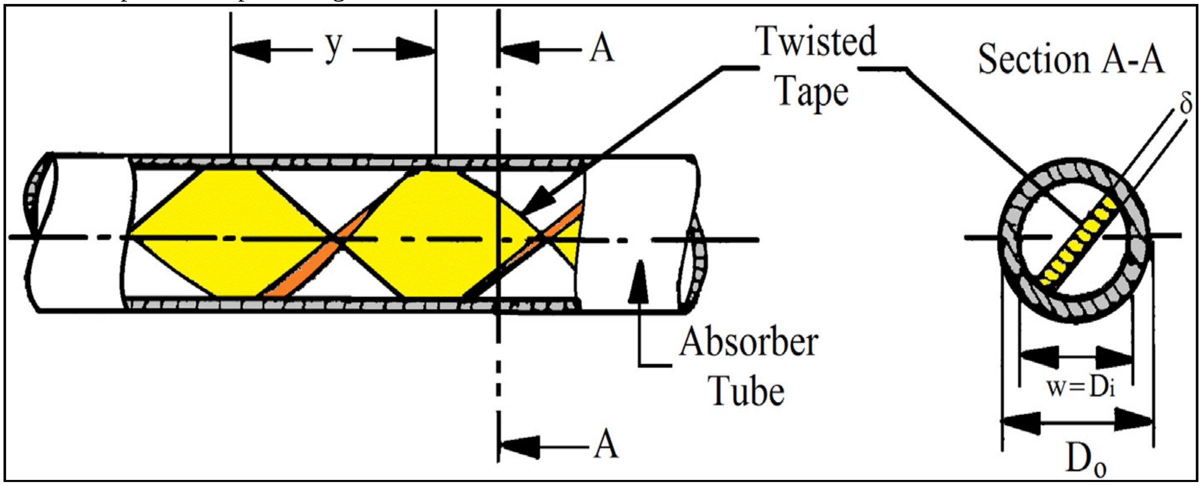

Fig. 3: Twisted Tape Insertion in Receiver Tube

IV. Review of Twisted Tape Inserts in PTC Receiver

Waghole D.R. et.al. experimentally determined heat transfer and friction factor data at various volume concentrations (with water and silver Nanofluid) for flow in absorber/receiver and with and without twisted tape inserts in the Reynolds number range 500≤ Re<≤ 6000 with twisted tape inserts of different twist ratios in the range 0.577 ≤H/D/≤1.732. They showed that the heat transfer coefficient and friction factor of 0≤ Φ≤0.1 % volume concentration of silver Nanofliud are higher compared to flow of water in absorber/receiver. Also they showed that Nussult Number, friction factor and enhancement efficiency are found to be 1.25 -2.10 times, 1.0 -1.75 times and 135%-205%, respectively, over, plain absorber/receiver of parabolic trough collector.

Fig. 4: Twisted Tapes with different Twist Ratios

Sh. Ghadirijafarbeigloo et.al. performed an experiment on PTC receiver tube with a perforated louvered twisted tape insert with three different twist ratios TR=2.67, 4, 5.33. They found that this twisted tape has higher thermal performance for lower Reynolds number. Also it is found that with decreasing Reynolds number and twist ratio, heat transfer coefficient increased and best result found with Reynolds number 5000 and twist ratio 2.67.

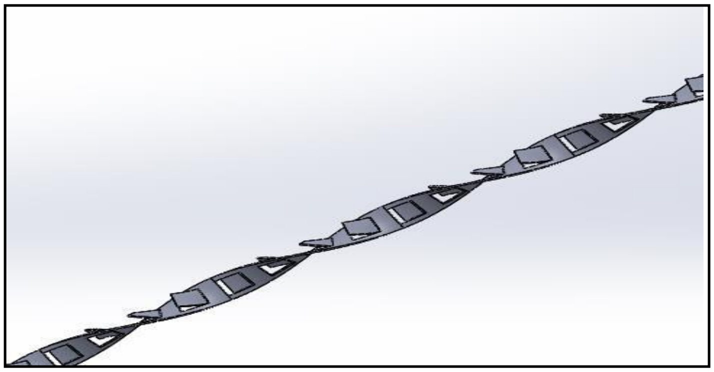

Fig. 5: Louvered Twisted Tape with Perforations

K. Syed Jafar and B. Sivaraman experimentally investigated the impact of absorber device with nail twisted tape of two different twist ratio 2 and 3 using Al2O3 / water nanofluid as the working fluid at 0.1% and 0.3% particle volume concentration on the heat Transfer and friction factor characteristics of a solar parabolic trough collector. Test performed in the laminar range (Re=710-2130). Results showed that Nusselt number considerably increases with increase in nanofluid concentration. At same conditions, heat transfer rate further increased due to twisted tapes and nanofluid and the use of nanofluid enhances the heat transfer coefficient in the range tested with no significant enhancement in pressure drop compared to water. The major findings of this experimental investigation were that the use of nanofluid (0.3%) with nail twisted tapes (N-TT) yields higher Nusselt Number and high friction factor.

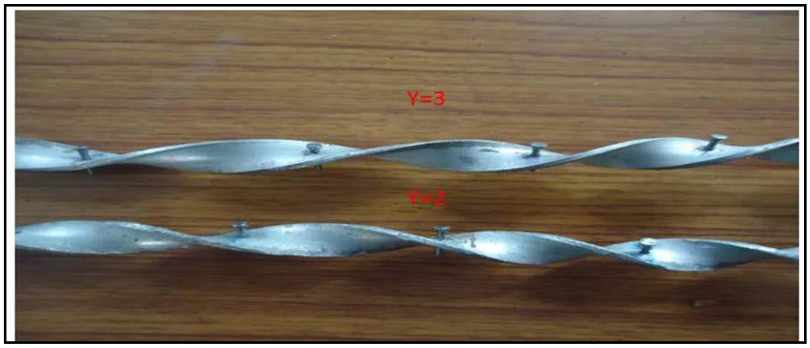

Fig. 6: Nail Twisted Tape

Aggrey Mwesigye et. al. numerically investigated heat transfer enhancement in a parabolic trough receiver using wall detached twisted tape inserts. The twist ratio and width ratio used in the range of 0.5-2 and 0.53-0.93 respectively. The Reynolds number ranging 10260-1353000 was used. The study showed considerable increase in heat transfer performance of about 169%, reduction in absorber tube's circumferential temperature difference up to 68% and increment in thermal efficiency up to 10% over a receiver with a plain absorber tube. It is also found that both the heat transfer performance and fluid friction performance increased as the twist ratio reduced and as the width ratio increased. Heat transfer in enhanced in the range 1.05-2.69 times while fluid friction increases in the range 1.6-14.5 compared to a receiver with a plain absorber tube. The thermal enhancement factors for constant pumping power comparison are in the range 0.74-1.27.

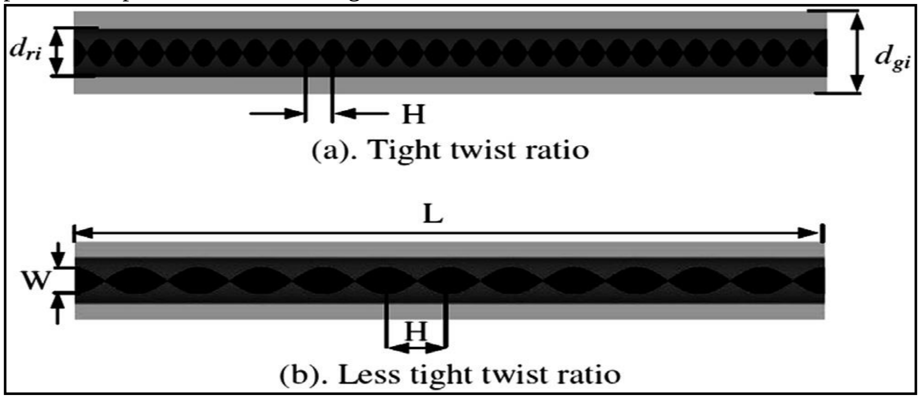

Fig. 7: Physical model of a parabolic trough receiver with wall detached twisted tape inserts

O.A. Jaramillo et. al. developed a thermodynamic model framework to analyse the performance of a parabolic trough collector with a twisted tape insert. The twist ratio used in range of 1-5 and Reynolds number ranging from 1350-8350. They found that the highest value of enhancement factor for Nusselt number is around 3.5 corresponding to Reynolds number of 1350 and at a twist ratio equal to 1. Also it is found that heat removal factor, FR, increase close to 3% while the overall heat loss coefficient, UL, decrease in about 1.5% when the twisted tape insert is placed in the receiver tube and it is possible to enhance the efficiency close to 3.5% when a twisted tape insert is used.

V. Conclusion

Many passive methods of heat transfer can be applied to PTC receiver but most effective among all other techniques is insertion of twisted tape having different geometries. From above literature it is concluded that twisted tapes can improve heat transfer within laminar range more than turbulent range. Lower the twist ratio, the more will be heat transfer on expense of pressure drop, but not affecting efficiency considerably. Width ratio of value approx 1 is best suited for twisted tape so that can have effective swirling motion of fluid inside the tube without bypassing over the tape.

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