CHAPTER 9

EXPERIMENTAL RESULTS FOR CUSTOMIZED TWISTED TAPE WITH REGULARLY SPACED ROD AND SPACER

The heat transfer and friction factor characteristics of thermosyphon solar water heating system using customized designs of twist inserts are reported in this chapter. The study on thermal performance, heat augmentation and pressure drop characteristics are compared with plain tube collector.

9.1 TECHNICAL DETAIL OF THE CUSTOMIZED TWISTED TAPES

The twisted tapes used in the present study are illustrated in Fig.9.1 and the photograph is shown in Fig.9.2. All the twisted tapes are made of thin copper strips of 0.3 mm thickness and 11 mm width exactly as the internal diameter of riser tube of the solar collector. A full length twist is a combination of helical, Left-Right and Kenics is made by brazing sequentially for a length of 1 m, with a twist ratio of 3 and is abbreviated as MFLT. The twist and rod (4 mm dia) of 125 mm connected alternately is designated as MTR125. For MTR250 and MTR500, the twist and rod length is maintained as 250 mm and 500 mm respectively. In twist with spacer, space of above said length is maintained and are designated as MTS125, MTS250 and MTS500.
Fig. 9.1 Full length customized twist and its various designs
9.2. RESULTS ON HEAT TRANSFER ENHANCEMENT

The effect of full length customized twist, customized twist regularly spaced with rod and spacer in Phase1 and 2 in the heat transfer enhancement compared to plain tube collector are described below.

9.2.1 Heat transfer enhancement in twisted tape collector

The collector with full length twist provided higher heat transfer rate when compared with other collectors. The fluid initially undergoes smooth swirling motion in the first two twist elements (helical twist), takes an 180° change in the next two elements (Left-Right) and then in the next two elements, it is split into two semicircular passage provided by the helical element which is attached at an angle of 90° to the first element (Kenics).
This phenomenon is repeated throughout the length of the twist. Thus, the swirl intensification takes place gradually and with ease.

The progressiveness in the swirl motion, change in the direction of flow and fluid passage elevate the secondary motion of the fluid, resulting in a better fluid mixing, steady temperature and superior turbulence. Thus the presence of Left-Right and Kenics twist elements provide additional disturbance in thermal boundary layer resulting in higher heat transfer through the fluid along the radial direction. Hence the Nusselt number for full length twist increases appreciably about 3.7 times that of plain tube collector.

9.2.2 Effect of rod and spacer in heat enhancement

The presence of rod and space between the twist elements play a crucial part in heat transfer augmentation by the customized designs. It is observed that, for all collectors the Nusselt number increases with increase in Reynolds number in Phase 1, decreases with Reynolds number in Phase 2. The variation of Nusselt number with Reynolds number is shown in Fig.9.3a and Fig.9.3b. The gradual increase in solar intensity in the Phase 1 increases the heat input to the collector. In case of full length twist, the fluid swirl intensity is maintained throughout the length of the tube. But in the case of twist with rod, alternate growth and dissemination of the particle disturbance in the twist and rod portion reduces the heat transfer by convection. However, the presence of rod after the twist portion maintains the particle turbulence to some extent. Hence, the reduction in heat augmentation in twist with rod is comparatively smaller than spacer. For twist with rod of 125 mm length, the reduction in Nusselt number and convective heat transfer coefficient is only 1.27 % and 1.91 % respectively when compared to full length twist. In case of twist with spacer, due to the presence of empty space between twists slightly accelerate the swirl diffusion. Hence, the reduction in Nusselt number and convective heat transfer efficient is slightly higher than
those offered by twist with rod and it is estimated as 4.16 % and 4.19 % respectively. Similarly for twist with rod and spacer of 250 mm length the reduction in Nusselt number is 5.56 % and 10.11 % respectively and if the length is increased to 500 mm the reduction in Nusselt number is found to be about 19.9 % and 27.2 % respectively. In phase 2, the heat input to the collector decreases since the solar intensity decreases after reaching a peak value in Phase 1. Subsequently this reduces both Nusselt number and convective heat transfer coefficient. The experimental values (Full length twist, MTR125, MTR250, MTR500, MSP125, MSP250 & MSP500) are shown in Tables A3.45, A3.47, A3.49, A3.51, A3.53, A3.55 and A3.57 in Appendix 3.

Following are empirical correlations for Nusselt number which depends on Reynolds number, twist ratio, Prandtl number and space ratio, developed for Phase 1 and Phase 2.

**Phase 1:**  
\[ Nu_s = 0.00397R_e^{1.066} \gamma^{0.332}Pr^{0.658} \left(1 + \frac{S}{D_h}\right)^{-0.0304} \]  
(9.1)

**Phase 2:**  
\[ Nu_s = 0.00047R_e^{1.425} \gamma^{0.172}Pr^{0.393} \left(1 + \frac{S}{D_h}\right)^{-0.0265} \]  
(9.2)

The Nusselt number predicted from the above correlations (9.1) and (9.2) for an individual phase fits the experimental values reasonably well within ±19 % and is shown in Fig.9.4.
Fig. 9.3 Variation of Nusselt number with Reynolds number for various designs of customized twist
Fig. 9.4 Comparison of experimental Nusselt number with correlation values
9.3 DISCUSSION ON FRICTION FACTOR CHARACTERISTICS

The friction factor of fluid is mainly due to the change in elevation, particle turbulence created by the sudden changes in the direction of fluid flow, the friction between fluid particles and between fluid and riser tube. The amount of pressure drop experienced by the fluid also depends on the fluid viscosity and the relative velocity between the fluid layers. In plain tube collector, the pressure drop is lesser, since there is no change in fluid flow direction and marginal variation in velocity gradient of the fluid.

9.3.1 Friction factor in twisted tape collector

In case of full length customized twisted tape collector, higher friction factor is observed due to the superior particle mixing effect. The twist not only induces swirl flow in tangential direction both clock wise and counter clock wise but also splits and reunite the fluid. Hence the fluid velocity is higher in full length twist when compared with the others. The friction factor in full length twist is 2.48 times higher than that of plain tube collector and is mainly due to the increase in the wetted surface area and increase in the hydraulic length of the fluid.

9.3.2 Friction factor in twist with rod and spacer

Presence of rod alternately between twists certainly reduces the wetted surface and the hydraulic length of the fluid decreases due to the gradual decay in the swirl flow. The swirl motion generated by the twist is maintained to certain extent in the rod portion. But in twist with spacer, due to the presence of open space, the swirl intensity is reduced at a faster rate. Moreover in twist with spacer, the average velocity of fluid through the tube is comparatively lower than twist with rod. Since the friction in the fluid is directly proportional to the average velocity of the fluid in the riser tube,
presence of spacer in the twist helps to reduce the friction to a greater extent. Compared to full length twist, the pressure drop for MTR125, MTR250, and MTR500 are decreased by 8.5 %, 17.2 % and 30.9 %. In case of twist with spacer, the pressure drop observed in MTS125, MTS250 and MTS500 are 15.1 %, 27.5 % and 49 % lower than the drop observed in full length twist. The variation of friction factor with Reynolds number is given in Fig.9.4a and Fig.9.4b. It is observed from the figure that, at lower Reynolds numbers, all modified forms of twists offered lower friction and it increases with increase in the value of Reynolds number. The following empirical correlations relating all the three parameters described above are developed for Phase 1 and Phase 2. The experimental values are shown in Tables shown in Tables A3.46, A3.48, A3.50, A3.52, A3.54, A3.56 and A3.58 in Appendix 3.

Phase 1:
\[ f_t = 1.31(R_e)^{-0.311}Y^{-0.125} \left( 1 + \frac{S}{D_h} \right)^{-0.064} \]  \hspace{1cm} (9.3)

Phase 2:
\[ f_t = 3.53(R_e)^{-0.442}Y^{-0.146} \left( 1 + \frac{S}{D_h} \right)^{-0.0661} \]  \hspace{1cm} (9.4)

The friction factor values predicted from Eqs. (9.3) and (9.4) were compared with the experimental values and found to agree within ±13% and is shown in Fig.9.6.
Fig. 9.5 Variation of Friction factor with Reynolds number for various designs of customized twist
Fig. 9.6 Comparison of experimental Friction factor with correlation values
9.4 THERMAL PERFORMANCE

The thermal output of the collector depends mainly on the collector efficiency factor, internal convective heat transfer coefficient and the collector heat removal rate. Observations show that the Instantaneous efficiency decreases with the increase in the ratio of temperature difference to the insolation. The Instantaneous efficiency of full length twisted tape collector is always higher than the plain tube collector and other collectors with customized designs of twisted tapes. The variation of Instantaneous efficiency with solar radiation for plain tube collector, collector with full length twist and modified designs of twisted tapes is shown in Fig.9.7.

For a typical solar radiation value of 988 W/m², the Instantaneous thermal efficiency of full length customized twisted tape collector is 82.85% and the same for plain tube collector is 65.4%. The value of Instantaneous thermal efficiency for twist with rod of 125 mm, 250 mm and 500 mm length are 82%, 80.4% and 78.9% respectively. The same for twist with spacer of above said length are 81.2%, 79.8% and 77.6% respectively.

![Fig.9.7 Variation of Instantaneous efficiency with solar radiation](image-url)
The effect of rod and spacer on absorber plate temperature is illustrated in Fig.9.8. In the case of plain tube collector, the fluid flows predominantly in the axial direction along the stream lines and there is minimum or no particle instability. Hence the heat loss from the plain tube collector is more and it has comparatively lower instantaneous efficiency. In case of collector with full length customized twist, the centrifugal convective heat transfer induced by the twist leads to increased heat removal from the absorber plate. Hence the plate temperature observed in the full length customized twisted tape collector is minimum compared to other collectors.

The heat removal factor, one of the performance parameter of collector indicates the amount of heat removed by the fluid circulated through the collector. It depends on the mass flow rate, average fluid velocity, variation in the fluid direction and intensity of particle mixing. It is also observed that the magnitude of heat loss varies directly with rod and spacer length.

For a typical solar radiation value of 988 W/m², the heat removal factor for full length helical twisted tape collector and plain tube collector are 0.99 and 0.83 respectively. For twist with rod of length 125 mm, 250 mm and 500 mm, the heat removal factor observed are 0.98, 0.96 and 0.97 respectively. The same for twist with spacer of above said lengths are 0.97, 0.96 and 0.95 respectively.

In twist with rod, the presence of rod alternately after the twist portion tends to sustain the swirl intensity and particle turbulence. The prolongation of the above depends on the length of rod.

In case of twist with spacer, the particle turbulence and swirl intensity is greatly influenced by the open space after the twist portion. It is observed that both suddenly vanish in the spacer section and again develops in the twist
section. Due to this alternate development and diffusion, the heat removal rate is comparatively lower than that offered by twist with rod.

![Graph showing absorber plate temperature vs. solar radiation](image)

**Fig. 9.8 Effect of rod and spacer on absorber plate temperature**

It is observed that the plate temperature increases throughout the trial in both phases and depends on the difference between the inlet and exit temperature of the water through the collector i.e., higher the difference in temperature lower the plate temperature and vice versa. The experimental values of Instantaneous efficiency and absorber plate temperature for various twist ratios are shown in Tables A3.45, A3.47, A3.49, A3.51, A3.53, A3.55 and A3.57 in Appendix 3.

### 9.5 REMARKS

This experimental study conducted in the thermosyphon solar collector with customized designs of twist to observe the heat transfer and friction
factor characteristics focusing on superior thermal performance and minimal friction factor are consolidated and reported.

i. The augmentation of convective heat transfer coefficient in twisted tape collector is comparatively higher than that of plain tube collector. The increase in Nusselt number for full length customized twisted tape collector is 2.75 times greater compared to the plain tube collector. The reduction in heat enhancement ranging between 1.91 % - 19.9 % and 4.2 % - 27.2 % respectively for the customized designs of twist with rod and twist with spacer compared to full length twist.

ii. The friction factor for full length customized and twist of different rod and spacer length decreases with increase in rod and spacer length. The friction factor for full length twist is 2.48 times greater than the friction factor observed in plain tube collector. For twist with rod and spacer the decrement in friction factor varies between 9% and 34% compared to full length customized twist.

iii. The improvement in Instantaneous thermal efficiency for full length twisted tape collector found to be 1.58 times greater than the plain tube collector. For twist with rod and spacer the decrement in efficiency varies between 1 % and 8 % compared to full length twisted tape collector.

iv. The average heat removal factor for full length twisted tape collector is 0.88 and for plain tube collector it is 0.67. For twist with rod and spacer the decrease in the heat removal factor varies between 1.2% and 7.9%.