CHAPTER 8

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

Experimentation on heat transfer and friction factor characteristics of thermosyphon solar water heater with full length Kenics twist of twist ratio 3, twist with rod and spacer of lengths 125, 250 and 500 mm have been performed and discussed below.

8.1 TECHNICAL DETAIL OF THE KENICS TWISTED TAPES

The twists are made from thin, flat copper strips of 0.3 mm thickness, 1000 mm length and 11 mm width. The strips are twisted through $180^\circ$ to form a single helix of required twist ratio 3. The complete Kenics insert consists of a series of such helical elements arranged axially so that the leading edge of a twist element is at right angles to the trailing edge of the previous element and is formed for a length of 1m. Copper rods of 4 mm diameter and length 125, 250 and 500 mm are brazed alternately with Kenics twists to make the combination of Kenics with rod are designated as KR125, KR250 and KR500. In Kenics with spacer, empty space is maintained alternately for the above mentioned lengths and is abbreviated as KS125, KS250 and KS500 and is shown in Fig.8.1 and the photograph is shown in Fig.8.2.
Fig. 8.1 Full length Kenics twist and its various designs
8.2 RESULTS ON HEAT TRANSFER ENHANCEMENT

The effect of heat transfer, friction factor and thermal performance of full length Kenics, Kenics twist regularly spaced with rod and spacer in Phase 1 and 2 compared to plain tube collector are described below.

8.2.1 Heat augmentation in twisted tape collector

When compared to twist with rod and spacer and plain tube collector higher heat transfer enhancement is observed in collector with full length Kenics. In Kenics twisted tape the elements are designed in such a way that a first mixing element splits the liquid into two streams and next element combines the streams formed by the previous element. This is achieved by placing the elements at an angle of 90°. The liquid is not only split at each element, but also forced to change its rotation, which also contributes to the
mixing by the formation of vortices and stretching of the fluid. The periodic change in swirl direction and change in the fluid passage elevate the secondary motion of the fluid, resulting in a superior fluid mixing, consistent temperature and higher turbulence and hence better mixing of fluid particles. Due to this the Nusselt number for full length twist increases significantly about 4.4 times when compared with a plain tube collector.

8.2.2 Effect of rod and spacer in heat augmentation

The heat augmentation in full length twist and twist with rod and spacer are compared. The empty space and rod between the twist elements plays a vital part in heat transfer augmentation by the modified Kenics designs. The variation of Nusselt number with Reynolds number is shown in Fig.8.3a and Fig.8.3b. For all the collectors, the Nusselt number increases with increase in Reynolds number in Phase 1 due to the gradual increase in the heat input to the collector. The Nusselt number for twist with rod of 125 mm length decreases by 0.75% and for spacer of same length is 2% compared to full length twist. Similarly for twist with rod and spacer of 250 mm length the reduction is 3% and 5% respectively. When the length is increased to 500 mm the reduction in Nusselt number is 11% and 18% respectively. In twist with rod, the presence of rod alternately after the twist section sustained the swirling effect, but in case of twist with spacer, the swirling effect suddenly gets diffused in the open space and is developed again in the twist section. This phenomena increases with increase in rod and spacer length and subsequently decreases the heat augmentation. Due to the alternate growth and dissemination of swirling motion of the fluid resulted in relatively higher decrease in Nusselt compared to the full length twisted tape collector.

The empirical correlations are developed for Phase 1 and 2 by using Gauss elimination method

Phase 1: \[ \text{\textit{Nu}}_s = 0.00396 R_e^{1.068} \nu^{0.342} P_T^{0.758} \left(1 + \frac{S}{D_h}\right)^{-0.033} \] (8.1)

Phase 2: \[ \text{\textit{Nu}}_s = 0.00037 R_e^{1.443} \nu^{0.155} P_T^{0.373} \left(1 + \frac{S}{D_h}\right)^{-0.024} \] (8.2)

The Nusselt number for Phase 1 and Phase 2 predicted from the above correlations (8.1) and (8.2) are compared with the investigational values and the deviation falls within ±18% for both Phases and are shown in Fig.8.4.
Fig. 8.3  Variation of Nusselt number with Reynolds number for various designs of Kenics twist
Fig. 8.4 Comparison of experimental Nusselt number with correlation values
8.3 DISCUSSION ON FRICTION FACTOR CHARACTERISTICS

The friction factor characteristics of full length Kenics, Kenics twist regularly spaced with rod and spacer in Phase1 and 2 compared to plain tube collector are described below.

8.3.1 Friction factor in full length Kenics

The variations of friction factor with Reynolds number for the tube fitted with modified designs of Kenics twist are as shown in Fig.8.5. In general, the pressure drop is lesser at lower fluid temperature and is more at elevated temperature since the viscosity of the fluid decreases with increase in temperature. As evident from the Figure, in Phase 1, the friction factor decreases with increase in Reynolds number. In case of twisted tape collector, higher increase in the friction factor is observed due the superior particle mixing effects and increase in the wetted surface area. The Kenics not only induces the 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 nearly 2.59 times higher than the plain tube and is mainly due to the increase in the wetted surface area and increase in the hydraulic length of the fluid. In Phase 1, initially the fluid velocity is lesser; as the solar insolation increases, the fluid velocity increases gradually which ultimately increases the pressure drop. Hence the friction factor decreases at a slower rate. In Phase 2, the solar intensity decreases which in turn affect the fluid velocity and pressure drop. Hence the friction factor increases gradually.
8.3.2 Friction factor in twist with rod and spacer

Presence of rod alternately between twists reduces the wetted surface and hydraulic length decreases due to the gradual decay in the swirl flow in the rod section and is directly proportional to the rod length. The pressure drop observed in twist with rod is significantly higher than twist with spacer. This is because of the extension of the swirl motion created in twist portion and its persistence in rod portion. But in twist with spacer, due to presence of empty space, the intensity of swirl motion suddenly reduced. The friction factor for KR125, KR250, and KR500 is 2%, 4.5%, and 10% lesser than the full length twist. Similarly the friction factor for KS125, KS250 and KS500 are lesser by 5%, 9% and 20% respectively. The friction factor observed in twisted tape collector and is a function of Reynolds number, twist ratio and spacer length. The variation of friction factor with Reynolds number is given in Fig.8.5a and Fig.8.5b. The following empirical correlations is developed for Phase 1 and Phase 2. The experimental values are shown in Tables A3.32, A3.34, A3.36, A3.38, A3.40, A3.42 and A3.44 in Appendix 3.

The following empirical correlations are developed for Phase 1 and 2.

Phase 1: \[ f_t = 1.3(R_e)^{-0.32}Y^{-0.13} \left( 1 + \frac{S}{D_h} \right)^{-0.064} \] \hspace{1cm} (8.3)

Phase 2: \[ f_t = 3.5(R_e)^{-0.44}Y^{-0.15} \left( 1 + \frac{S}{D_h} \right)^{-0.067} \] \hspace{1cm} (8.4)

The friction factor values of predicted from Eqs. (8.3) and (8.4) were compared with the experimental values and found to agree within ±13% for Phase 1 and Phase 2 and is shown in Fig.8.6.
Fig. 8.5 Variation of friction factor with Reynolds number for various designs of Kenics twist
Fig. 8.6 Comparison of experimental friction factor with correlation values
8.4 THERMAL PERFORMANCE

The variation of instantaneous efficiency with solar radiation for plain tube collector, collector with full length Kenics and twist with rod and spacer are shown in Fig.8.7

The instantaneous efficiency of full length twisted tape collector is always higher than the plain tube collector and other collectors with modified designs of twisted tapes. The fluid flow in tangential direction induced by the twist increases the wetted surface area and hydraulic length of the fluid which in turn magnifies the convective heat transfer between the tube wall and fluid. In the case of plain tube collector, in the absence of twist, there is no agitation of fluid particles and it follows a smooth streamlined flow in axial direction. This ultimately leads to more thermal losses and yield poor instantaneous efficiency.

For a solar radiation of 989 W/m², the instantaneous thermal efficiency of full length Kenics twisted tape collector is 90.58% and the same for plain tube collector is 65.4%. Instantaneous thermal efficiency for twist with rod of 125 mm, 250 mm and 500 mm length are 89.1%, 87.29% and 84.9% respectively. The same for twist with spacer of above said length are 87.3%, 86.2% and 84.1% respectively.

In case of twist with rod, the continuation of swirl flow and particle turbulence in the rod section increases the Instantaneous efficiency significantly than plain tube collector and the reduction is marginal when compared to full length twist.

In case of twist with spacer, the intensity of particle agitation suddenly vanished in the spacer section and leads to higher overall heat loss coefficient due to the reduction in wetted surface area and minimum swirl when
compared to full length twist and twist with rod. The particle turbulence and continuation of swirl flow is directly proportional to the length of the spacer.

Fig. 8.7 Variation of Instantaneous efficiency with solar radiation

The variation of absorber plate temperature with solar radiation is shown in Fig. 8.8. It is observed that the absorber plate temperature of plain tube collector is high and is low for collector with full length twist. In collector with full length twist maximum heat is removed from the absorber plate due to high intensity particle agitation induced by the twist. This indicates that the heat loss coefficient for full length twisted tape collector is minimum and has minimum absorber plate temperature. In case of plain tube collector, the heat removal is only by simple convective heat transfer and the internal tube surface area is comparatively lesser due to the absence of twist inserts. The heat transfer between the fluid and the absorber decreases thereby increase the absorber plate temperature.
For solar radiation of 989 W/m², the heat removal factor for full length Kenics twisted tape collector and plain tube collector are 0.99 and 0.82 respectively. For twist with rod of length 125 mm, 250 mm and 500 mm, the heat removal factor observed are 0.98, 0.97 and 0.95 respectively. The same for twist with spacer of above said lengths are 0.97, 0.94 and 0.92 respectively. This indicates that the heat removal factor is indirectly proportional to the length of the rod and spacer; overall heat loss coefficient is directly proportional to the length of the rod and spacer.

Fig.8.8 Effect of rod and spacer on absorber plate temperature

8.5 REMARKS

Experimental studies on heat transfer and friction factor characteristics of solar water heater fitted with full length Kenics and Kenics twist with rod and spacer are performed and compared with plain tube collector. From the experiments the following are observed.

i. The increase in Nusselt number for full length Kenics is 4.42 times higher than the plain tube collector. For twist with rod and spacer the decrement in Nusselt number varies between 0.7% and 18% compared to full length Kenics.

ii. The friction factor for full length twist is 2.59 times greater than the friction observed in plain tube collector. For twist with rod and spacer the reduction in friction factor varies between 2% and 20% compared to full length Kenics.

iii. The thermal performance of the collectors using different designs of Kenics twists showed significant improvement. Instantaneous thermal efficiency for full length Kenics twist improved by 1.7 times compared to plain tube collector. For twist with rod and spacer, the decrement in thermal efficiency varies between 1% and 13% compared to full length twist.

iv. The average heat removal factor for plain tube collector is 0.61 and for full length Kenics twist is 0.96. For Kenics twist with rod and spacer it varies between 2% and 5.2%