CHAPTER 12

CONCLUSIONS AND RECOMMENDATION FOR FUTURE WORK

This chapter scrutinizes the concluding remarks from the experimental and simulation studies and is as narrated below.

12.1 CONCLUSIONS FROM EXPERIMENT

The following conclusions have been drawn based on the results obtained from the experimental studies. The heat transfer, friction factor and thermal effects are studied for helical, Left-Right, Kenics and Customized twists tape collectors and performance is compared with that of the plain tube collector. The experimentation is carried out throughout the day.

12.1.1 Plain tube collector

1. The experimental data obtained for plain tube collector is compared with Sieder-Tate and Fanning equation from literature for Nusselt number and friction factor with an average deviation of $\pm 6\%$ and $\pm 11.05\%$ respectively.

2. The heat transfer increases and friction factor decreases in Phase 1 due to the increase in mass flow rate and solar radiation. In Phase 2, the decrease in solar radiation and mass flow rate reduces the heat transfer effect and increases the friction factor. Due to the above characteristics, the Instantaneous efficiency increases from 29% to 64.7% in Phase 1 and later decreases from 64.7% to 31.4 % in Phase 2. The improvement in thermal performance of helical, Left-Right,
Kenics and Customized twisted tape collectors are compared with that of the plain tube collector.

12.1.2 Helical twisted tape collector

1. The maximum heat transfer, friction factor and thermal performance are obtained in helical twisted tape collector as compared to that of plain tube collector, due to swirl generation.

2. The Nusselt number obtained for full length helical twist and plain tube collector is 14.4 and 5.4 for the same input of solar radiation (1106 W/m²). Similarly the friction factor is 0.104 and 0.034. The Instantaneous efficiency for the same is 76.25 and 66.28%.

3. Presence of rod and spacer in helical twist significantly reduces the friction factor values with marginal decrement in the thermal performance. This is due to the decline in the swirl effect induced in the rod and spacer section.

4. The heat removal factor, a measure of the thermal performance of the system stands high for full length helix. The heat removal factor for full length helix is 0.81 and it decreases with increase in rod and spacer length. It is 0.79, 0.77 and 0.75 for R125, R250 and R500 respectively. Similarly for twist with spacer of the same length its values are 0.78, 0.76 and 0.73.

5. The Nusselt number for twisted tapes is reliant on twist ratio, Reynolds number and Prandtl number. Similarly friction factor is leaning on twist ratio and Reynolds number. Based on the above, correlations are developed and compared with the experimental values with an average
deviation of ±11.23% and ±11.41% for Nusselt number and friction factor respectively.

12.1.3 Left-Right twisted tape collector

1. The heat transfer, friction factor and thermal performance characteristics of full length Left-Right twist is compared with its modified forms and with plain tube collector. For a solar intensity of 1106 W/m², the Nusselt number obtained for full length twist and modified forms of twist with rod and spacer (LR125, LR500 & LSP125, LSP500) are 23.58, 23.1, 20.5 and 22.7, 19.7 respectively. Similarly the friction factor is 0.107, 0.101, 0.091 and 0.0948, 0.077 and the Instantaneous thermal efficiency is 83.5%, 82.5%, 78.4% and 81.4%, 76.8%.

2. The maximum heat transfer, friction factor and thermal performance have been obtained for full length Left-Right twist compared to its modified forms with rod and spacer.

3. The heat removal rate obtained is 0.885 for full length twist 0.87, 0.80 for twist with rod 125 mm and 500 mm and 0.86, 0.781 for twist with spacer of same length respectively.

4. The empirical correlations developed for Nusselt number and friction factor for the above are compared with the experimental data with an average deviation of ±14.86% and ±13%.
12.1.4 Kenics twisted tape collector

1. The heat transfer, friction factor and thermal performance characteristics of full length Kenics twist is compared with its modified forms and with plain tube collector. For a solar intensity of 989 W/m$^2$, the Nusselt number obtained for full length twist and modified forms of twist with rod and spacer (KR125, KR500 & KS125, KS500) are 26.6, 26.1, 23.5 and 26.01, 21.8 respectively. Similarly the friction factor is 0.111, 0.104, 0.094 and 0.0984, 0.079 and the Instantaneous thermal efficiency is 83.5%, 82.5%, 78.4% and 81.4%, 76.8%.

2. The maximum heat transfer, friction factor and thermal performance have been obtained for full length Kenics twist compared to its modified forms with rod and spacer.

3. The heat removal rate obtained is 0.986 for full length twist 0.935, 0.89 for twist with rod 125 mm and 500 mm and 0.922, 0.812 for twist with spacer of same length respectively.

4. The empirical correlations developed for Nusselt number and friction factor for the above twist ratio are compared with the experimental data with an average deviation of ± 18% and ± 13%.

12.1.5 Customized twisted tape collector

1. The heat transfer, friction factor and thermal performance characteristics of full length customized twist is compared with its modified forms and with plain tube collector. For a solar intensity of 988 W/m$^2$, the Nusselt number obtained for full length twist and modified forms of twist with rod and spacer (MTR125, MTR500 & MTS125, MTS500) are 21.53, 21.02, 17.23 and 20.59, 15.65
respectively. Similarly the friction factor is 0.1073, 0.1016, 0.091 and 0.0987, 0.0727 and the Instantaneous thermal efficiency is 82.85%, 82.25%, 78.9% and 81.8%, 77.9%.

2. Like other twisted tape systems, maximum heat transfer, friction factor and thermal performance have been obtained for full length customized twist compared to its modified forms with rod and spacer.

3. The heat removal rate obtained is 0.875 for full length twist 0.867, 0.828 for twist with rod 125 mm and 500 mm and 0.856, 0.812 for twist with spacer of same length respectively.

4. The empirical correlations developed for Nusselt number and friction factor for the above twist ratio are compared with the experimental data with an average deviation of ±19% and ±15%.

The heat transfer, friction factor and thermal efficiency of systems with helical and Left-Right Kenics and customized twists tape collectors twisted tapes with constant twist ratio of 3, as compared to a plain tube system are as tabulated below.

### 12.2 FINAL VERDICT

Based on the experimental results Kenics twisted tape collector offered higher thermal performance and flow friction which is comparatively higher than twisted tape systems. As far as the twist with rod and spacer is concerned, Kenics twist with rod of length 125 mm offered better thermal performance and relatively lesser flow friction. The comparison of performance between various collectors with the standard plain tube collector is given in Table.12.1
### Table 12.1 Comparison of performance between various collectors

<table>
<thead>
<tr>
<th>System</th>
<th>Nusselt Number</th>
<th>Friction Factor</th>
<th>Thermal Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rod</td>
<td>Spacer</td>
<td>Rod</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>Full Length</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain (Standard)</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kenics</td>
<td>4.42</td>
<td>4.38</td>
<td>4.19</td>
</tr>
<tr>
<td></td>
<td>1.65</td>
<td>1.64</td>
<td>1.60</td>
</tr>
<tr>
<td>Left-Right</td>
<td>4.12</td>
<td>4.02</td>
<td>3.84</td>
</tr>
<tr>
<td></td>
<td>1.55</td>
<td>1.53</td>
<td>1.47</td>
</tr>
<tr>
<td>Customized</td>
<td>3.74</td>
<td>3.67</td>
<td>3.53</td>
</tr>
<tr>
<td></td>
<td>1.53</td>
<td>1.52</td>
<td>1.38</td>
</tr>
<tr>
<td>Helix</td>
<td>2.69</td>
<td>2.61</td>
<td>2.46</td>
</tr>
<tr>
<td></td>
<td>1.35</td>
<td>1.31</td>
<td>1.27</td>
</tr>
</tbody>
</table>
12.3 CONCLUSION FROM SIMULATION

The simulation studies have been carried out by using computational fluid dynamics and the simulated results are compared with the experimental values for validating the experimental results.

12.3.1 Plain tube collector

1. The data obtained by simulation are validated with Sieder-Tate and Fanning equations for plain tube collector for Phase 1 and Phase 2 with an average deviation of $\pm 9.61\%$ for Nusselt number and $\pm 14.21\%$ for friction factor respectively. The simulation trend for Nusselt number and friction factor for Phase 1 and Phase 2 are similar to the experimental trend.

12.3.2 Twisted tape collectors

1. CFD simulation for the heat augmentation and friction factor in a helical twisted tape collector and its modified forms with rod and spacer of different length under laminar flow conditions has been studied using Fluent version 13.0. The data obtained in simulation are compared with the experimental data with an average deviation of $\pm 12.5\%$ and $\pm 14.8\%$ for Nusselt number and friction factor respectively.

2. In the same way the heat augmentation and friction factor in a Left-Right twisted tape collector and its modified forms with rod and spacer of different length under laminar flow conditions has been studied. The data obtained in simulation are compared with the experimental data with an average deviation of $\pm 9.18\%$ and $\pm 11.8\%$ for Nusselt number and friction factor respectively.
3. Similarly for Kenics twisted tape collector and its modified forms with rod and spacer of different length, the heat augmentation and friction factor under laminar flow conditions has been analyzed. The data obtained in simulation are compared with the experimental data with an average deviation of \( \pm 12.18\% \) and \( \pm 10.32 \% \) for Nusselt number and friction factor respectively.

4. For customized twisted tape collector and its modified forms with rod and spacer of different length the heat augmentation and friction factor under laminar flow conditions has been deliberated. The simulation results agree with the experimental data with an average deviation of \( \pm 13.11\% \) and \( \pm 9.62 \% \) for Nusselt number and friction factor respectively.

12.4 SCOPE FOR FUTURE WORK

1. The present study reports that heat transfer and friction factor characteristics of twist with twist ratio of 3. This work may be extended by using twists with higher twist ratios which may be useful in reducing the friction factor.

2. Current study analyzes the performance of twist without centre core-rod. Thermal performance improvement of the system by using centre core-rod may be analyzed.

3. In the present investigation tight fit twisted tape is used for comparing the performance characteristics. The same may be analyzed by using loose fit twists.
4. The present work employs water as the working fluid. Performance of the system using different working fluids such as refrigerants, nanofluids etc. can be analyzed.

5. Finally this study is restricted to laminar flow conditions and it can be extended to turbulent flow condition.

12.5 GENERAL REMARKS

Based on the experimental results, it is really advantageous to use a twisted tape collector instead of a standard plain tube collector. The advantages of twisted tape collector over the standard one are listed below.

i. Higher thermal performance
ii. Reduction in physical dimension and weight
iii. Conservation of fossil fuels
iv. Reduction in cost

Disadvantages:

There is no significant disadvantage other than the few listed below.

i. Clogging of water due to the deposition of sediments/fouling and it need periodic cleaning of twists and tubes.
ii. Slight complexity in the design