University of Huddersfield Repository

Freegah, Basim, Asim, Taimoor, Albarzenji, Dlir, Pradhan, Suman and Mishra, Rakesh

Effect of the shape of connecting pipes on the performance output of a closed-loop hot water solar Thermo-syphon

Original Citation

Freegah, Basim, Asim, Taimoor, Albarzenji, Dlir, Pradhan, Suman and Mishra, Rakesh (2014)

This version is available at http://eprints.hud.ac.uk/21222/

The University Repository is a digital collection of the research output of the University, available on Open Access. Copyright and Moral Rights for the items on this site are retained by the individual author and/or other copyright owners. Users may access full items free of charge; copies of full text items generally can be reproduced, displayed or performed and given to third parties in any format or medium for personal research or study, educational or not-for-profit purposes without prior permission or charge, provided:

- The authors, title and full bibliographic details is credited in any copy;
- A hyperlink and/or URL is included for the original metadata page; and
- The content is not changed in any way.

For more information, including our policy and submission procedure, please contact the Repository Team at: E.mailbox@hud.ac.uk.

http://eprints.hud.ac.uk/
Effect of the shape of connecting pipes on the performance output of a closed-loop hot water solar Thermo-syphon

B. Freegah  
University of Huddersfield  
Huddersfield, UK  
HD1 3DH  
basim.freegah@hud.ac.uk

T. Asim  
University of Huddersfield  
Huddersfield, UK  
HD1 3DH  
t.asim@hud.ac.uk

D. Albarzenji  
University of Huddersfield  
Huddersfield, UK  
HD1 3DH  
dilr.albarzenji@hud.ac.uk

S. Pradhan  
University of Huddersfield  
Huddersfield, UK  
HD1 3DH  
s.r.pradhan@hud.ac.uk

R. Mishra  
University of Huddersfield  
Huddersfield, UK  
HD1 3DH  
r.mishra@hud.ac.uk

ABSTRACT
In order to conserve the environment from pollution, which is caused by the use of the fossil fuels, numerous research works have been carried out in renewable energy area to minimize the dependency on the fossil fuels. There are several energy sources naturally available, and solar energy is considered to be the best amongst them. Therefore it became a motivating area for the researchers in recent years. Thermo-syphon is one of many devices that use solar energy for power generation. Thermo-syphon converts solar energy into internal energy of the working fluid; mainly water. In this work, a computational fluid dynamics (CFD) code has been used to analyse the natural convection phenomenon in a thermo-syphon. The thermo-syphon model consist of steel pipes with an internal diameter of 25mm, along with a condenser having diameter equal to five times the pipe’s diameter, has been considered. The study has been carried out under no-loading conditions, for two thermo-syphon models comprising of straight and helical shaped pipes of 10, 20 and 30. A practical solar heat flux of 500W/m² has been applied on the pipes. The numerical results depict that the working fluid within the condenser, in case of helical pipes, gains higher temperature as compared to the straight pipes. Furthermore, increase in the number of helical pipes has negligibly small effect on the temperature of the fluid within the condenser, and hence on the performance output of the thermo-syphon.

Keywords
Computation Fluid Dynamics (CFD), Thermo-syphon, Helical pipe, Natural Convection

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>q</td>
<td>Heat flux (W/m²)</td>
</tr>
<tr>
<td>U</td>
<td>Overall heat transfer coefficient (W/m²·°C)</td>
</tr>
<tr>
<td>ΔT</td>
<td>the difference in temperature (°C)</td>
</tr>
<tr>
<td>T</td>
<td>temperature of water within the condenser (°C)</td>
</tr>
<tr>
<td>Tavg</td>
<td>average temperature within the condenser (°C)</td>
</tr>
<tr>
<td>t</td>
<td>time of operation (minute)</td>
</tr>
<tr>
<td>tavg</td>
<td>average time (minute)</td>
</tr>
<tr>
<td>nt</td>
<td>number of turns</td>
</tr>
<tr>
<td>np</td>
<td>number of pipes</td>
</tr>
</tbody>
</table>

1. INTRODUCTION
The amount of heat transfer through any material depends on several parameters; such as temperature variations, overall heat transfer coefficient, heat transfer surface area etc., as shown in Eq. (1).

\[ q = U\Delta T \] (1)

In recent decades, many researchers have been trying to improve the design of thermo-syphon in order to obtain excessive amount of useful heat energy. KE Amori et al. 2012 conducted a comparative study between a traditional absorber and a new design of solar collectors (known as the accelerated absorber) to analyse the performance of these systems. The performance evaluation was carried out in identical conditions for both the systems, having tilt angle of 33°. The evaluation tests were carried out in the presence of two different types of storage tanks. The results have shown that there is a significant increase in the thermal performance of the thermo-syphon (approximately 60%) for the new system. It has been observed that the temperature within the storage tank for the new design is 13°C higher to the conventional type. Subramanian et al. 2012 studied the impact of riser arrangement (zigzag pattern) on the performance of a flat plate collector system, and compared it with the conventional system. Experiments were conducted using copper tubes in header and riser having various geometrical characteristics. The results have shown that the performance efficiency reached 62.9% in the zigzag arrangement. El-Din et al. 2005 experimentally investigated the properties evaluation of the heat transfer in single-phase flow. In their study, a toroidal thermo-syphon type has been used. The parameters of investigation include heated-cooled length ratio, heated length tube diameter ratio, diameter ratio of torus-tube, and angle of inclination. Their results show that the increase in both heated-cooled length ratio and heated length-tube diameter ratio leads to decrease in the heat transfer rate, whereas increase in torus-tube diameter ratio increases the heat transfer rate. Furthermore, it was found out that the range of tilt angles between 30° and 45° produces maximum heat transfer rate. Freegah et al. 2013 numerically studied the effects of the length to diameter ratio of the riser, number of connecting pipes, angle of inclination of the thermo-syphon and the heat flux, on the performance of the
thermo-syphon. It was found that the heat flux and the length to
diameter ratio of the pipes have significant effects on the
performance of a thermo-syphon, whereas, the angle of inclination
has negligibly small effect. Furthermore, an increase in the number
of connecting pipes increases the temperature of the working fluid,
as they absorb more solar energy. Gurveer et al 2014 conducted an
experimental study to investigate the effects of the inclination
angle, wire coil inserts and wire mesh inserts on the thermal
performance of a flat-plate solar collector. The results that have
been reported indicate that the Nusselt number in novel insert
configuration is higher as compared to the conventional system,
and hence the thermal performance for the novel insert
configuration has been observed to be better than the conventional
one.
This study is the continuation of Freegah et al. 2013 and hence
the natural convection phenomena, and the distribution of
temperature and velocity of the working fluid, has not been
discussed in detail in the present study. Computational Fluid
Dynamics based tools have been used to carry out an extensive
numerical study, on the effects of using helical pipes, on the
performance of a closed-loop solar hot water thermo-syphon
system. The effects of helical pipes in a thermo-syphon have not
been explicitly analysed in the literature, and hence this study is
important for the design process of such systems.

2. NUMERICAL MODELLING
Two thermo-syphon configurations, comprising of helical and
straight pipes, have been modelled. The geometry of the two
models is shown in Figure 1. An internal diameter of 25mm has
been used for both helical and straight connecting pipes, with a
thickness of 2mm. Furthermore, the recirculating pipe, which has
been used in both the models, has the same diameter and thickness
as that of the connecting pipes. It has been assumed that the
thermo-syphon is operating under no-load condition. The diameter
of the condenser is five times the diameter of the pipes, and the
diameter of the collector is twice as that of the pipes. The working
fluid considered is water.
Hybrid meshing has been employed, using both hexagonal and
tetrahedral elements. Non-uniform mesh distribution has been
used, where the mesh elements are concentrated near the wall
region, using 10 layers of mesh elements. The mesh contains two
million elements, and has been shown previously to describe the
flow phenomena with reasonable accuracy. Furthermore, a time
step size of 12sec has been used.
Boussinesq approximation has been employed to accurately model
buoyant forces being generated. This approximation states that the
density differences are sufficiently small to be neglected, except
where they appear in terms multiplied by $g$ i.e. the acceleration
due to gravity. The essence of the Boussinesq approximation is
that the difference in inertia is negligible, but gravity is sufficiently
strong to make the specific weight appreciably different.
Furthermore, it has been observed by Dehdakhel et. al. 2010 that
the Boussinesq approach for the density of the working fluid in a
thermo-syphon gives fairly accurate results, and thus has been
used in the present study.
Three dimensional Navier-Stokes equations, in addition to the
continuity and the energy equations, have been numerically solved
in an iterative manner to simulate the transient flow of water in the
thermo-syphon for one hour of operational time.

3. Results and Analysis
Freegah et al 2013 successfully simulated the natural convection
phenomena in thermo-syphon; the simulations conducted to
investigate the effect of number of the straight pipes, the tilt angle
and the length-to-diameter ratio on thermo-syphon’s performance.
Authors presented numerical results in the form of temperature
contour within the thermo-syphon to show the natural convection
phenomenon (figure 2).
In the present study, which is a continuation of Freegah et al 2013, the effect of the number of turns in a helical pipe, on the temperature within the condenser, has been numerical analysed. The boundary conditions are the same for all the numerical simulations.

3.1. Straight pipes

Figure 3 depicts the temperature distribution within the cross-section of the condenser of the thermo-syphon model comprising of straight connecting pipes. It can be clearly seen that the hot working fluid occupies the upper section of the condenser while the cold working fluid settles on the bottom of the condenser.

3.2. Helical pipes

Figure 5 shows comparison of the temperature within the condenser for the straight and helical connecting pipes comprising of 10 turns. It can be clearly seen that the hot working fluid occupies the upper section of the condenser while the cold working fluid settles on the bottom of the condenser. It can also be seen that the average temperature of water is higher for helical pipe as compared to the straight pipe. This shows that by using helical pipes, the temperature within the condenser can be increased.

Figure 6 depicts the effect of the number of turns of the helical pipes on the condenser’s temperature after one hour of operating time. Figure 2(a) shows the difference between 20 and 10 turns, while figure 2(b) shows the difference between 30 and 20 turns. It can be seen that the temperature of the working fluid increases as the number of turns increases. This is true for both the cases i.e. increase from 10 turns to 20 turns, and increase from 20 turns to
30 turns. After one hour of operation, temperature difference within the condenser for straight pipes, 10 turns, 20 turns and 30 turns are 9.86°C, 9.3°C, 5.4°C, 4.39°C respectively.

Figure 6. Comparison in condenser’s temperature between (a) 20 and 10 turns (b) 30 and 20 turns

Figure 7 depicts the variations in the condenser’s temperature for three helical models. It can be seen that the temperature of the condenser increases linearly in all the different cases. Furthermore, the condenser’s temperature is considerably higher in case of 30 turns as compared to 20 and 10 turns’ cases, after one hour of operation. Meanwhile, the difference in the condenser’s temperature between 10 turns and 20 turns is significantly higher than the difference between 20 turns and 30 turns. This is because the increase in the volume of the working fluid from 10 turns to 20 turns model is 100%, whereas it is 50% from 20 turns to 30 turns.

Figure 7. Variations in condenser’s temperature for three models consisting of 10, 20, and 30 turns

Figure 8 depicts the variations in the condenser’s temperature with 10 turns configuration, however with different number of helical pipes (3 and 5 connecting pipes). After one hour of operating time, the difference in condenser’s temperature is 1°C between 3 and 5 connecting pipes. It can be seen that the working fluid’s temperature within the condenser is negligibly higher for 5 connecting pipes as compared to 3 connecting pipes.

Figure 8. Variations in condenser’s temperature for two helical models consisting of 3 and 5 connecting pipes

Temperature variations in the working fluid within the condenser for straight and helical pipes, at different times of operation, have been summarised in table 1. It can be clearly see that increase in time of operation and number of turns lead to increased temperature within the condenser. For example, for three connecting pipes, after one hour of turns, the temperature of the working fluid increases by 12.66%, 24.78%, and 30.10% for 10, 20 and 30 turns respectively, compared to straight pipes model.
### Table 1. Temperature of water in straight and helical pipe models at different times of operation

<table>
<thead>
<tr>
<th>Time (minute)</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature in 3 straight pipes model (°C)</td>
<td>33.40</td>
<td>39.80</td>
<td>46.10</td>
<td>52.40</td>
</tr>
<tr>
<td>Temperature in 5 straight pipes model (°C)</td>
<td>34.81</td>
<td>42.54</td>
<td>50.19</td>
<td>57.79</td>
</tr>
<tr>
<td>Temperature in 3 helical pipes model (°C) 10 turns</td>
<td>34.40</td>
<td>43.10</td>
<td>51.60</td>
<td>60.10</td>
</tr>
<tr>
<td>Temperature in 3 helical pipes model (°C) 20 turns</td>
<td>36.80</td>
<td>47.50</td>
<td>58.60</td>
<td>69.80</td>
</tr>
<tr>
<td>Temperature in 3 helical pipes model (°C) 30 turns</td>
<td>37.10</td>
<td>50.50</td>
<td>62.10</td>
<td>75.10</td>
</tr>
<tr>
<td>Temperature in 5 helical pipes model (°C) 10 turns</td>
<td>34.20</td>
<td>42.20</td>
<td>50.71</td>
<td>58.99</td>
</tr>
<tr>
<td>Temperature in 5 helical pipes model (°C) 20 turns</td>
<td>36.06</td>
<td>46.53</td>
<td>57.67</td>
<td>68.54</td>
</tr>
<tr>
<td>Temperature in 5 helical pipes model (°C) 30 turns</td>
<td>35.29</td>
<td>50.16</td>
<td>60.51</td>
<td>74.13</td>
</tr>
<tr>
<td>Temperature in 5 helical pipes model (°C) 20 turns</td>
<td>3.40</td>
<td>8.50</td>
<td>12.90</td>
<td>15.67</td>
</tr>
<tr>
<td>Temperature in 5 helical pipes model (°C) 30 turns</td>
<td>1.35</td>
<td>15.18</td>
<td>17.10</td>
<td>22.03</td>
</tr>
</tbody>
</table>

From the numerical results, using multiple regression analysis, equation (2) has been formulated in order to calculate working fluid’s temperature within the condenser for various thermo-syphon configurations. In order to check validity of Eq. (2) $T/T_{avg}$ values have been calculated using Eq. (2), and compared against the results presented in table 1. It has been observed that Eq. (2) gives an average percentage error of 9.3% compared to the results presented in table 1, and hence this equation can be used to predict the temperature within the condenser with 90.7% accuracy.

\[
\frac{T}{T_{avg}} = \left(10^{0.028}\left(\frac{t}{t_{avg}}\right)^{0.454}(nt)^{0.0124}(np)^{0.00137}\right)\text{ for }0 < \left(\frac{t}{t_{avg}}\right) \leq 0.8
\]

\[
\left(10^{0.028}\left(\frac{t}{t_{avg}}\right)^{0.454}(nt)^{0.0124}(np)^{0.00137}\right)\text{ for }0.8 < \left(\frac{t}{t_{avg}}\right) \leq 1.6
\]

### 4. Conclusions

In the present work, CFD simulations have been conducted for thermal performance evaluation for two types of thermo-syphon, namely helical connecting pipes and conventional thermo-syphon. From the numerical results, it can be concluded that a considerable enhancement in the performance output of the thermo-syphon is obtained for the helical pipe configurations, in comparison with the conventional model. Furthermore, increasing the number of turns in the helical connecting pipes increases the condenser’s temperature. Moreover, increasing the number of helical connecting pipes does not enhance the performance of the thermo-syphon significantly. It is expected that this study will help in the design process of thermo-syphons with optimal thermal performance.

### 5. References


