Ultra Low Cost Solar Water Heater

Engineering Analysis

11/19/13

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Overview

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• Parabolic Collector Analysis
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Bread Box Collector
Bread Box Collector Analysis

Energy Balance

\[ q_{\text{sun}} = q_{\text{in}} + q_{\text{radiation loss}} + q_{\text{losses}} \]

\[ q = \frac{\Delta T}{R} \]
Resistance Network

\[ R_{\text{conv}} = \frac{1}{hA_c} \]

\[ R_{\text{cond}} = \frac{L}{kA} \]

\[ R_{\text{conv}} = \frac{1}{hA_c} \]

\[ R_{\text{cyl,wall}} = \frac{r_2/r_1}{2\pi kL} \]

\[ T_\infty \quad 1 \quad R = 0.2000 \quad 2 \quad R = 0.0032 \quad T_{\text{air,in}} \quad 3 \quad R = 0.0598 \quad T_{s,\text{out}} \]

\[ T_{s,\text{out}} \quad 4 \quad R = 0.0005 \quad T_{s,\text{in}} \]

Chris Heine
Calculations

\[ q_{\text{sun}} = q_{\text{in}} + q_{\text{radiation loss}} + q_{\text{losses}} \]

\[ q_{\text{sun}} = \frac{T_{s,\text{out}} - T_{s,\text{in}}}{R_{\text{pipewall}}} + A\varepsilon\sigma(T_s^4 - T_{\text{surr}}^4) + \frac{T_{\text{air, in}} - T_\infty}{R_{\text{conv}} + R_{\text{cond}} + R_{\text{conv}}} \]

Key Assumptions: Some temperature values, heat transfer coefficient values

Plug in values to get:

\[
1309.83 = \frac{378K - T_{s,\text{in}}}{.0005} + 52.05 + \frac{378 - 293}{0.2000 + .0032 + .0598}
\]

Now: \( T_{s,\text{in}} = 104.6K \)

Solve: \( q_{\text{in}} = \frac{T_{s,\text{out}} - T_{s,\text{in}}}{R_{\text{pipewall}}} \)

Final Value:

\[ q_{\text{in}} = 776.7W \]
Parabolic Collector
Parabolic Collector

• Solar radiation:
  – 1070 W for painted galvanized steel pipe
  – 717 W for unpainted galvanized steel pipe

• Energy Balance:

\[ q_{solar} = q_{radiation} + q_{convection,out} + q_{in} \]
Parabolic Collector

- Radiation losses

\[ q_{\text{radiation}} = A_s \varepsilon \sigma (T_{s,o}^4 - T_\infty) \]

- Convection out

\[ q_{\text{conv},o} = \frac{(T_{s,o} - T_\infty)}{R_{\text{conv},o}} \]

\[ R_{\text{conv},o} = \frac{1}{h \pi r_o L} \]

\[ Nu_D = \frac{h_o D_o}{k_{\text{air}}} = C Re^{m} Pr_o^{1/3} \]
Parabolic Collector

• q in

\[ q_{in} = \frac{(T_{s,0} - T_w)}{R_{conv,i} + R_{cond}} \]

• Resistances

\[ R_{conv,i} = \frac{1}{h_i 2\pi r_i L} = 0.024223 \]
\[ R_{cond} = \frac{\ln \left( \frac{r_o}{r_i} \right)}{2\pi k_{steel} L} = 6.68 \times 10^{-5} \]
Parabolic Collector

• Solving for \( T_{s,o} \)

\[
q_{solar} = A_s \varepsilon \sigma (T_{s,o}^4 - T_\infty) + \frac{(T_{s,o} - T_\infty)}{R_{conv,o}} + \frac{(T_{s,o} - T_w)}{R_{conv,i} + R_{cond}}
\]

\[T_{s,o} = 318.53^\circ K\]

• Substituting back in to \( q \) in

\[
q_{in} = \frac{(T_{s,o} - T_w)}{R_{conv,i} + R_{cond}}
\]

\[
q_{in} = 737.0396 \text{ W}
\]

\[
q_{in} = 514 \text{ W}.
\]
Flat Plate Collector

- $q_{solar} = q_{into\ water} + q_{radiation\ loss} + q_{other\ losses}$
$Ra_L \overset{\text{def}}{=} \frac{g\beta(T_1 - T_2)L^3}{\alpha \nu} \rightarrow 1708$

The Rayleigh number was found to be 647 with a gap of 5mm between the pipes and the glass.
Flat Plate Collector Analysis

\[ q_{\text{into water}} = 738.475 \, \text{W/m}^2 \]

\[ q_{\text{other losses}} = 27.506 \, \text{W/m}^2 \]

\[ q_{\text{solar}} = 765.99 \, \text{W/m}^2 \]

\[ q_{\text{radiation loss}} = 1.222 \, \text{W/m}^2 \]

**Calculations on this side provided for Galvanized pipe covered by glass**
Flat Plate Collector Analysis

\[ T_{mo} = T_{mi} + \frac{q_{\text{into water}}PL}{\dot{m}C_p} \approx 284^\circ K \]

Mass flow rate was chosen so the pipe system would be replaced every minute. Using tabulated inlet temperatures the final temperature can be calculated at the exit of the solar collector.

Average Water Inlet Temperature in Phoenix Arizona: 82.3 degrees Fahrenheit
Results

Absorption/area/$:

- Bread box: Best design used glass as a cover and cost $201.36 (with circulation) based on $1.67 m^2$. A/A/$ comes out to 2.31.
- Parabolic: Best design used galvanized, black painted pipes and cost $260.23 (with circulation) based on 1.16m^2. A/A/$ comes out to 2.44.
- Flat plate: Using galvanized piping with no spacing and cost $488.41 (with circulation) based on .93m^2. A/A/$ comes out to 1.63.

- It is most likely that we will use the parabolic collector with galvanized, black painted pipes based on this analysis.
Timeline

Gantt Chart

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<tr>
<th>Name</th>
<th>Begin date</th>
<th>End date</th>
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<tr>
<td>Research</td>
<td>9/2/13</td>
<td>10/15/13</td>
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<tr>
<td>Problem Formulation and Project Plan</td>
<td>9/4/13</td>
<td>10/8/13</td>
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<td>Problem Formulation/Project Plan Presentation</td>
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<tr>
<td>Identify Key Technologies and Approaches</td>
<td>10/16/13</td>
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<td>Prepare Concept Generation and Selection</td>
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Conclusion

• In summary, the analysis of the bread box, parabolic, and flat plate collectors showed that the parabolic collector had the highest A/A/$.  
• Our next step will be the circulation analysis which will be completed on the 25\textsuperscript{th} of Nov. 
• The proposal will be finalized on the 3\textsuperscript{rd} of Dec.


