EFFICIENCY OF EVACUATED TUBULAR SOLAR THERMAL COLLECTOR

Junkun Ma; Xialu Wei
Southeastern Louisiana University

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Solar heating

- Solar thermal energy for both domestic and commercial applications such as water heating;
- Composed of solar thermal collectors, storage tank, heat exchanger, and control systems;
- A thermodynamic process;
- Passive vs. active systems
- High efficiency of converting and utilizing solar energy.
Solar Thermal Collector

- Solar Thermal Collector
  - Captures the sun’s radiation energy;
  - Turns solar energy into thermal energy;
  - Transfers heat to the working fluid.

- Batch Collector
  - Easy to design and install;
  - Less energy capture;
  - Inefficient.
Solar Thermal Collector (continue)

- Flat Plate Collector
  - Weather proofed box;
  - Dark absorber plate;
  - Flow tubes

- Evacuated Tube Collector
  - Two concentric glass tubes;
  - Vacuum in between;
  - Most efficient collector.
Objectives

- Efficiency of Single Ended Evacuated Tube Collector
Objectives (continue)

- **Mounting Angle**
  - Components of gravity:
  - Facilitating or impeding Efficiency;
  - Range: $15^\circ - 90^\circ$.

- **Aspect Ratio**
  - Aspect ratio between tube diameter and length;
  - Longer tube vs. shorter tube (same diameter);
  - Length: 1.2m – 1.8m.

\[ G_x = G \cdot \sin \theta \\
\[ G_y = G \cdot \cos \theta \]
Approaches – Geometry Modeling

- 2D and 3D Geometric Models
  - Length: 1200 mm
  - Inner Tube Diameter: 47 mm
  - External Tube Diameter: 52 mm
## Approaches – System Analysis

### Heat Transfer

**Heat Conduction in Solid:**

\[ \nabla \cdot (-k \nabla T) = Q \]

Where,

- \( k \): thermal conductivity;
- \( T \): absolute temperature;
- \( Q \): heat source.

**Heat Convection in Fluid**

\[ \nabla \cdot (-k \nabla T) = Q - \rho C_p u \cdot \nabla T \]

Where,

- \( \rho \): density of fluid;
- \( C_p \): specific heat capacity;
- \( u \): velocity of fluid.
Fluid Dynamics

Causes: Temperature difference and density changes

\[ \rho u \cdot \nabla u = \nabla [-pI + \eta (\nabla u + (\nabla u)^T) - (2/3)\eta (\nabla \cdot u)I] + F \]

\[ \nabla \cdot (\rho u) = 0 \]

Where:

\( \rho \): density;

\( u \): velocity field;

\( p \): pressure;

\( I \): identity matrix;

\( \eta \): dynamic viscosity;

\( F \): volume force.
Approaches – System Analysis

- **Volume Force - F**
  - Acting on a unit volume of water
  
  Volume Force = Buoyancy – Gravity

  \[
  F = \frac{(B - G)}{V} \\
  = \frac{(\rho \cdot g \cdot V' - \rho \cdot g \cdot V)}{V} \\
  = \rho \cdot g \cdot \frac{(V' - V)}{V} \\
  = \rho \cdot g \cdot \frac{\Delta V}{V}
  \]

- **Coefficient of Thermal Expansion - \(\alpha\)**

  \[
  \frac{\Delta V}{V} = \alpha (T' - T)
  \]

  \[
  F = \rho \cdot g \cdot \alpha (T' - T)
  \]
Approaches – System Analysis

- Simulation Assumptions
  - Inward Heat Flux – 120 W/m²;
  - Inlet and Outlet

- Other Assumptions
  - Ignore thermal expansion of glass;
  - Ambient temperature is 298.15 K;
  - Other than natural convection, no other types of dynamic;
  - Ignore effects of water tank.
Energy increment at the Outlet Boundary

- A certain mass of water (M);
- Initial temperature \(T_0\) at the inlet boundary;
- After being heated over a certain time \(t\);
- Final temperature \(T\) at the outlet boundary;

Energy Increment:

\[
\Delta Q = C_p M (T - T_0)
\]

\[
= C_p \rho V \Delta T
\]

\(\rho\) is the density of water;

\(V\) is the volume of water.
Approaches – Post Processing

- Efficiency Function

\[ \Delta Q = C_p \times \rho \times V \times \Delta T \]

Divided by the time ---- t:

\[ \frac{\Delta Q}{t} = C_p \times \rho \times \frac{V}{t} \times \Delta T \]

\( \frac{\Delta Q}{t} \) is the efficiency;

\( \frac{V}{t} \) is the volume of water flows through per unit time;

Two variables: \( \frac{V}{t} \) & \( \Delta T \)
Approaches – Post Processing

- **Velocity Field**
  \[
  V_{2D} = \int nVdV = \int (nx*u + ny*v)dV
  \]
  \[
  V_{3D} = \int nVdV = \int (nx*u + ny*v + nz*w)dV
  \]

- **Temperature Difference**
  \[
  \Delta T_{2D} = \int (T - T_0)dT
  \]
  \[
  \Delta T_{3D} = \int (T - T_0)dT
  \]

- **Thus,**
  \[
  P_{2D}Cp*\rho\int (nx*u + ny*v)(T - T_0)d(V,T)
  \]
  \[
  P_{3D} = Cp*\rho\int (nx*u + ny*v + nz*w)(T - T_0)d(V,T)
  \]
Results – 2D Finite Element Model
Results – 3D Finite Element Model
Results – Mounting Angles

<table>
<thead>
<tr>
<th>Mounting Angle (Deg)</th>
<th>Efficiency (W/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>158.46</td>
</tr>
<tr>
<td>20</td>
<td>166.12</td>
</tr>
<tr>
<td>25</td>
<td>168.22</td>
</tr>
<tr>
<td>30</td>
<td>167.47</td>
</tr>
<tr>
<td>35</td>
<td>165.00</td>
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<tr>
<td>40</td>
<td>162.78</td>
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<tr>
<td>45</td>
<td>160.91</td>
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<tr>
<td>50</td>
<td>158.91</td>
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<tr>
<td>55</td>
<td>157.19</td>
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<tr>
<td>60</td>
<td>155.53</td>
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<tr>
<td>65</td>
<td>153.63</td>
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<td>70</td>
<td>152.93</td>
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<tr>
<td>75</td>
<td>151.64</td>
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<tr>
<td>80</td>
<td>147.93</td>
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<tr>
<td>85</td>
<td>145.93</td>
</tr>
<tr>
<td>90</td>
<td>143.87</td>
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</table>
## Results – Aspect Ratios

<table>
<thead>
<tr>
<th>Tube Length (m)</th>
<th>Efficiency (W/m)</th>
<th>Adjusted Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.20</td>
<td>167.47</td>
<td>139.5583</td>
</tr>
<tr>
<td>1.25</td>
<td>174.38</td>
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<td>1.30</td>
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<td>243.78</td>
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<td>1.80</td>
<td>250.71</td>
<td>139.2833</td>
</tr>
</tbody>
</table>
Conclusions

- Mounting Angles: Efficiency rises and reaches the maximum at 25°, then begin falling and reaches the minimum at 90°.

- Aspect Ratios: As tube diameter maintains as a constant, tube with aspect ratio of (1500/47) has the highest efficiency.
Future Work

- Compare the results with experimental data
Questions?