Solar Energy
Focus or Concentrating Collectors
The heat transfer rate delivered to the focal point of a concentrating solar collector is given by
\[ Q_H = h_{\text{conc}} A_{\text{col}} G_i \]
where
- \( h_{\text{conc}} \): focusing efficiency of the collector
- \( A_{\text{col}} \): area of the collector
- \( G_i \): solar radiation incident to the collector

Flat Plate Solar Collector
To determine the energy that can be delivered to a moving fluid that is in contact with our flat solar collector, we use the following equations
Conservation of energy for the Collector
\[ \alpha_s G_i = h_{\text{fluid}} f_{\text{coll}} (T_{\text{coll}} - T_{\text{fluid,in}}) \exp\left\{ \frac{-h_{\text{fluid}} f_{\text{coll}} A_{\text{col}}}{m c_p} \right\} \]
\[ + \varepsilon_{\text{IR}} \sigma (T_{\text{coll}}^4 - T_{\text{surr}}^4) + \frac{(T_{\text{coll}} - T_{\text{air}})}{R_{\text{tot}}} \]
Energy Balance on Working Fluid
\[ T_{\text{fluid,out}} = T_{\text{coll}} - (T_{\text{coll}} - T_{\text{fluid,in}}) \exp\left\{ \frac{-h_{\text{fluid}} f_{\text{coll}} A_{\text{col}}}{m c_p} \right\} \]
where
- \( \alpha_s \): solar absorptivity of the collector
- \( G_i \): incident solar radiation
- \( h_{\text{fluid}} \): convective heat transfer coefficient between the fluid and the collector
- \( f_{\text{coll}} \): fraction of collector in contact with water
- \( T_{\text{coll}} \): temperature of the collector
- \( T_{\text{fluid,in}} \): inlet temperature of the fluid
- \( T_{\text{fluid,out}} \): outlet temperature of the fluid
- \( c_p \): specific heat of fluid
- \( \dot{m} \): mass flow rate of fluid
- \( \varepsilon_{\text{IR}} \): infrared emissivity of the collector
- \( \sigma \): Stefan-Boltzman constant, \( 5.67 \times 10^{-8} \, \text{W/m}^2\cdot\text{K}^4 \)
- \( T_{\text{surr}} \): radiation temperature of the surroundings

\[ R_{\text{tot}} = \frac{1}{h_{\text{air}}} + N_{\text{AG}} \left[ \frac{1}{h_{\text{AG}}} + \frac{\delta_{\text{glass}}}{k_{\text{glass}}} \right] \]
- \( h_{\text{air}} \): convective heat transfer between the air and the collector or top cover glass
Photovoltaic Collectors

For solar photovoltaic collector the electric power produced is given by,

\[ W_{\text{elec}} = \eta_{\text{PV}} A_{\text{coll}} G_i \]

where

- \( \eta_{\text{PV}} \): conversion efficiency of the photovoltaic cell
- \( A_{\text{coll}} \): area of the collector
- \( G_i \): incident solar radiation

The efficiency of the solar cell is given by

\[ \eta_{\text{PV}} = \eta_o [1 - \beta_{\text{PV}} |T_o - T_c|] \]

where

- \( \eta_o \): conversion efficiency of the photovoltaic cell at the reference temperature
- \( T_o \): reference temperature, 25°C
- \( \beta_{\text{PV}} \): temperature coefficient for the solar cell
- \( T_c \): average solar cell temperature

with

\[ T_c = T_{\text{amb}} + C_f (218 + 823 K_i) \frac{\text{NOCT} - 20}{800} \]

where

- \( K_i \): monthly clearness index (comes from weather data)
- \( \text{NOCT} \): Nominal Operating Cell Temperature
- \( C_f \): tilt correction factor
- \( C_f = 1 - (1.17 \times 10^{-4}) (s_M - s)^2 \)

where \( s_M \) is the optimum tilt angle and \( s \) is the actual tilt angle, both expressed in degrees. The constants for the above equations are provided in the table below for several different types of solar cells.

<table>
<thead>
<tr>
<th>PV module type</th>
<th>( \eta_o ) (%)</th>
<th>NOCT (°C)</th>
<th>( \beta_{\text{PV}} ) (%/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-Si</td>
<td>13.0</td>
<td>45</td>
<td>0.40</td>
</tr>
<tr>
<td>Poly-Si</td>
<td>11.0</td>
<td>45</td>
<td>0.40</td>
</tr>
<tr>
<td>a-Si</td>
<td>5.0</td>
<td>50</td>
<td>0.11</td>
</tr>
<tr>
<td>CdTe</td>
<td>7.0</td>
<td>46</td>
<td>0.24</td>
</tr>
<tr>
<td>CIS</td>
<td>7.5</td>
<td>47</td>
<td>0.46</td>
</tr>
</tbody>
</table>
**Fuel Cells**

**Enthalpy and Entropy Evaluations**

The enthalpy of a reactant or product is taken as

\[ \bar{h}_i = \bar{h}_{f,i} + \Delta \bar{h}_i \]

where

- \( \bar{h}_{f,i} \): enthalpy of formation for the compound

- \( \Delta \bar{h}_i \): change in enthalpy for the compound as it goes from 298 K and 101 kPa to the fuel cell temperature and pressure

The entropy of a reactant or product for an ideal gas is taken as

\[ s_i = s_i^0 - R_u \ln(y_i) \]

where

- \( s_i^0 \): temperature part of the entropy for the compound, read from the tables

- \( R_u \): universal gas constant. 8.314 kJ/(kmole·K)

- \( y_i \): mole fraction of the compound in the gas mixture

**Electrical Calculations**

Assuming an isothermal, reversible fuel cell:

**Specific Electrical Work**

\[
W_{\text{elec}} = \sum_{\text{reactants}} v_i \bar{h}_i - \sum_{\text{products}} v_j \bar{h}_j - T_{\text{FC}} \left\{ \sum_{\text{reactants}} v_i s_i - \sum_{\text{products}} v_j s_j \right\}
\]

where the \( v \)'s are the stoichiometric coefficients from the balanced chemical reaction equation.

**Ideal Efficiency**

\[
\eta_i = 1 - \frac{T_{\text{FC}} \left\{ \sum_{\text{reactants}} v_i s_i - \sum_{\text{products}} v_j s_j \right\}}{\sum_{\text{reactants}} v_i \bar{h}_i - \sum_{\text{products}} v_j \bar{h}_j}
\]

**Ideal Voltage**

\[
V_i = \frac{W_{\text{elec}}}{(96,487)N_e}
\]

**Ideal Current**

\[
I_i = \frac{W_{\text{elec}}}{V_i}
\]

**Required Mass Flow Rate of Fuel**

\[
m_{\text{fuel}} = \frac{MW_{\text{fuel}} \dot{W}_{\text{elec}}}{W_{\text{elec}}}
\]

**Number of Fuel Cell Stacks Required**

\[
\text{number of stacks} = \frac{V_{\text{required}}}{V_{\text{cell}}}
\]