Characterisation and design methods of solar cookers & ovens

Dr. Tony Robinson
Dept. Mechanical & Manufacturing Engineering
Parsons Building (across from ECAL)
arobins@tcd.ie
The Problem

- Half the world’s people must burn wood or dried dung to cook their food.

- Nearly 1.2 billion people, a fifth of the world’s population, do not have access to clean drinking water.

- Over 1 million children die yearly because of un-boiled drinking water.

- Wood cut for cooking purposes contributes to the 16 million hectares of forest destroyed annually.

- Half the world’s population is exposed to indoor air pollution, mainly the result of burning solid fuels for cooking and heating.

http://solarcooking.org/
I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait 'til oil and coal run out before we tackle that."

Thomas Edison (1847–1931)

http://www.climatechangechallenge.org/Media/Quotations.htm
Classification of Solar Cookers

Classification of Solar Cookers


(A) Flat plate collector with direct use – type A

(B) Flat plate collector with indirect use – type B
Classification of Solar Cookers

(C) Parabolic reflector with direct use – type C

(D) Parabolic reflector with indirect use – type D
The average heating-power of a solar cooker is calculated as

\[ Q_{\text{heat}} = \frac{m_w \cdot c_p \cdot \Delta T_{\infty - 95}}{\Delta t} \]

Which is the power required to heat \( m_w \) of water from ambient temperature, \( T_{\infty} \) to \( T_{95} = 95^\circ \text{C} \) over a time interval of \( \Delta t \).

\( C_p \) is the specific heat of water (the amount of energy required to raise 1 kg of by 1 °C.)
The evaporation-power, $Q_{ev}$, is determined during the evaporation of water at boiling point

$$
\dot{Q}_{ev} = \dot{m}_{ev} \cdot h_{fg}
$$

Which is the power required to evaporate the water at a rate of $\dot{m}_{ev}$ (in kg/s).

$h_{fg}$ is the latent heat of water (the amount of energy required to completely vaporize 1 kg at constant saturation pressure and temperature).
Power & Efficiency of Solar Cookers

Efficiency is the power-output divided by the incoming power.

\[ \eta = \frac{\dot{Q}}{I \cdot A} \]

The incoming power is the solar radiation \( I \) in W/m\(^2\) multiplied by the collector surface \( A \) in m\(^2\).

For flat plate collectors, the solar radiation is the global radiation on the surface.

For parabolic concentrators, it is the direct solar radiation on the aperture surface.
Design of Solar Cookers

First Law of Thermodynamics

- *Energy can be neither created nor destroyed, it can only change form*
- Provides a basis for studying the relationships among the various forms of energy and energy interactions

Energy Balance

- The net change (increase or decrease) in the total energy of a any system during any process is equal to the difference between the total energy entering and the total energy leaving the system during that process

\[
\Delta E_{\text{system}} = E_{\text{in}} - E_{\text{out}}
\]
Design of Solar Cookers

First Law of Thermodynamics

\[ \frac{d\dot{E}}{dt} = (\dot{Q}_{\text{in}} - \dot{Q}_{\text{loss}}) \]

\[ m \cdot c_p \frac{d\theta}{dt} = \{\eta_0 \cdot I - U \cdot \theta\} \cdot A \]

- \( m \) is the mass in the pot in kg
- \( c_p \) is the specific heat capacity at constant pressure in J/(kg K)
- \( \theta \) is the temperature difference between the pot content and the ambient
- \( \eta_0 \) is the optical efficiency-\textit{experimentally determined}.
- \( I \) is the global solar radiation in W/m\(^2\)
- \( U \) is the thermal loss coefficient in W/(m\(^2\) K) efficiency-\textit{experimentally determined}
- \( A \) is the collector aperture surface in m\(^2\)
Design of Solar Cookers


**Closed System**

Thermal Loss Coefficient

\[ U = \frac{m \cdot c_p}{t_{\text{end}} - t_{\text{start}}} \ln \frac{\theta(t_{\text{start}})}{\theta(t_{\text{end}})} \]

and is determined from experimental data available in literature
The solution of the ODE is obtained by integrating giving the temperature rise with time

\[ \theta(t) = \frac{K_1}{K_2} \left( 1 - e^{-K_2 \cdot t} \right) \]

The time that the cooker needs to heat an amount of water with a given temperature difference \( \theta_{\text{heat}} \) is then,

\[ t_{\text{heat}} = -\frac{1}{K_2} \ln \left( 1 - \frac{K_2}{K_1} \theta_{\text{heat}} \right) \]

Where simple groupings of constants are

\[ K_1 = \frac{I \cdot \eta_o \cdot A}{m \cdot c_p} \]

\[ K_2 = \frac{U \cdot A}{m \cdot c_p} \]
Get Started!

http://solarcooking.wikia.com


