Experiment 2a: Performance of box type solar cooker

Introduction: A box type solar cooker is an alternative food cooking technology with sunlight as its only energy source, which essentially consists of a black painted metallic trapezoidal tray (cooking tray) and is usually covered with a double glass window. It is kept in a metal or a fibre glass outer casing and the space between the cooking tray and outer casing is filled with insulation like glass wool.

Aim: Performance evaluation of Solar Cooker

Apparatus used:
Solar cooker, Thermocouples, Pyranometer, voltmeter and measuring cylinder.

Methodology:
Box types solar cookers are suitable for boiling type of cooking, where cooking temperature is close to 100^0C. A large fraction of the mass of most food products is due to water, and more water may be added in the boiling type of cooking. So, the sensible heating up to the cooking temperature requires almost 4.2 kJ/kg °C [1].

The quantities of heat required for physical and chemical changes involved in cooking are small compared to the sensible heat of increasing food temperature and energy required for meeting heat losses that occur in cooking. Once the contents of the vessel have been sensibly heated up to the cooking temperature (100 °C), the speed of cooking is independent of heat rate. Difference in the time required to cook equal quantities of food in cookers of various heat supply capabilities are mainly due to different sensible heating periods [1].

The complete thermal analysis of the cooker is complex due to the 3-dimensional transient heat transfer involved. However, a standard and simple procedure of determining the time required for a sensible heating of a known quantity of water up to the boiling point is adopted. The time for sensible heating depends upon the climate variable-solar radiation and ambient temperature. For evaluation of solar cookers and comparison between cookers, the cooker parameters are to be more or less independent of the climatic variable. Here such parameters are identified and procedure is developed to obtain the same.

Two tests are proposed, the first is a stagnation test without load and an important parameter known as "First degree of merit", F_1 is obtained.

$$F_1 = \frac{OpticalEfficiency}{HeatLossFactor} = \frac{\eta_o}{U_L} = \frac{T_{Ps} - T_{as}}{H_s} \tag{1}$$

where,

T_{Ps} = Plate stagnation temperature
T_{as} = ambient temperature at stagnation
H_s = solar insolation on a horizontal surface at stagnation
U_L = loss coefficient at stagnation
η_0 = Optical efficiency

The second test involves sensible heating of a full load of water in container and from this "Second degree of merit" F_2 is obtained. F_2 is more or less independent of the climatic variables and takes into account the heat exchange efficiency factor F^1.

$$F_2 = F^1 \eta_o C_R = \frac{F_1 (MC)_w}{A\tau} \ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{H}\right)} \right] \quad (2)$$

$(MC)_w$ = product of mass of water taken and its specific heat capacity
T_{w1} = initial temperature of water for sensible heating period
T_{w2} = upper limit of water temperature for sensible heating
C_R = Capacity ratio
A = aperture area
T_a = ambient temperature
tau = time

Procedure:

No Load Test:

1. Keep the solar cooker (without utensils) in the sunshine and allow the temperature to rise gradually.
2. Note down the plate temperature, ambient temperature and solar radiation intensity at desired time of intervals.
3. After the solar noon the plate temperature will become quasi-steady and the stagnation temperature is reached. The plate temperature, ambient temperature and total solar insolation on a horizontal surface are observed at this time.
4. Calculate the "First degree of merit" F_1 using the equation.

Full Load Test:

1. Keep the solar cooker with full load of utensils with contents (equivalent amount of water in this case) in the sun and allow the water temperature to rise gradually until it reaches the boiling point.
2. Water temperature is measured at desired time interval until it reaches the boiling temperature.
3. Plot a graph between water temperature and time of the day, to find out the value of T_{w1} and $T_{w2.}$
4. Calculate the F_2 using the equation.

Observations and Calculations:

No Load Test

Sl.No.	**Local Time (Hrs)**	**Solar radiation on horizontal surface (W/m^2)**	**Total solar radiation on horizontal surface (W/m^2)**	**Ambient temperature (^0C)**	**Ambient temperature ^0C**

$$F_1 = \frac{OpticalEfficiency}{HeatLossFactor} = \frac{\eta_o}{U_L} = \frac{T_{Ps} - T_{as}}{H_s} \quad , \quad T_{Ps} = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5}$$

Full load Test:

Mass of water kept in utensils = Volume of water taken x density of water
Specific heat of water = 4.18 kJ/kg

S. No.	**Local Time (h)**	**Total solar radiation on horizontal surface (W/m^2)**	**Ambient temperature (^0C)**	**Plate temperature (^0C)**	**Plate temperature (^0C)**

$$F_2 = F^1 \eta_o C_R = \frac{F_1 (MC)_w}{A\tau} \ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{H}\right)} \right]$$

Error Analysis:

For no load test

$$F_1 = \frac{OpticalEfficiency}{HeatLossFactor} = \frac{\eta_o}{U_L} = \frac{T_{Ps} - T_{as}}{H_s}$$

Taking natural logarithmic of both sides

$$\ln F_1 = \ln(T_{ps} - T_{as}) - \ln H_s$$

Differentiate on both the sides

$$\frac{dF_1}{F_1} = \frac{1}{T_{ps} - T_{as}}(dT_{ps} - dT_{as}) - \frac{dH_s}{H_s}$$

For maximum error in F_1, let the error in measurement of T_{ps} , T_{as} , H_s be +1%, -1% , and -1% respectively.
Thus maximum possible error in F_1 = 3%

For full load test

$$F_2 = F^1\eta_o C_R = \frac{F_1(MC)_w}{A\tau}\ln\left[\frac{1-\frac{1}{F_1}\left(\frac{T_{w1}-T_a}{H}\right)}{1-\frac{1}{F_1}\left(\frac{T_{w2}-T_a}{H}\right)}\right]$$

Taking natural logarithmic of both sides

$$\ln F_2 = \ln\left[\frac{F_1(MC)_w}{A\tau}\right] + \ln\left[\ln\left[\frac{1-\frac{1}{F_1}\left(\frac{T_{w1}-T_a}{H}\right)}{1-\frac{1}{F_1}\left(\frac{T_{w2}-T_a}{H}\right)}\right]\right]$$

Differentiate on both the sides

$$\frac{dF_2}{F_2} = \frac{1}{\ln\left[\frac{1-\frac{1}{F_1}\left(\frac{T_{w1}-T_a}{H}\right)}{1-\frac{1}{F_1}\left(\frac{T_{w2}-T_a}{H}\right)}\right]}\left[\frac{-1}{1-\frac{1}{F_1}\left(\frac{T_{w1}-T_a}{H}\right)}d\left(\frac{1}{F_1}\left(\frac{T_{w1}-T_a}{H}\right)\right)+\frac{1}{1-\frac{1}{F_1}\left(\frac{T_{w2}-T_a}{H}\right)}d\left(\frac{1}{F_1}\left(\frac{T_{w2}-T_a}{H}\right)\right)\right]$$

For maximum error in F_2, let the error in measurement of T_{w1}, T_{w2}, H, T_a be –1%, +1% , +1% and –1% respectively. Thus maximum possible error in F_2 = 4%

<u>Precautions:</u>

1.Before starting the experiment clean the glass surfaces and internal area of solar cooker.
2.Make sure that the solar cookers as well as pyranometer are kept in unshaded area.
3.Mirror booster should not be used in any of the tests performed in this experiment.
4.The cookers should be properly oriented towards the sun in the beginning of the experiment and no further adjustments should be done during the experiment.
5.Ensure that the cold junction terminal is touching the bottom of the glass tube in the icebox.
6.Record the temperature quickly, after selecting the toggle switch for particular thermocouple point.
7.Make sure that the tip of the thermocouple touches the contents of the utensils.
8.Ensure that measuring instruments are not exposed to direct sunlight.

Questions

1. How can we increase the performance of box type solar cookers?
2. What are the limitations of using these cookers?
3. What ambient factors affect the performance of box-type solar cookers?

References

1. Mullick S.C., Kandpal T.C. and Saxena A.K., “Thermal test procedure for box type solar cookers”, *Solar energy*, Vol. 39, (4), 353-360, 1987.

2. Lof G.O.G., “Recent investigations in the use of solar energy for cooking”, *Solar energy*, Vol. 7, (3), 125-133, 1963.

Experiment 2b: Performance of basin-type solar still

Introduction: The basic principles of solar water distillation are simple yet effective, as distillation replicates the way nature makes rain. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapour rises, condensing on the glass surface for collection. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. The end result is water cleaner than the purest rainwater. The basin type solar still is a passive solar distiller that only needs sunshine to operate. There are no moving parts to wear out.

Aim: To compare the distillate yields of basin type solar still with the theoretically calculated values using Dunkle's relation.

Apparatus used: Water heater, pyranometer and basin type solar still, measuring bottles, thermocouples cold junction, switching box, anemometer and dc microvoltmeter.

Theory:

Solar energy is allowed through glass into the collector basin to heat the water. The water evaporates and condenses on the underside of the glass. When water evaporates, only the water vapor rises, leaving contaminants behind. The gentle slope of the glass directs the condensate to a collection trough, which in turn delivers the water to the collection bottle.

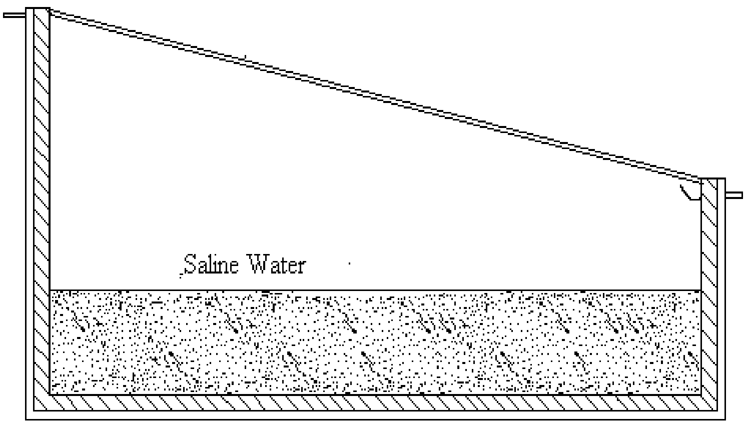

Figure1. Solar Still

Mass transfer rate (dm_D/dt , $kg/m^2 s$) in a solar still is theoretically given by Dunkle's relations as follows.

$$\frac{dm_D}{dt} = 16.276 \times 10^{-3} \times h_c (p_w - p_g) / L \qquad (1)$$

Or

$$\frac{dm_D}{dt} = 6.8742 \times 10^{-9} \times h_c (p_w - p_g) \qquad (2)$$

$$h_c = 0.884 \left[(T_W - T_g) + (p_w - p_g)(T_W + 273.15)/(268900 - p_w) \right]^{1/3}$$

where,

p_w = Saturation vapour pressure of water at temperature T_W of water surface (N/m^2).

p_g = Saturation vapour pressure of water at glass cover temperature T_g (N/m^2).

L = Latent heat of evaporation corresponding to water temperature (J/kg).

The efficiency of solar still is given below,

$$\eta = \frac{\frac{dm_D}{dt} L}{I_g} \qquad (3)$$

Where, I_g = radiation incident on the basin.

Procedure:

1. Note down the temperatures of water, glass cover and outer surface of basin after every 15-minute time span.
2. Record solar radiation, shade air temperature and wind velocity during the experiment.
3. Note down distillate yield after every 15-minute time span from 2 to 5 pm. (Repeat the readings at late evening (7pm) and early morning (7 am) and hourly thereafter till 12 noon.)

Results:

1. Use steam table to find out saturation vapour pressure of water corresponding to the observer values of water and glass temperatures.
2. Calculate the distillate yield and compare with the experimentally observed values.
3. Calculate the efficiency of the still
4. Plot the efficiency against the time (over 24 hour period.)
5. Plot yield rate against time (over 24 hour period.)
6. Estimate the losses from the glass surface based on glass temperatures and wind speed.

Precautions:

1. Avoid leakage of humid air from the still.
2. Make sure that the outer surface of the still cover is clean.
3. Avoid shadow on glass surface.
4. Make sure that all accessories and apparatus are kept at safe place.
5. Note down the respective thermocouple reading in order.
6. Do not stand close to the boundary of the terrace to avoid an accident

Questions:

1. What are some advantages and disadvantages of using solar stills?
2. How can we increase the performance of solar stills?
3. Compare between the various methods of solar distillation.