Performance analysis of Solar Parabolic concentrator for cooking applications

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Cooking Energy Scenario in India

URBAN SECTOR

- LPG (47.96%)
- Firewood (22.74%)
- Kerosene (19.16%) and
- Other fuels(10.14)

RURAL SECTOR

- Firewood (64.10%)
- Other sources of biomass – crop residue (13.10%)
- Cow-dung (12.80%), and
- LPG (5.67%) is now increasing in importance.

COOKING FROM SOLAR ENERGY

Solar cookers are mainly of two types

BOX TYPE SOLAR COOKER

- A well-insulated box with a transparent cover and side reflectors, which result in an intensification factor of two to four (Lo¨f, 1963).
- Slow to heat up, but work well even under diffuse radiation and windy conditions (Telkes, 1959).
- Box type solar cooker even with booster mirrors has low concentration ratios (up to 10) and low temperature (up to 100°C). (Hosny Z. Abou-Ziyan, 1998)

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FOCUSING TYPE SOLAR COOKER

- The focusing or direct-type cooker uses a reflector to concentrate beam radiation onto the food or onto the cooking vessel in which the food is cooked.
- These cookers use mirrors, fresnel lenses, and parabolic concentrators to achieve intensification factors of 20–100, allowing high temperature cooking (Lo¨f, 1963).
- Heating-up periods are small, but these cookers require adjustment to track the sun. Since concentrating cookers uses direct beam radiation, the lack of sky clearness (dust, clouds, dust, etc) reduces their performance.

SCHEFFLER SOLAR COOKER – DIRECT COOKING MODEL

- Concentrate the solar radiation to one point through absorption onto the black colored surface of a cooking vessel, this concentrated energy is converted into heat and used to cook food inside the cooking vessel.

COMPONENTS OF SCHEFFLER COOKER

- Primary Reflector,
- Secondary Receiver, and
- Clock mechanism powered by gravity or photovoltaic panels.

Technical Specifications

Area of the Primary Reflector	7.14 m^2
Area of the secondary reflector	0.96 m^2
Temperature at focal point	950°C (at 960 wm^{-2})
Temperature at the secondary reflector	680°C (at 975 wm^{-2})
Temperature at the cooking pot	480°C (at 955 wm^{-2})
Material of construction for the primary reflectors	Acrylic mirrors
Material of construction of secondary reflector	Anodized aluminum sheet
Focal length of Primary Reflector	1.730 m
Concentration Ratio	143.8

Cooking Efficiency

- The fundamental operational problem with solar cookers is the collection and delivery of solar energy to users with minimum losses.
- The optimum operating conditions for solar cookers can be investigated using different modes of performance.
- To optimize the thermal efficiency of any collector, which is defined as the ratio of 'useful energy output' to that of 'incident solar energy' during the same time period.
- The amount of useful energy (exergy) delivered by solar cookers is found to be affected by heat transfer irreversibility's between the sun and the cooker, between the cooker and the ambient air.(S.K. Tyagi et.al.,2007)

Cooking Efficiency Calculations

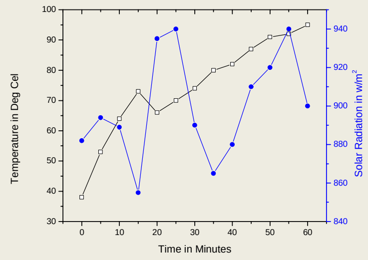
$$\eta = \frac{m_a C_a X m_c C_c}{s \int_o^T I \, dT} X 100$$

m_a is the water mass in cooking vessel (kg),
c_a the specific heat of water (J $kg^{-1}C^{-1}$),
m_c the mass of Rice (kg),
c_c the specific heat of Rice (J $kg^{-1}C^{-1}$),
t_f the final water temperature (C),
t_i the initial water temperature (C),
S the reflector cross-sectional area (m^2),
I the solar radiation (Wm^{-2}), and
T the time elapsed up to reaching a suitable cooking temperature (min).

Cooking Test - Experimental Data's

Time	Temperature	Solar Radiation
11.45	38	882
11.50	53	894
11.55	64	889
12.00	73(Rice Added)	855
12.05	66	935
12.10	70	940
12.15	74	890
12.20	80	865
12.25	82	880
12.30	87	910
12.35	91	920
12.40	92	940
12.45	95 (Rice Cooked)	900

Comparison graph



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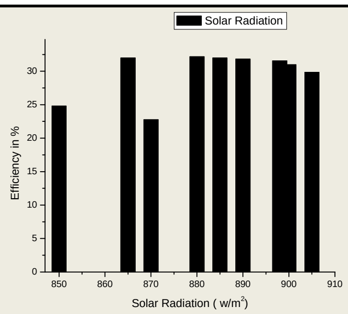
- From the above graph water temperature in the cooking vessel gradually increased from ambient to boiling temperature. At the temperature of 73 deg Celsius the raw rice was added. So that the temperature of the cooking vessel falls to 66 deg Celsius and once again it rise gradually due the solar radiation.
- In the cooking period solar radiation levels are in the range of 850 wm^{-2} to 950 wm^{-2}. it is above average level of solar radiation, so that the system efficiency was not highly affected. Moreover the cooking vessel is closed by the lids, because of this the evaporation losses are minimum and the vessel temperature was not affected during the process.
- This efficiency figure relates to the perfection of the reflector surface area, its reflectance, absorptance of the outer surface of the cooking pot.



Cooking Experiments in Efficiency Optimization

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- The cooking experiments are repeated in 10 days and the efficiency results presented in the bar diagram with average solar radiation in the particular day. There are two experiments are conducted in the dusty condition of the primary and secondary reflector and the other eight experiments are conducted in the cleaned condition.
- In the unclean condition the average solar radiation comes around 850-870wm^{-2} and the efficiency level comes in the range of 22-25 %.
- In the cleaned condition the efficiency comes from 22 % to 32 % in the mean solar radiation ranges from 850 wm^{-2} to 905 wm^{-2}. The dusts are playing the major role to affect the concentrator efficiency.

COMPARISION WITH OTHER FUELS

Fuel	Calorific Value	Efficiency	Fuel Cost	Solar Power for One Dish	Approx Savings
LPG(commercial)	8600 Kcal/Kg	80 %	Rs: 50.00	17201 Kcal/day	2.5 Kg Rs:125.00
Diesel	10000 Kcal/Lit	80 %	Rs:36.00	17201 Kcal/day	2.15 Lit Rs: 77.40
Electricity	860 Kcal/KWh	85 %	Rs:5.00	17201 Kcal/day	23.53 Kwh Rs:117.65
Fire wood	3800 Kcal/Kg	17 %	Rs:2.00	17201 Kcal/day	26.62 Kg Rs: 53.24

Conclusion

- This experience of the solar cooker is quite positive.
- It is the correct replacement option for institutional cooking. Normally they use firewood and LPG. Savings up to Rs.16000(in case of fuel wood in average of 300 days/year)
- Thermal efficiency of paraboloid solar cooker were determined as 22 - 32 % in the average solar radiation level of 800 w/sq.m respectively on different days.
- Thermal efficiency determination is one of the criteria for comparing the performance of concentrating cooker under different climatic conditions.
- Cooking process done with in one hour.
- It needs alternative system for cloudy and rainy days. It is the only drawback of this system.

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