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Thermal Performance Analysis of Solar Box type Cooking System

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ABSTRACT

Heating and cooking are two big energy consumers in India. Since food is one of life's essentials, cooking is a fundamental part of every human being. When gasoline is either scarce or very expensive, a dilemma develops. Indoor air pollution, caused by the burning of solid fuels such as wood or coal, affects half of the world's population. According to the World Health Organization (WHO), cooking with solid fuels, including wood and charcoal, and poor water and sanitation are responsible for 10% of deaths in 23 countries. Therefore, using renewable energy sources, such as solar, biogas, and biomass for cooking is a need. In terms of F1, F2, energy efficiency, and exergy efficiency, the box-type solar cooker's thermal performance was computed and determined.

Key words: Thermal Performance Analysis, Solar Box, Cooking System

1. INTRODUCTION

1.1 General

The main ingredient in each country's socioeconomic progress is energy The sun is the main source of energy for the entire planet, and it provides all of the planet's needs. Due to the scarcity of fossil fuels, the entire globe is currently experiencing a severe energy crisis. The rise in oil prices, heavy energy use brought on by rapid industrialization, rapid urbanization, automated farming, and other factors have all contributed to this issue. Fossil fuels such as coal, oil and natural gas have been overfished in unsustainable ways to meet this ever-increasing demand [1-8].

The efforts to use different renewable energy sources more efficiently are primarily motivated by the steadily rising demands for energy for home, industrial, and agricultural purposes. The best use of these resources reduces their negative effects on the environment and generates the least amount of secondary waste, making renewable energy technologies considered clean energy sources. Due to its accessibility all around the world, abundance in nature, and sustainability despite the erratic nature of sunshine, solar energy is one of the most important sources of sustainable energy. In nature, solar energy is readily accessible and free [9-20].

The two primary methods for capturing solar energy at the moment are solar energy conversion into electricity using photovoltaic cells and solar heat energy conversion into solar thermal energy [21-27]. Utilizing solar energy as thermal energy for heating purposes is the simplest and most effective method. Such an approach's acceptance is influenced by the system's overall efficiency, ease of use, design, and cost-effectiveness. Numerous daily actions for domestic applications consume a sizable quantity of energy [28-34]. The most frequent tasks include cooking, drying, boiling water, etc. A straightforward solar thermal energy conversion equipment is the solar stove and solar dryer.

The primary solar contribution to energy needs at the moment is solar heating. They come in the form of solar energy systems that are either "passive" or "active."

Designing structures to capture and transform solar energy for passive heating, lighting, and natural ventilation is known as passive solar energy. Use of solar collectors for water or space heating, active solar cooling, heat pumps, desalination, and industrial high-temperature heat are all examples of active solar energy.

1.2 Solar-Powered Cooking

Since eating is one of the most basic essentials for survival and cooking is the domestic activity that uses the most energy, cooking is a fundamental part of every human being. In India, the daily burning of 133 million tonnes of firewood accounts for more than 90% of all household energy use in rural areas. Firewood, biomass, cow dung, kerosene, electricity, liquefied petroleum gas (LPG), biogas, and other fuels are frequently used for cooking. The majority of

indoor air pollution, which is brought on by burning solid fuels for cooking and heating, affects half of the world's population.
Over 4% of India's entire land area, or 16 million hectares, of forest are lost each year as a result of wood being cut for cooking. According to the World Health Organization (WHO), indoor air pollution from solid fuel use for cooking and contaminated water are the only two environmental risk factors that account for 10% of mortality in 23 countries [9]. Women in developing nations typically have to go two kilometers and spend a lot of time gathering firewood for cooking. Therefore, reducing or lowering these danger concerns through the use of solar cooking technology is the answer to all of these issues.
A solar cooker is a device that only uses sun radiation to cook food, which significantly reduces the need for traditional fuels. The easiest, safest, and most practical method of preparing meals without using fuels or heating the kitchen is solar cooking. The box-style solar cooker has the ability to cook meals using only sun radiations. The photo-thermal effect occurs when high energy photons of solar electromagnetic radiation strike a transparent surface, converting the incident solar energy into heat energy. This phenomena is caused by the accumulated solar energy being absorbed by the absorber inside the cooking chamber and then being heated again by the cooking pot, which raises the temperature inside the box to above 100oC, which is sufficient to boil and cook the meal. The steam produced by the food is absorbed again.
The most effective method of cooking in terms of heat utilization uses all of the heat that is present inside the food item as well as its latent heat.
The box-style solar cooker has several benefits, including the use of both direct and diffuse solar radiation, minimal user involvement, ease of construction, ease of use, safety, and a high tolerance for tracking mistake.

2. THERMAL PERFORMANCE OF COOKING SYSTEMS

Thermodynamics of cooking systems Systems have already been created and developed by many organizations, so it is necessary to assess their effectiveness for increased viability. The performance of a few renewable energy-based cooking systems was evaluated in accordance with BIS requirements. According to normal method, thermal performance was carried out by calculating the thermal efficiency, energy efficiency, and exergy efficiency. According to systems, the detailed process was presented as follows:

2.1 Solar cooking (Portable Box Type Solar Cooker)

The box type solar cooker's (portable) thermal performance was evaluated in accordance with IS 13429 (2000) part 3. The following conditions were used for the thermal performance test, and F1 and F2 values were computed. The stated values of F1 and F2 were calculated using the arithmetic average of at least three test results with a standard deviation of less than 0.002. The IS standard for thermal performance lists the following fundamental factors:

2.1.1 Stagnation temperature test

- **First Figure of Merit (F_1): (No Load Test)**

The thermocouple's hot junction (with radiation seal) is mounted at the tray's midpoint with good thermal contact and without sticking out. Starting at 10:30 am on a clear day, the no load test is performed in the steps below to reach the stagnation temperature immediately before or just after solar noon:
Solar cooker was set in open sun without a pot.
a. A black cloth was placed over the solar cooker's reflector.
b. Continuously check the temperature of the cooker tray every 5 minutes. At the height of the solar cooker's glass, the amount of total solar radiation, the surrounding temperature, and the wind speed were all simultaneously monitored.
c. The final steady cooker tray temperature (Tpz), the equivalent outside ambient air temperature (Taz), as well as the solar radiation (Gs) at that moment, were measured once the cooker tray temperature had reached a quasi-stationary state.
A 10-minute interval is considered the steady state condition when:
1. There is a 1 °C difference in the cooker tray temperature.
2. There is a 20 W/m2 variance in sun radiation.
3. There is a 0.2°C variation in the ambient temperature.
4. There is more solar radiation than 600 W/m2.
Calculate F1, also known as the optical efficiency to heat loss coefficient ratio, as follows:
Priority Number of Merit (F1)
Calculate $F1$, which is defined as the ratio of optical efficiency to the heat loss coefficient follows:
First Figure of Merit (F_1)

$$F_1 = \frac{\eta_0}{U_{L,sc}} \quad [1]$$

Experimentally formula is,

$$F_1 = \frac{T_{pz}-T_{az}}{G_s} \quad [2]$$

Where,
η_0 =Optional Efficiency
$U_{L,sc}$ = Overall Heat Loss Coefficient of the box type solar cooker.
T_{pz} = Final Temperature of trey at steady state condition (^{0}C)

T_{az} = Average Ambient Temperature (^{0}C)
G_s = Average solar radiation (w/m^2)

- **Secondly Figure of Merit (F2) (Load Test)**

The weight of the empty cooking pots was first determined, and 8 litres of water per square meter of aperture area were then added. The cooker, from which the mirror has either been removed or covered with cloth, was filled with pots. The biggest cooking pot was used to house the thermocouple's temperature probe, which had its measuring tip submerged in water. Where the temperature probe lead exits the cooking pots and the cooker, it was sealed. Throughout the test, the temperature and wind speed at the solar cooker's level of the glazing were recorded. The test was launched between ten and ten thirty local solar time in the morning. Spot inspections that were no more than five minutes apart were used to measure radiation and temperature. It is preferable to continuously monitor at intervals of 30 seconds or fewer, with radiation averages recorded every 2 minutes. The subsequent measurements must be made:
a. The precise time at which the water temperature was measured.
b. Data collection was kept on until the water temperature surpassed 95°C.
c. Data pairs for local initial and end temperatures and lime. The temperature was maintained between the initial 60°C and the ultimate 90°C. d. The average ambient air temperature (Ta) between the limes t1 and t2 was computed. These were indicated as Tw1 and Tw2, and the associated limes t1 and t2, respectively.
d. The experiment was carried out in a clear environment. It was periodically examined whether the radiation reading between the two spots consistently exceeded 600 W/m2.
e. Fro Calculation for the second Figure of merit F_2 as follows:

$$F_2 = \frac{F_1(M_w C_w)}{A\,\tau} \ln\left[\frac{1-\frac{1}{f_1}\left(\frac{T_{w1}-\bar{T}a}{\bar{H}}\right)}{1-\frac{1}{f_1}\left(\frac{T_{w2}-\bar{T}a}{\bar{H}}\right)}\right] \quad [3]$$

Where,
F_1 =First figure of merit
M_w =Mass of water
C_w =Specific heat of water
$\bar{T}_a$ =Average ambient temperature
T_{w1} ,T_{w2} = Initial and Final temperature respectively
$\bar{H}$ =Average solar radiation incident on the aperture of the cooker
A =Aperture area of solar cooker
τ = Time difference of water temperature rises from T_{w1} toT_{w2} .
m time t1 to time t2, the average radiation (G) was determined.

- **Performance efficiency of solar cooker:**
  - **a. Energy Input:**
    For calculation of energy input the experimental setup were carried out same as the second figure of merit (i.e. load test).

$$E_i = I_s * A_{sc} \quad [4]$$

Where,
Is =Solar radiation (w/m^2)
A_{SC} = Area of aperture of solar cookers (m^2)

  - **b. Energy Output:**
    According to load test carried out earlier the following energy output was done.

$$E_o = w_m.C_{pw}(T_{wf} - T_{wi})/\Delta T \quad [5]$$

Where,
w_m = Mass of water
C_{pw} = Specific heat of water
T_{wf} = Final temperature of water
$\square_{wi}$ = Initial temperature of water
$\square T$ =Time difference.

  - **c. Efficiency(η_0)**
    The ratio of energy output to energy input is energy efficiency.

$$\eta_0 = \frac{Energy\ Output}{Energy\ Input} = \frac{Eo}{Ei} \quad [6]$$

Solar cooker's energy effectiveness: energy analysis

- **Exergy efficiency of Solar cooker:**

The entire exergy balance of the solar cooker for a steady-state flow process over a finite time period can be expressed as follows, with the exergy of a solar cooker considering just global radiation:
Energy input is equal to energy output plus energy loss plus irreversibility.

Exergy Input = Exergy Output + Exergy loss + Irreversibility

1. Exergy Input = $I_s\left[1+\frac{1}{3}\left(\frac{T_a}{T_s}\right)^4-\frac{4}{3}\left(\frac{T_a}{T_s}\right)\right]A_{sc}$ [7]
2. Exergy output: $\varepsilon_{out}=m_w\frac{Cpw\left[(Twf-Twi)-Ta\ \text{In}\frac{Twf}{Twi}\right]}{\Delta T}$ [8]
3. Efficiency = ψ = Exergy Output / Exergy Input

Where,

ε_i &ε_{out}= Exergy input and output of solar Cooker

I_s = Intensity of Solar radiation (W/m^2)

T_a = Ambient temperature (^{0}C)

T_s = Sun temperature (^{0}C)

2.2 Apparatus used for evaluating performance of cooking devices.

a. Solar Cooker:

Size of Cooker - 0.45m*0.45m

Cooker body casing - Aluminium

Cover Plate - 2 transferring glass 0.88 % (Tranmissivity)

Mirror - Single mirror having 0.91% (Reflectivity)

Pots - 4 pots of aluminum with black paint

Insulation - Glass Wool

Fig. 1 Box Type Solar Cooker (Portable)

3. THERMAL PERFORMANCE OF COOKING SYSTEMS

According to BIS criteria, the thermal performance of a few renewable-based cooking systems was evaluated. Chapter III provided an explanation of the technical specification.

3.1. Solar Cooking

Box type solar cooker (Portable) thermal performance/stagnation test was performed in accordance with IS 13429 (2000) part 3.

Table -1 Observations recorded in performance of solar cooking.

Sr. No.	Parameters	Values
1	Outside Ambient Temperature	23 ^{0}C
2	Final Steady cooker trey temperature	124 ^{0}C
3	Average Solar radiation (Global)	912 W/m^2
4	Mass of Water	1.62 kg
5	Specific Heat of water	4.186 kJ/kg. ^{0}C
6	Aperture area of Solar cooker	0.45m x 0.45m
7	Time difference	4 h

The performance evaluation took place from 10.30 am to 2.30 pm, with readings taken every five minutes in between. 2.10 km/h was the average wind speed during the performance. During the test, 23 °C and 124 °C were recorded as the final constant cooker temperature and outdoor ambient temperature, respectively. Additionally, average solar radiations of 912 W/m2 and 932 W/m2 for F1 and F2, respectively, were noted. The initial figure of merit (F1) was determined as a result, and it was discovered to be 0.11. Additionally, the second merit number (F2) was established as 0.58.

Fig. 2 Experimental Setup of Box type solar cooker with temperature sensor

3.1.1 Energy and Exergy Analysis of Box Type Solar Cooker

Energy input and output values were calculated as 188.7 J/s and 50.45 J/s, respectively, using the parameters listed in Table 4.1, according to standard procedure. As a result, it was determined that Energy Efficiency was 26.89 percent. The Appendix I provides detailed readings for the ambient temperature, wind speed, solar radiation, and temperature change during the test. The graphic representation of Energy Efficiency with respect to time and solar radiation is also shown in Fig. 3.

Based on an analysis of exergy, a box-type solar cooker (portable) has been studied. The variation in energy efficiency and solar radiation with respect to the amount of time needed to boil 1.62 kg of water in a box-style solar cooker is shown in Fig. 3.

The findings showed that the energy and exergy efficiency initially was low, increased over time, and then descended with respect to time at the conclusion of the test. It was discovered that variations in solar radiation were to blame for the variation in efficiencies. The calculated average energy efficiency was 2.61 percent.

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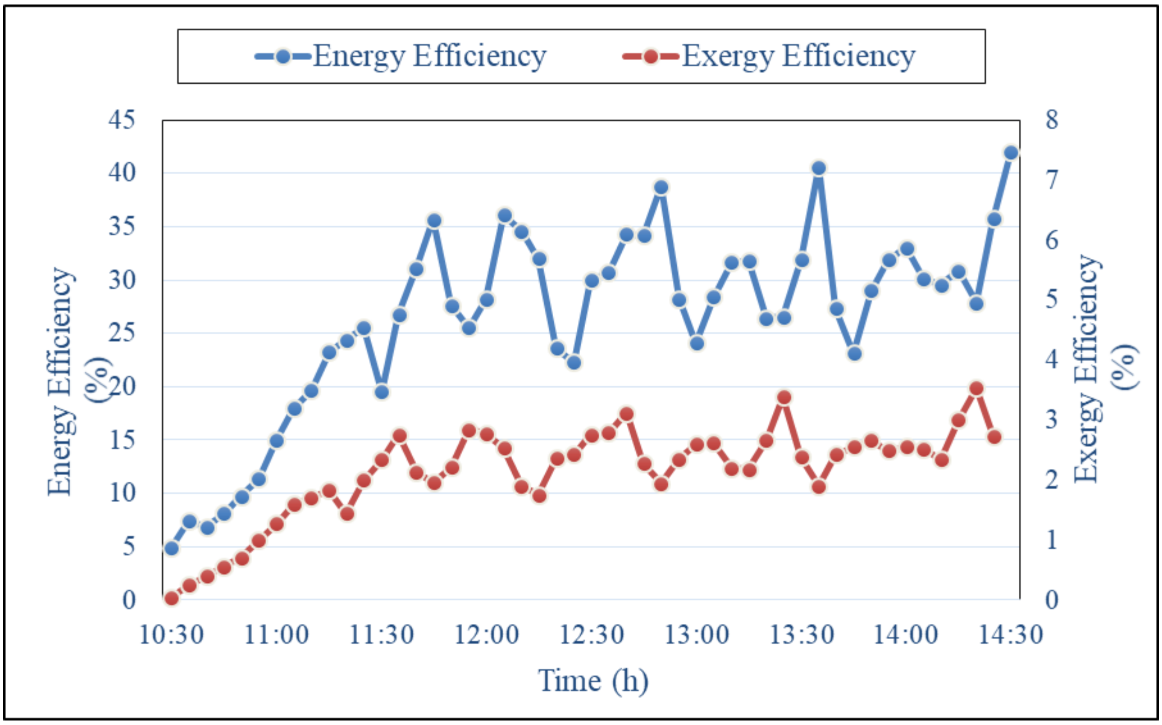

Fig. 3 Energy and Exergy Efficiency with respect to time

At the conclusion of the test, an observation was made between solar radiation and wind speed, and the results are shown in Fig. 4. The average wind speed was 2.10 km/h, and the average solar radiation was 932 W/m2. The solar radiation and wind speed are depicted in Fig. 4 with respect to time.

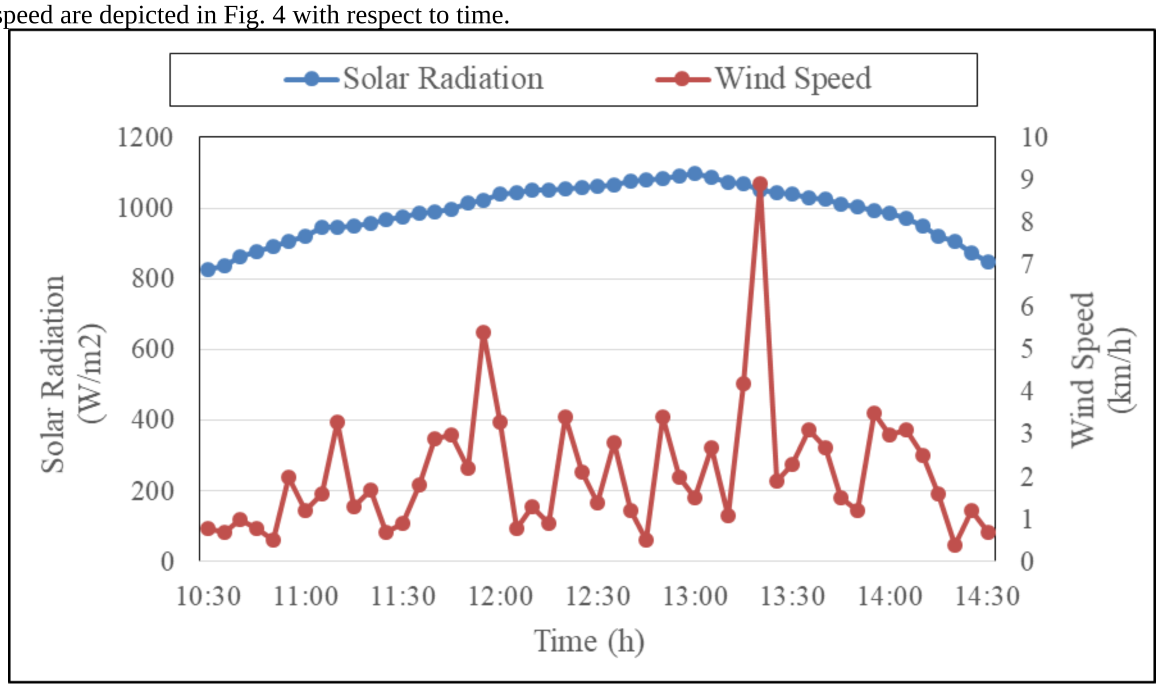

Fig. 4 Solar Radiation and Wind Speed with respect to Time

4. CONCLUSION

The box type solar cooker's (portable) thermal performance was evaluated in accordance with IS 13429 (2000) part 3. The first figure of merit (F1) was calculated with no load test and was found to be 0.11; the second figure of merit (F2) was calculated with a full load test and was found to be 0.58. 26.89 percent energy efficiency was discovered. Additionally, a box-style solar cooker has been the subject of research based on energy analysis. In a box-style solar cooker, the variation in energy efficiency and solar radiation were illustrated with respect to how long it took to boil 1.62 kg of water. The outcome showed that the energy and exergy efficiency was initially low, increased over time, and then declined at the conclusion of the test. Efficiency variations were discovered to be caused by variations in solar radiation. The calculated average energy efficiency was 2.61 percent.

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