



Thermo-physical Characterization and Performance Evaluation of Castor Oil as a Sensible Heat Storage Medium in a Box-Type Solar Cooker

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ABSTRACT

Box-type solar cookers (BSCs) provide a clean alternative to conventional biomass fuels, but their operation is limited by intermittent solar radiation. This study investigated castor oil as a sensible heat storage (SHS) medium for improving thermal performance and post-solar heat retention. The castor oil had a density of 956 kg/m³, specific heat capacity of 1900 J/kg K, thermal conductivity of 0.168–0.175 W/m K, and kinematic viscosities of 298.94 and 22.42 mm²/s at 40 and 100°C, respectively. Thermo-gravimetric analysis indicated thermal stability up to approximately 250–280°C, followed by major decomposition between 280 and 350°C. The cooker was fabricated and tested at the Federal University of Technology Minna, Nigeria, during February–March 2026 under outdoor solar irradiance of 615–790 W/m². Experiments were conducted in triplicate. During stagnation testing, the absorber plate reached a maximum temperature of 101.6°C, while the castor oil attained 74.8°C. The calculated thermal efficiency was 50.7%, based on 115.98 kJ of useful energy output from 228.76 kJ of solar energy input. During post-solar testing, 1 kg of water was heated from 30.0°C to 75.6°C within 60 minutes without solar input, demonstrating the heat-retention capability of the castor oil. However, the study did not compare the cooker with an equivalent system without castor oil. Therefore, claims of improved performance and extended cooking capability should be interpreted cautiously. Overall, the results demonstrate the potential of castor oil as a locally accessible and biodegradable SHS medium for extending solar cooking beyond sunshine hours, while further comparative and field-scale studies are recommended.

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INTRODUCTION

The pressing need to address climate change, energy poverty, and the unsustainable depletion of fossil fuel supplies is causing a major shift in the global energy environment, and for their everyday cooking needs, about four billion people worldwide still rely on conventional biomass fuels like wood, agricultural waste, and animal dung, a practice that not only adds to greenhouse gas emissions and deforestation but also exposes millions of people to dangerous indoor air pollution with detrimental health effects (Vishwakarma & Sinha, 2024), while the World Health Organization has recognized household air pollution from inefficient cooking techniques as a serious public health emergency, making the development of clean, economical, and sustainable cooking technology a global priority, and solar cooking, particularly the box-type solar cooker (BSC), has attracted considerable interest among the different designs of solar cookers because of its inherent benefits, which include ease of construction and operation, affordability, portability, and suitability for a variety of cooking applications, especially in rural and remote areas (Vishwakarma & Sinha, 2024), yet a significant drawback has prevented BSCs from being widely used their sporadic nature since the cooker cannot be used in cloud cover, the early morning, or the evening after sunset because the cooking process is limited to daytime hours when solar radiation is accessible, and according to Gawande and Ingole (2019), this fundamental constraint offers a significant obstacle to societal acceptance and user confidence and

contrasts with traditional cooking habits that frequently entail meal preparation during these off-sunshine periods; researchers have therefore looked into integrating thermal energy storage (TES) devices with BSCs in order to overcome this restriction, since thermal energy can be captured and stored using TES technology during times of high solar irradiance and then released for cooking at times when solar radiation is not available, thereby improving usefulness, dependability, and practicality and allowing solar cookers to become the main cooking equipment in many homes rather than just an add-on, and sensible heat storage (SHS), latent heat storage (LHS), and thermochemical storage are the three basic categories into which thermal energy storage can be divided (Sharishoy et al., 2025; Gawande & Ingole, 2019), with this study focusing on sensible heat storage, which is the process of storing thermal energy by increasing a storage medium's temperature without causing a phase shift, where the material's mass, specific heat capacity, and temperature rise all affect how much energy is stored, and water, pebbles, concrete, and different types of oil are common SHS materials; the potential of vegetable oils as SHS media for solar cooking applications has been emphasized by recent reviews and experimental studies (Mawire et al., 2022; Bala et al., 2025), since vegetable oils are generally accessible, biodegradable, and have comparatively high specific heat capacities, and show good thermal stability up to the temperatures at which they decompose, and crucially, unlike water, they may be heated much above 100°C without the

need for pressurized containment, allowing for higher temperature cooking methods like frying (Bala et al., 2025; Nydal, 2023), although it must be qualified that the statement that vegetable oils are generally non-toxic requires caution, particularly because the properties and safety characteristics of different oils vary, and it is important to distinguish the thermal storage function of castor oil from its possible use as a cooking oil; existing sensible heat storage materials nevertheless present specific limitations water is restricted to temperatures below 100°C unless pressurized and has relatively low volumetric heat capacity, pebbles and concrete suffer from low specific heat capacity and poor heat transfer characteristics, and many vegetable oils experience oxidative degradation, polymerization, and rancidity upon repeated heating cycles that compromise long-term thermal performance (Mawire et al., 2022; Nydal, 2023; Sharishoy et al., 2025) and among candidate vegetable oils, castor oil (*Ricinus communis*) has good thermal qualities, is locally accessible, inedible, and renewable, and is an excellent option for use as a sensible heat storage medium in solar cooking systems because of its high boiling point, good heat retention capacity, low volatility, and biodegradability (Misra et al., 2023), with a relatively high density of approximately 956 kg/m³ that enhances volumetric heat capacity, a specific heat capacity of about 1900 J/kg K, thermal conductivity in the range of 0.168-0.175 W/m K, and thermal stability below approximately 250-280°C, while its very high viscosity at low temperatures creates engineering challenges such as greater pumping power, weaker natural convection, and slower charging/discharging, though these are less critical in passive solar cookers and are partially offset by a significant viscosity drop at cooking temperatures; furthermore, castor oil is readily available in many parts of Asia and Africa where solar cookers are most in demand, making it economically viable and culturally acceptable as a thermal storage medium rather than a food commodity; despite these promising

attributes, there remains a significant research gap, as comprehensive thermo-physical characterization of locally sourced castor oil and its systematic integration as a sensible heat storage medium in box-type solar cookers has not been adequately investigated, and few studies have linked detailed laboratory characterization including proximate analysis, thermal conductivity profiling, viscosity behaviour, and thermo-gravimetric analysis to actual cooker performance under real solar conditions with post-solar heat retention testing; the objective of this study is therefore to characterize castor oil as a sustainable sensible heat storage medium and to design, fabricate, and experimentally evaluate the thermal performance of a box-type solar cooker incorporating castor oil for post-solar cooking, and the novelty of this work lies in its comprehensive thermo-physical characterization of castor oil specific to solar cooking applications, the demonstration of its thermal stability and safe operating range relative to its flash point, and the experimental validation of its heat retention capability through combined stagnation, heat retention, and water heating tests that confirm the cooker's practical cooking potential during off-sunshine periods.

MATERIALS AND METHODS

Materials

The materials used for the research are Distilled water, Ethanol, Ether (diethyl ether), Potassium hydroxide (KOH) solution (standardized), Phenolphthalein (indicator), Alcoholic potassium hydroxide (KOH) solution, Hydrochloric acid (HCl) solution (standardized), Iodine reagent (Wijs solution, Potassium iodide (KI), Sodium thiosulfate (Na₂S₂O₃) solution (standardized), Starch solution (indicator), Acetic acid, Chloroform, Organic solvent (diethyl ether or petroleum ether), Standard reference material (for refractometer calibration), thermal energy storage (castor oil). The list of materials that are used for the design and fabrication of the research is shown in the Table below.

Table 1: List of Materials for Fabrication

S/N	Components	Specifications
1	Plywood (Inner and Outer Box)	585mm x 550mm x 345mm
2	Glass (Double Glazing)	4 mm Thickness
3	Silver Glass Mirror (Reflector)	Adjustable angle
4	Copper Sheet (Absorber Plate)	550mm x 500mm Thickness
5	Aluminium (Cooking Pot)	200 mm x 100 mm height
6	Castor Oil (Thermal Storage Medium)	5 Liters

Equipment

The Table 2 shows the list of equipment for the experimental

characterization of the oil and Table 3 shows the list of equipment and tools for fabrication and testin

Table 2: Experimental Characterization of the Castor Oil

S/N	Equipment	Parameter	Standard
1	Gravimetric Oven	Moisture Content	AOCS Ca 2c-25
2	Specific Gravity Pycnometer (Specific Gravity Bottle)	Specific Gravity	ASTM D1217
3	Differential Scanning Calorimeter (DSC)	Specific Heat Capacity (Cp)	ASTM E1269
4	Thermal Conductivity Analyzer (using Transient Hot-Wire method)	Thermal Conductivity (k)	ASTM D7896
5	Calibrated Capillary Viscometer (Ostwald-type)	Kinematic Viscosity (at 40°C & 100°C)	ASTM D445
6	Abbe Refractometer	Refractive Index	ISO 6320:2000
7	Pensky-Martens Closed Cup Tester	Flash Point	ASTM D93
8	Cleveland Open Cup Tester	Flash Point	ASTM D92
9	Titration Apparatus (Burette, flask)	Acid, Saponification, Iodine, Peroxide Values	ISO: 660:2020, 3657:2023, 3961:2024, 3960:2017.

S/N	Equipment	Parameter	Standard
10	Separating Funnel	Unsaponifiable Matter	ASTM D1065.

Table 3: Equipment and Tools for Fabrication and testing

S/N	Equipment/Tool	Specification	Manufacturer
1	Infrared Thermometer	Temperature range: -50°C to 550°C, accuracy: $\pm 2^\circ\text{C}$	Fluke corporation, USA.
2	Data Logging System	Multi-channel thermocouple data logger (temperature range: -200°C to 1370°C)	Reyax Technologies Pvt Ltd. INDIA.
3	Pyranometer	Solar irradiance range: 0-2000W/m ² , accuracy: $\pm 5 \text{ W/m}^2$	Tenmars Electronics Co.,Ltd. TAIWAN
4	Electronic Weighing Balance	Capacity: 10Kg, readability: 0.1g	Shimazu Corporation. JAPAN.
5	Anemometer	Wind speed range: 0-30 m/s, accuracy: $\pm 0.1 \text{ m/s}$	Aicevoos company Ltd. CHINA.
6	Stopwatch	Digital stopwatch resolution: 0.01 s	Florentino industries Ltd. CHINA.

Characterization of Castor Oil to Determine the Thermo-Physical Properties

The parameters analysed include moisture content, specific gravity, density, specific heat capacity, thermal conductivity, kinematic viscosity (at 40°C and 100°C), refractive index, flash point, pour point, acid value, saponification value, iodine value, peroxide value, and unsaponifiable matter. The thermo-gravimetric analysis (TGA) of the oil was also carried out to determine the thermal stability and mass-loss behaviour of the castor oil used as sensible heat storage medium.

Moisture Content

The gravimetric oven-drying method was used to determine the castor oil's moisture content. A calibrated analytical balance was used to weigh about 5.00 g of oil in a moisture container that had already been weighed. The sample was dried at $105 \pm 2^\circ\text{C}$ in a hot-air oven until it reached a consistent mass. It was then cooled in a desiccator and weighed again. The percentage of mass loss was used to compute the moisture content:

$$MC(\%) = \frac{m_1 - m_2}{m_s} \times 100 \quad (1)$$

Where: m_1 and m_2 are the sample masses before and after drying, respectively, and m_s is the initial sample mass.

Specific Gravity

The pycnometer method was used to calculate the castor oil's specific gravity. First, a calibrated analytical balance was used to weigh a dry, clean pycnometer with a known volume. After that, distilled water was added to the pycnometer at the regulated reference temperature of 25°C to make sure no air bubbles remained inside. The filled pycnometer was weighed once the outside was dried. The castor oil sample was then added to the pycnometer at the same temperature after it had been emptied, cleaned, and dried. The filled pycnometer was weighed after any extra oil was removed from the outside. The mass of castor oil in the pycnometer volume divided by

the mass of an equivalent volume of distilled water yielded the specific gravity:

$$SG = \frac{m_o}{m_w} \quad (2)$$

Where m_o is the mass of castor oil in the pycnometer (g), and m_w is the mass of distilled water occupying the same volume (g).

Density

The gravimetric oven-drying method was used to measure the castor oil's specific gravity before determining its density. The density in kg/m³ was then calculated by multiplying the measured specific gravity by 1000.

$$\rho_o = SG \times \rho_w \quad (3)$$

Specific Heat Capacity (Cp)

A calibrated Differential Scanning Calorimeter (DSC) was used to calculate specific heat capacity. The sample pan was filled with a known mass of castor oil, usually 5-10 mg, and heated at a predetermined rate using a controlled heating program. Prior to testing, the DSC was calibrated using a suitable certified reference material. The measured heat-flow response yielded the specific heat capacity, which was expressed in J/kg K. Three separate measurements were made.

Thermal Conductivity (k)

The oil's thermal conductivity was determined using the Transient Hot-Wire (THW) method using a thermal conductivity analyzer. The measurement chamber is filled with the oil sample, and a probe is used to provide a regulated quantity of heat. Heat flow characteristics and temperature response are used to calculate thermal conductivity, while the rate of heat transfer thru the sample is tracked. The transient hot-wire method was used to measure k (T) across the expected operating range (40°C-70°C). The following data have been incorporated:

Table 4: Analysis on Thermal Conductivity of Castor Oil

Temperature (°C)	Thermal Conductivity (W/m K)
40	0.175
50	0.173
60	0.171
70	0.168

Kinematic Viscosity at 40°C

A calibrated capillary viscometer method (Ostwald-type viscometer method) was used to measure the kinematic

viscosity at 40°C. Initially, the oil sample is kept in a thermostatic bath at a steady 40°C. After that, the material is let to pass throughout the capillary tube while being pulled by

gravity. The kinematic viscosity is calculated using the viscometer calibration constant and the time it takes for the oil to flow between two calibrated markings.

Kinematic Viscosity at 100°C

With the exception of heating and maintaining the oil sample at 100°C prior to testing, the process is similar to that employed at 40°C. After measuring the oil's flow time through the calibrated capillary viscometer, the kinematic viscosity is calculated using the instrument constant and the measured flow time. Castor oil's very high viscosity creates engineering challenges like the greater pumping power, weaker natural convection, and slower charging/discharging but these are less critical in passive solar cookers, and its viscosity drops significantly at cooking temperatures, partially offsetting the problem.

Refractive Index'

The Abbe refractometer method was used to calculate the castor oil's refractive index. A few drops of the oil sample are applied to the instrument's prism surface after it has been carefully cleaned. The sample is exposed to light after the device has been calibrated to the necessary reference temperature. After being calibrated using a standard reference material, the refractive index is derived straight from the instrument reading.

Flash Point

Using tools like the Cleveland Open Cup tester method and the Pensky-Martens Closed Cup tester, the flash point of the castor oil was ascertained. A little test flame is applied at regular temperature intervals while the oil sample is gradually heated at a regulated rate. The lowest temperature at which the vapor above the oil briefly ignites is known as the flash point.

Pour Point

By cooling the oil sample under carefully monitored laboratory settings, the pour point of the sample was ascertained using the conventional cooling and tilting procedure. The sample container is gently tilted to check if the oil continues to flow at predetermined temperature intervals. The process is repeated until the oil stops moving and the pour point is determined in accordance with the applicable testing standard.

Acid Value

Approximately 3g of castor oil was dissolved in a neutral solvent mixture comprising ethanol and ether, the acid-base titration method was used to calculate the oil sample's acid value. Phenolphthalein is used as an indicator when titrating the solution with a standard potassium hydroxide (KOH) solution. When the oil's free fatty acids are neutralized and a light pink hue continues, the endpoint is reached.

Saponification Value

Approximately 2g of castor oil was refluxed with an excess of standardized alcoholic potassium hydroxide solution, the saponification value of the oil was ascertained using the Alcoholic KOH reflux and back-titration method. Triglycerides are transformed into soap and glycerol during this process. Following refluxing, a normal hydrochloric acid solution is used to titrate the residual unreacted potassium hydroxide. The saponification value is calculated from the amount of alkali employed in the reaction.

Iodine Value

The Wijs method was used to calculate the iodine value. An excess of Wijs reagent was reacted with around 0.2 g of oil in a controlled environment that was shielded from light. The released iodine was then titrated with standardized sodium thiosulfate using starch close to the endpoint after potassium iodide and water were added. The analysis was done in triplicate, and a blank was also examined.

Peroxide Value

A suitable acetic acid-chloroform mixture was used to dissolve around 5 g of castor oil, which was then reacted with potassium iodide. Standardized sodium thiosulfate was employed to titrate the released iodine, and starch was used close to the endpoint. The peroxide value was computed from the titre differential after a blank determination. Three separate analyses were conducted.

Unsaponifiable Matter

By first saponifying the oil sample with alcoholic potassium hydroxide, the unsaponifiable matter of the oil was ascertained utilizing the saponification, solvent, extraction, and gravimetric method. A suitable organic solvent, such as petroleum ether, is used to remove the unsaponifiable components from the soap solution after it has been transferred to a separating funnel. After being cleaned and dried to eliminate moisture, the solvent extract is evaporated. The unsaponifiable material in the oil is represented by the residue that remains after the solvent is removed.

Thermo-gravimetric Analysis (TGA)

The thermal stability of castor oil was evaluated using Thermo-Gravimetric Analysis (TGA), in which the mass (weight) change of the sample was measured continuously as a function of temperature during heating. The castor oil sample was heated over a temperature range of 30°C to 950°C, and the TGA curve was recorded starting from an initial weight of 100%, indicating that no mass had been removed at the beginning of the experiment. The weight loss behaviour was then analysed by dividing the curve into four distinct regions: Region I (30-150°C), Region II (150-250°C), Region III (250-350°C), and Region IV (350-950°C), corresponding to moisture evaporation, slight heat breakdown, rapid thermal decomposition, and carbonaceous residue formation, respectively. The percentage of residue remaining at the end of the experiment (approximately 9-10%) was also determined from the final plateau of the TGA curve.

Design Parameters and Calculation

This section presents the engineering and design calculations required for the development of a box-type solar cooker using castor oil as a sensible heat storage (SHS) medium. The calculations are based on heat transfer principles and thermo-physical properties of castor oil.

Thermo-Physical Properties of Castor Oil

The performance of the solar cooker depends strongly on the thermo-physical properties, the parameters analysed include moisture content, specific gravity, density, specific heat capacity, thermal conductivity, kinematic viscosity (at 400C and 1000C), refractive index, flash point, pour point, acid value, saponification value, iodine value, peroxide value, and unsaponification matter.

From the experiment conducted on the thermo-physical properties of castor oil:

Moisture content was calculated using

$$MC(\%) = \frac{m_1 - m_2}{m_s} \times 100 \quad \text{from equation (1)}$$

Where m_1 and m_2 are the sample masses before and after drying, respectively, and m_s is the initial sample mass.

Mass of empty container = 25.00 g, Mass of oil sample = 5.00 g,
Initial combined mass = 30.00g
Final combined mass after drying = 29.9931 g

$$MC(\%) = \frac{30.00 - 29.9931}{5.00} \times 100$$

$$MC(\%) = 0.138\%$$

Specific gravity is calculated from the mass of equal volumes of oil and water from equation (2) $SG = \frac{m_o}{m_w}$

Where m_o is the mass of castor oil in the pycnometer (g), and m_w is the mass of distilled water occupying the same volume (g).

Mass of pycnometer + Water = 35.00g

Mass of empty pycnometer = 25.00g

$$m_w = 35.00 - 25.00 = 10.00g$$

Mass of pycnometer + oil = 34.56g

$$m_o = 34.56 - 25.00 = 9.56g$$

$$\text{Therefore: } SG = \frac{9.56}{10.00} = 0.956$$

The Density was obtained from the measured specific gravity and the density of water at the same temperature:

$$\rho_o = SG \times \rho_w \quad (4)$$

Where: ρ_o = density of the oil, SG = specific gravity, ρ_w = density of water.

$$\rho_o = 0.956 \times 1000$$

$$\rho_o = 956 \text{ kg/m}^3$$

Using volume and density to calculate for the mass of the oil we have;

The volume (V) of the castor oil is 5 litres (0.005m³)

The density (ρ) of the castor oil was gotten to be 956Kg/m³

The mass (m) of the castor oil is given

$$\text{Density} = \frac{\text{mass}}{\text{volume}} \quad (5)$$

Therefore: $\text{mass} = \text{Density} \times \text{volume}$; $\text{mass (m)} =$

$$956 \times 0.005; \text{mass (m)} = 4.78 \text{ Kg}$$

Therefore, the Density of the oil is 956Kg/m³, the volume of the container is 0.005m³ and the mass of the oil is 4.78Kg.

Solar Energy Input

According to Abdulrahim *et al.* (2020), the solar energy incident on the cooker is given by:

$$Q_{in} = I \times A \times t \quad (6)$$

Where:

Q_{in} = Total solar energy input (W), I = Solar insolation (W/m²), A = Aperture area (m²)

t = time in seconds

From the Design:

Length (L) = 0.585 m, Width (W) = 0.55 m

$$A = L \times W; A = 0.585 \times 0.55 = 0.32175 \text{ m}^2$$

The time (t) = 900s (15 minutes)

$$Q_{in} = 790 \times 0.32175 \times 900; Q_{in} = 228,764.25 \text{ J (228.77 KJ)}$$

Heat Stored in Castor Oil

According to Çengel and Ghajar (2015), the quantity of heat stored in a substance is given by the expression:

$$Q = mc\Delta T \quad (7)$$

Where: m= mass of castor oil (kg), c= specific heat capacity of castor oil (1.9 kJ/kg K)

ΔT = Temperature rise (K)

The following analysis are made for simplicity and practical design:

The Average solar irradiance, I = 790 W/m²

The Ambient temperature, T_a = 30°C

Surface temperature (T_s) = 820C

The Maximum operating temperature = 101.6°C

The amount of heat stored in castor oil is giving by:

$$Q = mc\Delta T$$

Where: m = mass of castor oil (kg), C = specific heat capacity (J/kg K), ΔT = temperature rise (K)

Heat Storage Capacity:

The temperature rises from 300C to 74.80C

Therefore:

From (30 + 273) K to (74.8 + 273) K:

From 303K to 347.8K

The temperature difference becomes:

$$\Delta T = 347.8K - 303K$$

$$: \Delta T = 44.8K$$

$$Q = mc\Delta T$$

$$Q = 4.78 \times 1900 \times 44.8; Q = 406,873.6J (406.8736kJ)$$

Heat Loss through Conduction

The general form of Fourier's Law is:

$$Q = \frac{kA(T_1 - T_2)}{L} \quad (8)$$

From the given parameters

Length = 585mm = 0.585m, Width = 550mm = 0.55m, Height

= 345mm = 0.345m

Insulation Material:

Thermal Conductivity (K) of Fiberglass is 0.04W/m K

K = 0.04W/m K

Insulation Thickness (L) is 0.05m

L = 0.05m

Operating Temperatures:

Inner cooking temperature (T_1) = 74.80C, Ambient temperature (T_2) = 300C

Thus,

$$\Delta T = T_1 - T_2 \quad (9)$$

$$\Delta T = (74.8 + 273) - (30 + 273)$$

$$\Delta T = 44.8K$$

Heat Transfer Area:

Heat is mainly lost through:

- Bottom Surface

- Side walls

Bottom Area A_b :

$$A_b = L \times W$$

$$A_b = 0.585 \times 0.55$$

$$A_b = 0.32175 \text{ m}^2$$

Slide Wall Area (A_s)

Two longer sides:

$$A_{long} = 2(L \times H)$$

$$A_{long} = 2(0.585 \times 0.345)$$

$$A_{long} = 0.40365 \text{ m}^2$$

Two shorter sides:

$$A_{short} = 2(W \times H)$$

$$A_{short} = 2(0.55 \times 0.345)$$

$$A_{short} = 0.3795 \text{ m}^2$$

Total Conductive Area:

$$A_{total} = A_b + A_{long} + A_{short}$$

$$(13)$$

$$A_{total} = 0.32175 + 0.40365 + 0.3795$$

$$A_{total} = 1.1049 \text{ m}^2$$

Apply Fourier's Law from equation (8):

$$Q = \frac{kA(T_1 - T_2)}{L}$$

Substituting Values:

$$Q = \frac{0.04 \times 1.1049 \times 44.8}{0.05}, Q = 39.6W$$

Therefore, the heat loss through conduction is given:

$$Q = 40W$$

$$\text{For 15 minutes: } Q = 40 \times 900 = 36,000J (242.388kJ)$$

Heat Loss through Convection

In a solar cooker, convection heat losses mainly occur through:

- i. The outer walls
- ii. The glazing surface
- iii. The air surrounding the cooker

Newton's Law of Cooling is used to determine convection heat loss.

The convection heat transfer equation is:

$$Q_c = hA(T_s - T_a) \quad (14)$$

Where:

Q_c = Convective heat loss

h = Convective heat coefficient

A = Surface area exposed to air

T_s = Surface temperature

T_a = Ambient temperature

Top Surface Area:

$$A_t = L \times B \quad (15)$$

$$A_t = 0.585 \times 0.55$$

$$A_t = 0.32175\text{m}^2$$

Bottom Area:

$$A_b = 0.32175\text{m}^2$$

Total Exposed Area:

$$A = A_t + A_b \quad (16)$$

$$A = 0.32175 + 0.32175$$

$$A = 0.6435\text{m}^2$$

• Surface Temperature of Cooker:

$$T_s = 820\text{C}$$

• Ambient temperature:

$$T_a = 300\text{C}$$

Thus,

$$\Delta T = T_s - T_a \quad (17)$$

$$\Delta T = (82 + 273) - (30 + 273)$$

$$\Delta T = 52\text{K}$$

For natural convection solar cookers:

$$h = 5\text{W/m}^2\text{K}$$

Applying Newton's Law of Cooling, from equation (14):

$$Q_c = hA(T_s - T_a)$$

Substituting Values:

$$Q_c = 5 \times 0.6435 \times 52$$

$$Q_c = 167.31\text{ W}$$

For 15 minutes:

$$Q_c = 167.31 \times 900 \quad Q_c = 150,579\text{J}$$

Heat Loss through Radiation

According to Stefan-Boltzmann Radiation Equation, the radiation heat loss equation is:

$$Q_r = \varepsilon \sigma A(T_s^4 - T_a^4) \quad (18)$$

Where:

Q_r = Radiation heat loss

ε = Emissivity of surface

σ = Stefan – Boltzmann constant

A = Radiation surface area

T_s = Surface temperature

T_a = Ambient temperature

Surface area (A) = 0.3075m²

Surface temperature (T_s) = 82 + 273 = 355K

Ambient temperature (T_a) = 33.5 + 273 = 306.5K

Emissivity for black-coated absorber surfaces:

$$\varepsilon = 0.90$$

Stefan-Boltzmann constant (σ) = 5.67 x 10⁻⁸ W/m².K⁴

Applying Stefan-Boltzmann Equation from equation (18):

$$Q_r = \varepsilon \sigma A(T_s^4 - T_a^4)$$

Substituting values:

$$Q_r = 0.9 \times 5.67 \times 10^{-8} \times 0.32175 \times (355^4 - 306.5^4)$$

$$Q_r = 115.9\text{W}$$

For 15 minutes:

$$Q_r = 115.9 \times 900$$

$$Q_r = 104,310\text{J}$$

Total Heat Loss in the Solar Cooker

$$Q_{total} = Q + Q_c + Q_r$$

$$Q_{total} = 40 + 167.31 + 115.9$$

$$Q_{total} = 323.21\text{W}$$

For 15 minutes:

$$Q_{total} = 323.21 \times 900 = 290,889\text{J}$$

Therefore, the total heat loss is 290,889J (290.89kJ)

d. Thermal Efficiency (η)

Expressed the thermal efficiency to be given as:

$$\eta = \frac{\text{Useful Energy Output}}{\text{Solar Energy Input}} \times 100 \quad (19)$$

Useful Energy Output = Heat Stored in the castor oil – Total Heat loss

$$\text{Useful Output} = 406,873.6 - 290,889 = 115,984.6\text{J}$$

$$\text{Solar Energy Input } (Q_{in}) = 228,764\text{J}$$

Substituting values:

$$\eta = \frac{115,984.6}{228,764} \times 100 \quad \eta = 0.507 \times 100;$$

$$\eta = 50.7\%$$

Fabrication Method

The research involved the design and fabrication of a rectangular box-type solar cooker consisting of an insulated cooking chamber, a transparent double-glazed glass cover, a plane reflector, a black-coated absorber plate, a cooking pot, and a castor oil thermal energy storage unit. The absorber plate captured solar energy and converted it into heat, while the cooking pot received the heat for cooking. The castor oil served as a sensible heat storage medium, storing excess thermal energy during peak sunshine and releasing it gradually when solar radiation decreased, thereby improving the thermal performance of the solar cooker.

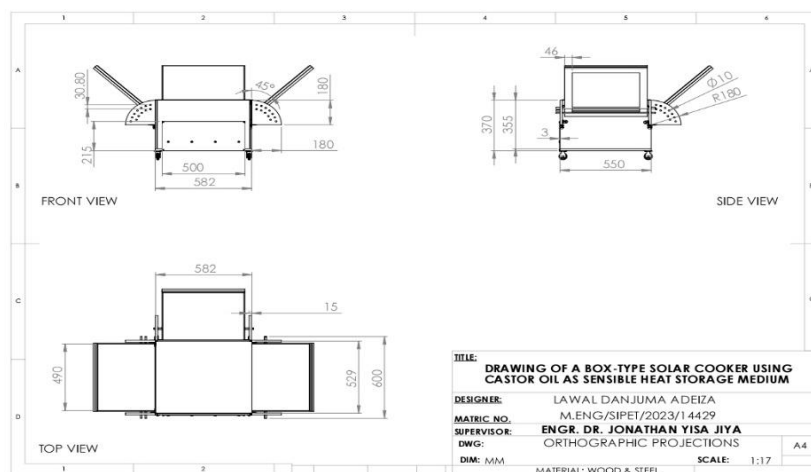


Figure 1: Orthographic view of the B0x-Type Solar Cooker

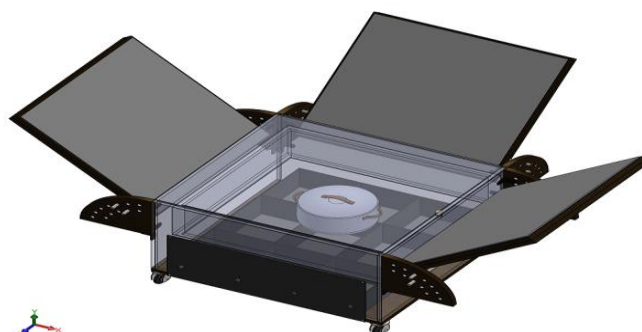


Figure 2: Isometric view of the Box-Type Solar Cooker

RESULTS AND DISCUSSION

5.

The result of characterization of castor oil is shown in Table

Table 5: Laboratory Analysis Result on the Thermo-Physical Properties of Castor Oil

Serial Number	Parameters	Sample A
1	Moisture Content %	0.138
2	Specific Gravity	0.956
3	Density (ρ)	956Kg/m ³
4	Specific Heat Capacity (C_p)	1900J/Kgk
5	Thermal Conductivity (K)	0.175W/m K, 0.173W/m K, 40°C, 50°C, 60°C, 70°C
6	Kinematic Viscosity 40°C mm ² /s	298.94
7	Kinematic Viscosity 100°C mm ² /s	22.42
8	Refractive Index	1.483
9	Flash Point (°C)	220
10	Pour Point (°C)	-10
11	Acid Value mgkOH/g	8.86
12	Saponification Value mgkOH/g	192.18
13	Iodine Value g/100g	79.63
14	Peroxide Value mmol/Kg	3.20
15	Unsaponifiable matter %	1.03

According to the results shown in Table 5, castor oil has advantageous thermo-physical characteristics for sensible heat storage applications. The reported density of 956 kg/m³ indicates that a little volume of the Storage medium may hold a comparatively big amount of heat. Castor oil can absorb a huge amount of thermal energy before experiencing a significant increase in temperature, according to its specific heat capacity of 1.9 kJ/kg K. Because it allows the oil to store

surplus heat during times of intense solar radiation and gradually release the stored heat when solar intensity diminishes, this characteristic is especially advantageous in solar cooking applications. According to Bala et al. (2025), sunflower oil works well for low heat simmering (above 90°C), but it is less efficient for energy-intensive processes like boiling water. In a similar vein, castor oil exhibits potential for boiling-type cooking and may be appropriate for

high-temperature uses (roasting, frying). The working temperature stayed considerably below the 220°C flash point, which guarantees safety for solar cooking applications. This is consistent with the observation made by Gawande & Ingole (2019) that storage materials ought to retain their thermal stability during numerous cycles. Since the created cooker's working temperature stayed much below this value during the trial period, the flash point of 220°C further supports the safety of castor oil for solar cooking applications.

These results are consistent with those of Martínez et al. (2024), who found that castor oil has strong heat retention properties and outstanding thermal stability for solar thermal applications.

Stagnation Temperature Result

The determined stagnation temperatures are shown in Figure 3

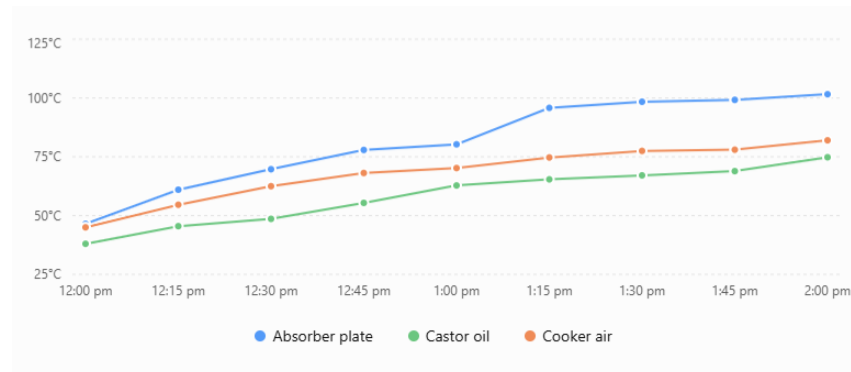


Figure 3: Temperature Profile of the Box-Type Solar Cooker during Stagnation Periods

Figure 3 shows the stagnation temperature performance of the developed box-type solar cooker integrated with castor oil as a sensible heat storage medium. During the test, solar radiation increased from 615 to 790 W/m², while ambient temperature increased slightly from 30.0 to 33.5°C. The relatively small change in ambient temperature indicates that the progressive temperature increase inside the cooker was mainly associated with solar energy absorption.

The absorber plate temperature increased from 46.5°C at 12:00 pm to a maximum of 101.6°C at 2:00 pm. The absorber recorded the highest temperature throughout the test because of its direct exposure to the incoming solar radiation. The cooker air temperature also increased from 45.0 to 82.0°C, indicating effective transfer of absorbed heat into the cooking chamber.

The temperature of the castor oil increased progressively from 38.0 to 74.8°C. Although the oil temperature remained below that of the absorber plate, its continuous increase indicates that heat was being transferred from the absorber to the oil and stored as sensible thermal energy. This behavior is important for a solar cooker integrated with thermal storage because the stored heat can contribute to cooking after the intensity of solar radiation decreases.

The maximum absorber temperature obtained in this study (101.6°C) is lower than the 165.1°C reported by Abdulrahim et al. (2020) for a solar oven insulated with kapok wool. However, the difference may be associated with variations in solar radiation, insulation material, reflector arrangement, cooker geometry, ambient conditions and test period. Abdulrahim et al. (2020) conducted their stagnation test under clear-weather conditions, whereas the present test was conducted under comparatively lower solar-radiation conditions.

Overall, the results demonstrate that the developed cooker was capable of converting solar radiation into useful thermal energy while simultaneously heating the castor oil. The maximum temperatures of 101.6°C for the absorber plate, 82.0°C for the cooker air and 74.8°C for the castor oil demonstrate the thermal response of the system and confirm the potential of castor oil to function as a sensible heat storage medium in the developed solar cooker.

Heat Retention Performance Results

The result of heat retention performance of the solar box cooker is shown in Figure 4

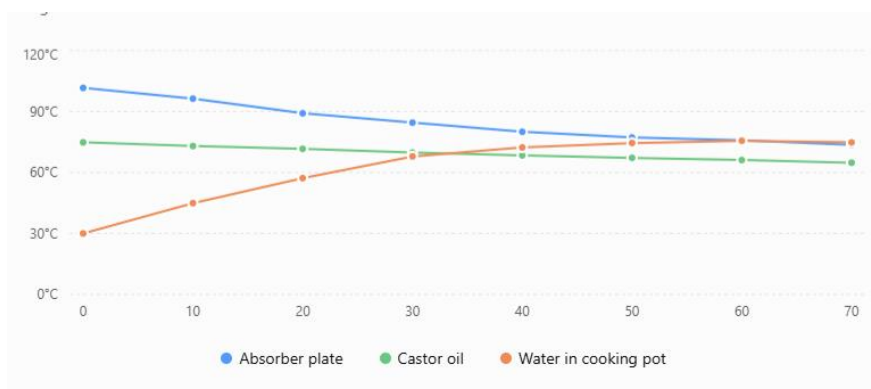


Figure 4: Temperature Profile of the Box-Type Solar Cooker during Heat Retention Periods

Figure 4 presents the heat retention performance of the developed box-type solar cooker after removal from sunlight. The water temperature increased from 30.0°C to 75.6°C within 60 minutes, despite the absence of solar radiation. This indicates that heat stored in the absorber plate and castor oil continued to be transferred to the cooking pot after solar input had ceased. At 60 minutes, the absorber plate temperature was 75.8°C, the water temperature was 75.6°C, and the castor oil temperature was 66.1°C. The difference of only 0.2°C between the absorber plate and water indicates that the two components had reached approximate thermal equilibrium. After 60 minutes, the water temperature began to decrease, reaching 74.8°C at 70 minutes, while the absorber plate and castor oil temperatures decreased to 73.6°C and 64.8°C, respectively. The gradual temperature decrease demonstrates that the stored thermal energy was released progressively rather than being lost immediately after removal from

sunlight. This behavior is desirable in a solar cooker because it can extend the useful cooking period beyond the period of direct solar radiation. The result is consistent with studies reporting the potential of sensible thermal storage materials to maintain useful temperatures after solar input has ceased. Overall, the heat retention results demonstrate that the integration of castor oil provided useful thermal storage capability. The continued increase in water temperature for 60 minutes after removal from sunlight confirms that stored thermal energy remained available for cooking. Thus, the developed cooker has the potential to support continued heating during periods of reduced or unavailable solar radiation.

Thermo-gravimetric Analysis (TGA)

The Thermo-Gravimetric Analysis (TGA) is shown in Figure 5

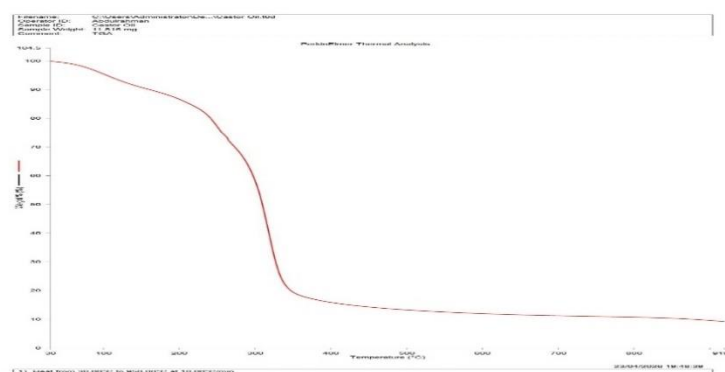


Figure 5: Thermo-gravimetric Analysis (TGA) Curve of Castor Oil

The thermo-gravimetric analysis (TGA) curve is shown in Figures 5 of the graph above. Because it identifies the temperature range in which castor oil is thermally stable before it starts to break down, these test is crucial to the study of castor oil as a sensible heat storage medium.

Thermo-Gravimetric Analysis (TGA) Curve (Figure 5)

The mass (weight) change of a material during continuous heating is measured by thermo-gravimetric analysis (TGA). When the TGA curve starts at 100% weight, no mass has been removed.

Region I (30-150°C)

There is only a very slight drop in weight. This shows moisture evaporation, traces of volatile contaminants, and a small amount of light compound evaporation. In this area, castor oil is still very stable.

Region II (150-250°C)

The weight gradually drops, indicating that very slight heat breakdown has started and the molecular structure is still mostly intact. Good thermal stability is still maintained by the oil.

Region III (250-350°C)

This is the most important area; the graph displays a dramatic decline in weight. This shows the quick thermal breakdown, triglyceride breakdown, fatty acid chain breakdown, and volatile gas release. In this temperature range, about 80% of the material is lost. We refer to this as the primary stage of breakdown.

Region IV (350-950°C)

The graph becomes almost horizontal after deconstruction, with only a slight, slow weight decrease remaining. This shows that the majority of organic stuff has already broken down, leaving just carbonaceous residue, and that decomposition is slowing down significantly. At the conclusion of the experiment, about 9-10% residue is still present. The findings show that castor oil has exceptional thermal stability below 250-280°C. The oil is resistant to thermal degradation under typical working settings if there is little mass loss at lower temperatures. The greatest proportion of weight loss is seen during a big breakdown event that takes place between roughly 280°C and 350°C. The breakdown of castor oil's long-chain fatty acids and triglycerides is responsible for this activity. The majority of volatile organic chemicals have broken down because there is very little Carbonaceous residue left after this point. The TGA results verify that castor oil may safely operate as a sensible heat storage medium without considerable thermal degradation in a solar cooker application, where temperatures rarely rise above 180-200°C.

CONCLUSION

This study successfully demonstrated the usefulness of castor oil as a sensible heat storage medium for enhancing the thermal performance of a box-type solar cooker. According to the experimental characterization, castor oil has good thermo-physical properties that make it suitable for solar cooking applications, including a density of 956 kg/m³, a specific heat capacity of 1.9 kJ/kg K, and thermal stability up to 250°C. The TGA analysis, which revealed that the primary degradation occurred between 280°C and 350°C much higher

than the cooker's operating temperatures further validated its thermal stability. The produced solar cooker obtained a maximum absorber plate temperature of 101.6°C and a castor oil temperature of 74.8°C under peak solar radiation of 790 W/m². The heat retention data demonstrated that the stored thermal energy effectively extended cooking capabilities after sunset, with water temperatures reaching 75.6°C in 60 minutes without solar input. The water heating test, which reached 84°C in 30 minutes, verified the cooker's practical cooking potential. The calculated thermal efficiency of 50.7% indicates an effective use of solar energy.

These findings show that castor oil is a feasible, locally available, and sustainable thermal storage medium for solar cooking systems, offering a practical solution to the intermittency issue and supporting the global transition to clean cooking technology.

Acknowledgement

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