Python Coding of *Lagenaria siceraria* Cucurbitaceae Material Heat Transfer for Food Conservation

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Abstract — This paper investigates the thermal properties of *Lagenaria siceraria*, as a natural insulating material for food and thermal energy preservation using python analysis.. The paper focuses around: (1) developing a Python-based model to simulate heat transfer processes within this material; (2) the validation of the model with laboratory collected and generated experimental data to assess its accuracy (3) the evaluation of the effectiveness of *Lagenaria siceraria* to conserve the temperature of contained food. The findings show that inside the calabash container heat is transferred by conduction, while from the outer surface of the calabash, heat is transferred by convection. The developed Python's code shows visualization of heat transfer model between the contained pap, the calabash container material and its surroundings.

Keywords—Calibash Material, Coding with Python, Food Conservation, Heat Transfer, *Lagenaria siceraria* Cucurbitaceae.

I. Introduction

Lagenaria siceraria (Calabash) also known as the bottle gourd is widely cultivated vine grown for its fruits, it has a unique shape that allows to be used for many things. The bottle gourd is a plant member of the *Cucurbitaceae* family and has been used in many cultures for making containers, musical instruments and kitchen utensils [1]. The key advantage of using the bottle gourd is its unique sound and temperature insulation properties. It has a hard but brittle and relatively thick shell that acts as an insulator helping to maintain a consistent temperature within itself.

Calabash offers a sustainable and easy solution to extend the shelf-life of food in places where electricity is not reliable or there is no access to electricity. The bottle gourd has been trusted for preserving food like pap, a staple meal which is made from maize flour. Cooked maize flour, which is pap can easily spoil and needs proper storage in a well-controlled environment. The bottle gourd has shown that it is ideal for preserving food, maintaining freshness to extend the shelf life of food, and for transporting liquids. In Cameroon [2] it is used to collect water from the reiver while in South Africa it is used to drink traditional beverages during ceremonies [3].

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The longest the food that is cooked can remain before being eaten by the household is for a day, that means during the day the pap can remain at its optimal temperature.

By understanding the thermal properties of *Lagenaria siceraria*, this research seeks to provide an alternative method for preserving pap in conditions where conventional refrigeration is not available. The thermodynamic derived equations were used to simulate the temperature distribution in and transfer through the bottle gourd.

II. Background

The degree to which a material prevents heat from escaping defines how well it insulates. There are three main heat transfer processes radiation, convection, and conduction. When it comes to biological materials such as *Lagenaria siceraria*, conduction is the primary heat transmission mechanism. Heat is transferred through a substance via conduction when molecules vibrate, collide and the measure of a material's capacity to allow heat to flow is called thermal conductivity [4]. Excellent insulators are those that prevent heat flow and excellent conductors are those that allow heat to flow more easily in a material

Composition, density, and structure all affect the heat conductivity of a material, and these are the observed and influencing parameters. Because the *Lagenaria siceraria* materials, are porous and fibrous, biological materials, they demonstrate some form of high resistance to heat transfer and are therefore typically excellent insulators [4] As the material becomes more porous, the air pockets in the material's structure lower the material's total thermal conductivity [5], [6]. Insulating quality of a material is influenced by its specific heat capacity as well as thermal conductivity. The specific heat capacity is the quantity of heat needed to increase a material's unit mass temperature by one degree. Greater thermal energy absorption by a material with high specific heat capacity allows it to function as heat sinks and slow down the rate of temperature change within the material [7] An additional element affecting the thermal insulating properties of a material is density.

Because lower density materials contain more air pockets or spaces that prevent heat transmission by conduction, they often have higher insulating qualities [8]. Research on the thermal qualities of wood and other plant materials has shown that their good thermal conductivity, particular heat capacity, and density features may efficiently lower heat transfer [9]. These materials may provide thermal insulation in part because of their low thermal conductivity, having high specific heat capacity, and comparatively low density. Because it is a plant-based

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substance, *Lagenaria siceraria* is structurally and chemically comparable to wood and other plant materials. Low density and porous, fibrous structure indicate that it may have low thermal conductivity and high specific heat capacity, which makes it a useful insulator for uses in food preservation [10]..Using the thermal characteristics of *Lagenaria siceraria*, conventional food preservation methods may be created that make use of the material's inherent insulating qualities. In areas without easy access to conventional preserving methods and these methods may assist in preserving the ideal temperature of pap, therefore prolonging the shelf life and lowering food waste.

2.1 Research Problem Statement

The primary challenge addressed in this research is the need to find out how long the *Lagenaria siceraria* can preserve the heat of pap throughout the day. In many rural and low-resource settings, conventional refrigeration methods are not feasible due to a lack of infrastructure and consistent electricity supply. Therefore, alternative methods using locally available materials need to be explored and be scientifically validated. This study seeks to address the following problem: Can *Lagenaria siceraria* provide effective thermal insulation for pap conservation, thereby maintaining its temperature within an optimal range.

2.1.1 Research Aim

The primary aim of this research is to investigate the thermal properties of *Lagenaria siceraria* and evaluate its potential as a natural insulating material for maintaining the temperature of pap. This study seeks to provide a scientific basis for the use of *Lagenaria siceraria* in food conservation by modelling its heat transfer properties and validating its effectiveness in maintaining stable temperatures over extended periods.

By observing traditional practices of using natural materials for food storage and having demonstrated their effectiveness in maintaining food quality and extending shelf life. There is also a lack of scientific data to support these practices and optimize their use. Calabash, with its unique properties and historical use in various cultures, presents part of a promising solution for natural insulation. Understanding its thermal characteristics can lead to innovative applications.

Furthermore, the use of Python as a modelling tool offers significant advantages in terms of computational efficiency, accessibility, and versatility. Python's extensive libraries for numerical analysis and visualization enable detailed simulations of heat transfer processes, providing valuable insights into the material's performance. This research aims to leverage python as a language for data analysis to enhance our understanding of *Lagenaria siceraria* and promote its use in practical, sustainable solutions in the world.

2.2 Research Hypothesis

The study hypothesizes that: *Lagenaria siceraria*, due to its natural insulating properties, can effectively maintain the temperature of pap within a desired range. Specific hypotheses include the thermal conductivity of *Lagenaria siceraria* is significantly lower than that of conventional insulating materials, making it an effective thermal insulator. The specific heat capacity and density of *Lagenaria siceraria* contribute to its ability to maintain stable temperatures over time. The use of *Lagenaria siceraria* for pap conservation results in slower temperature drops for pap

III. Literature Review

3.1 Introduction

The literature review, providing a comprehensive review from existing bodies of knowledge, is structured based on key words derived from the topic, to identify the underlying principles around *Lagenaria siceraria* (Calabash) and heat transfer for the material..

3.2 Description of the Material

Calabash, scientifically known as *Lagenaria siceraria* and the bottle gourd, has been used throughout history for many purposes. It is a climbing plant that produces hard and shelled fruits that when harvested young they are edible as vegetables but when allowed to dry up they can be used for crafting containers, utensils or other items because of their durability. The plant grows well in tropical or subtropical conditions. They prefer well drained soil because they produce yield twice a year. The planting time is when temperatures are warm allowing it to be properly grown, the plant needs a lot of sunlight and space to properly grow [13], [14].

The Calabash yield per year is 35 to 40 metric tons per hectare and the fruit harvests 2 to 3 months from the time of planting, they have diverse shapes, and the round shape type are called calabash gourd and while the bottle neck-type are called bottle gourd [14] . Once it has reached maturity the plant is harvested and left to dry and the dried calabash can be cut for whatever use it is meant to be used for, if it needs to be reshaped the shell can be soaked to soften it making it easier to work with it. Historically it has been part of many cultures used as vessels for carrying water, storing food, food bowls and in some cultures, it is crafted for use into musical instruments such as maracas and other string instruments [15]. In the context of this study, calabash is being investigated for its potential use of thermal insulation material. The natural properties of calabash, being fibrous and thermal resistant make it a promising material for composite materials used for improving thermal insulation. The use of Calabash as a thermal composite material will offer some good benefits such as biodegradability and cost effectiveness because as an agricultural byproduct it is readily available and is a promising material that can substitute some synthetic materials. The calabash skin is primarily composed of lignocellulosic fibers, which provide strength and durability, they give it its toughness and rigidity making it an excellent reinforcing material in composites [9], [10] .

The craftsmanship involving calabash includes techniques like carving and shaping the dried shells into various functional items [16]. The methods used are passed on from generation to generation to preserve the knowledge and skills required to work with the plant, currently the plant has found uses in sustainable eco-friendly products. It’s also being explored in this current study as an insulating material and additionally it is used in decorative items, fashion accessories, showing that it can have multiple uses. Calabash offers a unique combination of traditional uses and applications, making it valuable for multiples uses. Its natural properties such as toughness, high thermal resistance, and sustainability highlight its potential for use as a thermal insulating material. By understanding and taking advantage of these properties, the aim will be to contribute to the growth and advancement of eco-friendly and efficient thermal insulating materials.

3.3 Heat transfer theory

Before the development of kinetic theory heat was understood as something that resulted in the feeling of being warm. When the Kinetic theory was then established, what we understood about heat changed because the kinetic theory treats molecules as tiny particles in the shape of a ball always in motion possessing kinetic energy [17]. The definition of heat then became energy associated with the random motion of atoms and molecules. One theory was in existence though at that time and was suggested years prior was the caloric theory which stated that heat is the manifestation of motion of at molecular level and set the ongoing views about heat up until the kinetic theory was then developed [18], [19].. Scientific problems most of the time involve equations that relate the change of some variables to one another, equations for the conservation of mass and energy are one of the ones that govern heat transfer. By using these equations, we can lay out a proper foundation for some of the most complex heat transfer simulations.

3.3.1.Conservation of Energy:

Heat Equation: This equation describes the distribution of heat for a given area over a specific time. The first law of Thermodynamics states that energy cannot be created nor be destroyed but it moves from one form to another [20]. The conservation equations are derived from the first law and includes conductive heat transfer

$$p\, c_p \left(\frac{\partial T}{\partial t} + u \cdot \nabla T\right) = -k\; A\;\; \nabla^2 T + \dot{q\Delta} \qquad (1)$$

Cp is the specific heat capacity, ***T*** is the temperature, **k** is the thermal conductivity, and $\dot{\boldsymbol{q}}$ represents heat that is generated per unit volume.

During heat transfer the heat in the form of energy transferred from one system to another resulting in temperature difference, thermodynamic studies focus on the amount of heat transferred as the system will shift from one equilibrium point to another. Energy transfer in the form of heat always moves from a region of high temperature to a region of low temperature and transfer will stop when both regions are in equilibrium [21]. Heat is transferred in three different ways, conduction, convection, radiation and the energy transfer work the same way throughout the different ways of heat transfer. For the sake of this project, we will only focus on conduction and convection with relevant theories being discussed around the two phenomena.

3.3.2 Conduction

Conduction is energy transfer in the form of heat through contact from one object to another, it takes place at a microscopic level` through collision of particles, but at a large scale the is no movement of material and objects that are in contact [22]. The transfer of heat from one abject to another can be measured over time, Fourier's law describes that for us, it states that the rate at which heat is transferred from one material to another is proportional to the negative gradient of the temperature and the area through which the heat flows.

$$q = -kA\frac{dT}{dx} \qquad (2)$$

From the above equation **q** is the heat transfer rate, **k** is the thermal conductivity of the material, **A** is the area through which heat is being transferred, $\frac{\mathbf{dT}}{\mathbf{dx}}$ is the temperature gradient. Materials with high thermal conductivity, such as metals, are excellent conductors of heat, while materials with low thermal conductivity, like wood or foam are good insulators [23]

3.3.3 Convection

Convection is the movement of particles through a substance, transporting their heat energy from a high temperature region to a low temperature region, this is through fluids. The is forced and natural convection in natural convection, the main thing that drives the fluid motion is buoyancy forces that are a result of density variation because of temperature gradient, in forced convection the fluid is forced to move using fans or pumps [24]

$$q = hA\,(T_s - T_\infty) \qquad (3)$$

The heat transfer is described by the above equation, which is described by Newton's law of cooling, where **q** is the heat transfer rate, **h** is the heat transfer coefficient, **A** is the surface area $\boldsymbol{T_s}$ is the surface temperature and T_∞ is the fluid temperature moving heat away from the surface. The efficiency of heat transfer through convection depends on the properties of the fluid used to move the heat, flow velocity and surface geometry [25]. The principles discussed will be important in solving complex heat transfer problems, they lay up the foundation for running the simulations needed in python. The principles are not just principles but have had many practical applications so by leveraging them it will be possible to get a more detailed description of how heat will be distributed throughout the calabash body.

3.4 Computer Programming in General

Coding is essential to many industries, such as finance, healthcare and entertainment, where use of software is in importance. Computer programming involves the creation of instructions that computers must follow to perform tasks, specifically to what the computer programmer wants to do. It is an important skill in computer science, allowing the development of software, websites, and applications that results in innovation in the technology industry [26].

3.4.1 Python

Python is a high-level interpreted language known for how simple and easy it is to read it. The language was created by Guido van Rossum, he first released it in 1991, and python has gained immense popularity due to its ease of use and many applications [26], [27]. The design of python and its philosophy are focused on code readability and simplicity, which make it an excellent choice for beginners and experienced individuals alike. Python offers several features that make it a preferred language for many developers. Python syntax is designed to be readable and straightforward, allowing developers to write clear and concise code. Python supports many language paradigms, including procedural, object-oriented and functional programming making it an adaptable language for different needs of programmers [28].. Python has many libraries and a huge number of third-party libraries that allow it to have many functions too, allowing it to do tasks from web development to scientific computing special in the field of data science [29] . The large community that Python has provides extensive documentation, tutorials, and forums that support developers in learning and using the language effectively. Because of its flexibility and extensive library resources python is widely used. Web development through frameworks like Django and Flask streamline the development of challenging web applications, allowing for fast prototyping and development [30]. Libraries such as Pandas, NumPy and Scikit make it a popular choice for data analysis, visualization, machine learning projects and python are used a lot for automating repetitive tasks, improving efficiency and productivity [31], [32]. Libraries like SciPy and Matplotlib support complex scientific computation and data visualization, allowing python to be a valuable tool for researchers and academia to which for this project these libraries will be taken advantage of extensively. Pythons' programming language capabilities in data analysis and scientific computing were particularly relevant, libraries such as NumPy and SciPy, were used to analyze thermal properties of calabash, and visualization libraries such as Matplotlib helped present data in a clear and informative way. Coding was essential and as the literature progressed, the effectiveness of Python was highlighted, specifically when it came to simulating the heat transfer equation.

3.5 Heat Conduction in 3D objects

3.5.1.General Heat Conduction equation:

Above the heat transfer through conduction was discussed just at a basic level, through it we can express the rate of heat conduction in a material and is given by:

$$q = -kA\frac{dT}{dx} \quad (4)$$

Let us consider conduction through a plane wall such as the wall of a house, heat conduction can be expressed in one dimension, this makes the other directions negligible. Let us take the fact that the density of the wall is *p*, the specific heat is *c*, the area of the wall is A. Figure 1 shows the image of the one dimensional through a volume element in a large plane wall.

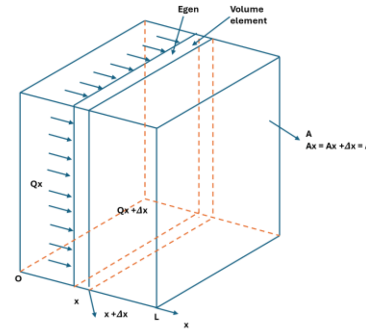

Fig.1: One-dimensional heat conduction through a volume element in a wall.

An energy balance based on the above diagram can then be established, what is being observed is that the rate of energy change of the content of the element is equal to the rate of heat generation inside element minus rate of heat conduction at **x + *Δ*x** and minus rate of heat conduction at **x**.

$$\dot{Q}_x - \dot{Q}_{x+\Delta x} + \dot{E}_{gen,element} = \frac{\Delta E_{element}}{\Delta t} \quad (5)$$

But the change in the energy content of the element and the rate of heat generation within the element can be shown as.

$$\Delta E_{element} = E_{(t+\Delta t)} - E_t \quad (6)$$

$$mc(\dot{T}_{t+\Delta t} - \dot{T}_t) = pcA\Delta x(\dot{T}_{t+\Delta t} - \dot{T}_t) \quad (7)$$

$$\dot{E}_{gen,element} = \dot{e}_{gen}V = \dot{e}_{gen}A\Delta x \quad (8)$$

Substituting into Eq. (3.4), we get:

$$\dot{Q}_x - \dot{Q}_{x+\Delta x} + \dot{e}_{gen}A\Delta x = pcA\Delta x\frac{\dot{T}_{t+\Delta t} - \dot{T}_t}{\Delta t} \quad (9)$$

Divided by A Δx gives:

$$-\frac{(\dot{Q}_x - \dot{Q}_{x+\Delta x})}{A\Delta x} + \dot{e}_{gen} = pc\frac{\dot{T}_{t+\Delta t} - \dot{T}_t}{\Delta t} \quad (10)$$

Taking the limit as $\Delta x \to 0$ and $\Delta t \to 0$ $yield$:

$$\frac{1}{A}\frac{\partial}{\partial x}\left(kA\frac{\partial T}{\partial x}\right) + \dot{e}_{gen} = pc\frac{\partial T}{\partial t} \quad (11)$$

Since, from the definition of the derivative and Fourier's law of heat conduction,

$$\lim_{\Delta x \to 0}\frac{\dot{Q}_{x+\Delta x} - \dot{Q}_x}{\Delta x} = \frac{\partial \dot{Q}}{\partial x} = \frac{\partial}{\partial x}\left(-kA\frac{\partial T}{\partial x}\right) \quad (12)$$

Noting that area A is constant for a plane wall, the one-dimensional transient heat conduction equation in a plane wall becomes.

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \dot{e}_{gen} = pc\frac{\partial T}{\partial t} \quad (13)$$

The thermal conductivity k of a material, in general, depends on the temperature T (and therefore x), and it cannot be taken out of the derivative [32], [33], [34], 35] and [36].. However, the thermal conductivity in most practical applications can be assumed to remain constant at some average value

3.5.2. Combined One dimensional Heat conduction:

By examining the one-dimensional transient heat conduction for a plane wall, we can take that equation to create a general equation that can express heat transfer in cylinders and spherical objects too,

$$\frac{1}{r^n}\frac{\partial}{\partial r}\left(r^n k\frac{\partial T}{\partial r}\right)+\dot{e}_{gen}=pc_p\frac{\partial T}{\partial t} \quad (14)$$

n = 0 for a plane wall, n = 1 for cylinder, and n = 2 for sphere. When it comes to plane walls it is important to replace r with x, the equation can be simplified to steady-state or no heat generation.

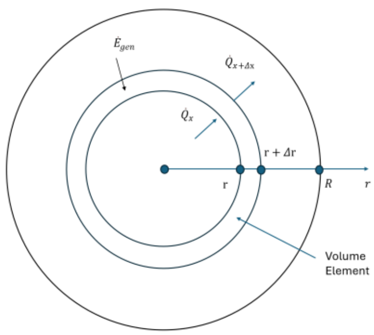

Fig. 2: One-dimensional heat conduction through a volume element in a sphere.

Now let us consider a sphere with density p, specific heat c and out radius R. The area of the sphere is $A = 4\pi r^2{}_0$ and r is the radius of the sphere, the heat transfer area is dependent on r and varying the position within the length of r. By considering a shell element with a thickness of Δr based on the general heat conduction equation formulated, the equation of a spherical shell determined by looking at the figure 2 can be given as.

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 k\frac{\partial T}{\partial r}\right)+\dot{e}_{gen}=pc_p\frac{\partial T}{\partial t} \quad (15)$$

3.6 Data base used for research

To ensure that a comprehensive foundation was developed , a wide range of reputable academic databases where used, the key databases selected were: ResearchGate, Elsevier, cienceDirect, Springer: In conducting the literature review, a systematic approach was employed to ensure the inclusion of high-quality and relevant research articles. The criteria for inclusion and exclusion were defined.:

IV. Methodology

4.1. Introduction

The research methodology used in this study, focuses on heat transfer properties of calabash material. The experimental design discussed, highlighting the procedures and techniques used to gather data on the material, the chosen methodology was intended to ensure the reliability and validity of the findings.

4.2 Research Methodology

This study adopted a positive philosophy due to its emphasis on objectivity, quantifiable measurements, and empirical validation. Positivism is aligned with the study focus on developing a Python-based model and conducting experimental research to assess the properties of the material. The deductive approach was suitable for this study because the research seeks to investigate generating new insight into the thermal properties of the material. Through experiments, It was looked to develop a general principle regarding material suitable for not losing heat easily. The experimental approach is one that is focused on in this research, as it allows for the systematic investigation of the heat transfer properties of the material, such as how long the material will take overtime to lose heat energy. The research used mixed-method approach, considering both quantitative and qualitative research methods. The quantitative was through experiments that measured the temperature of the calibash over time to see how well it stored heat over time. The qualitative data were collected from the observations made on the material. The study followed a cross-sectional time horizon, where data is collected at a single point in time for each experimental setup. This approach is effective for comparing different material compositions and their properties without requiring extended time frames. The cross-sectional design was appropriate for this study because it is focused on assessing how the material will transfer heat properly.A dry Calabash sample will be collected, which will be used as a shell that will store the hot pap to see how long the temperature will be maintained. The experiment will measure the variation in temperature over time using laboratory equipment. The Python model will be coded to simulate the heat transfer withing the material, using heat conduction in spherical coordinates and the numeric integration is done using python mathematical libraries. The collected data will undergo statistical analysis to determine the quality of the results. The data was visualized using python libraries like matplotlib to provide clear insight into the material how it conducts heat.

4.3 Mathematical Model and Python Code

4.3.1 Building the mathematical model

To develop a model for observing the heat transfer within calabash shell material, one focused on the following aspects:

- Governing equation for heat conduction in spherical coordinates.
- Finite Difference Method to discretize the governing equation.
- Heat loss though convection at the outer surface of the wall.
- Effects of thermal conductivity, Heat transfer coefficient on the heat distribution and heat transfer of the material.

Assumptions:

- The material is a spherical shell with an inner radius r_i

and outer radius r_o.

- The heat source is the pap at the center of the sphere and heat transfer takes place radially outward.
- Heat loss is mainly due to convection from the outer surface.
- The system is transient, meaning the temperature changes with time

Governing Equation: Heat conduction in spherical Coordinates

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 k \frac{\partial T}{\partial r}\right) + \dot{e}_{gen} = pc_p \frac{\partial T}{\partial t} \quad (16)$$

Where:

- T (r, t) is the temperature as a function of radius r and time t.
- k is thermal conductivity of the calabash material
- r is the radial coordinate.
- p is the density of the calabash material
- c is the specific heat capacity of the material
- t is time.

Boundary and initial conditions:

At the inner surface:

$$T_{(r_i,t)} = T_{pap} \quad (17)$$

The temperature at the inner surface is initially at the pap's temperature.

At the outer surface:

$$-k \frac{\partial T}{\partial r}\bigg|_{r_0} = h\left(T_{(r_0,t)} - T_\infty\right) \quad (18)$$

This condition represents heat loss due to convection from the outer surface, where:

- h is the heat transfer coefficient
- T_∞ is the ambient temperature outside shell.

Initial condition:

$$T_{(r_i,o)} = T_o \quad (19)$$

Initially, the temperature inside the material is uniform at T_o.

Finite Difference Method

To solve this problem numerically we use the finite difference method. We discretize the radial direction r and time t into small increments.

- Let r = r_i inner radius and $r_N = r_0$ outer radius, with N discrete radial points.
- Let $\Delta r = \frac{r_0 - r_i}{N-1}$ be the radial step size.
- Let Δt be the step size.

Discretized form of the Governing Equations:

Using central differences for the spatial derivative and forward differences for the time derivative, we can approximate the heat equation as follows.

$$\frac{T^{n+1}{}_i - T^n{}_i}{\Delta t} = \frac{k}{pc_p}\left(\frac{1}{r^2{}_i}\left(r^2{}_{i+1}\frac{T^n{}_{i+1} - T^n{}_i}{\Delta r} - r^2{}_i\frac{T^n{}_i - T^n{}_{i-1}}{\Delta r}\right)\right) \quad (20)$$

Where:

- $T^n{}_i$ is the temperature at the i-nth radial point at time step n.
- Δr is the radial grid spacing.
- Δt is the time step.

Boundary condition Discretized:

Inner surface Boundary condition at r = r_i:

$$T^n{}_0 = T^n{}_{pap} \quad (21)$$

Outer surface boundary condition convective heat loss:

$$k\frac{T^n{}_N - T^n{}_{N-1}}{\Delta r} = h(T^n{}_N - T_\infty) \quad (22)$$

This can be rearranged to solve for $T^{n+1}{}_N$

Convective heat loss at the outer surface:

The rate of heat loss at the outer surface due to convection is given by Newton's law of cooling.

$$q_{conv} = hA(T_0(t) - T_\infty) \quad (23)$$

Where:

- q_{conv} is the rate of heat loss.
- $A = 4\pi r^2{}_0$ is the surface area of the outer shell.
- $T_0(t)$ is the temperature at the outer surface as a function of time.

These equations provide the foundation for analyzing the heat distribution and loss in the spherical calabash shell material. You can now use these formulas to implement a numerical model solution using python.

4.3.2 Applying Python to solve a heat transfer problem.

To model and analyze transfer characteristics of a spherical calabash shell containing hot pap as a food item. Python will be used, and the primary focus will be on how calabash material preserves the heat and how heat is lost over time and that will be represented on multiple plots generated through python code

TABLE I: PARAMETERS FOR THE MODELS

Symbol	Quantity	Units
r_i	Inner radius	m
r_o	Outer radius	m
k	Thermal conductivity of calabash	W/m·K
rho	Density of calabash	kg/m³
c_p	Specific heat capacity	J/kg·K
h	Convective coefficient	W/m²·K
T_pap_initial	Initial temperature	°C
T_info	Ambient temperature	°C
T_0	Initial temperature of Calabash	°C
rho_pap	Density of pap	kg/m³
c_p_pap	Specific heat capacity pap	J/kg·K
v_pap	Volume of pap	m³)

N	Number of radial points	
dt	Time step	s
total_time	Simulation time	s

Code Implementation:

a) The radial heat conduction equation was discretized using finite difference method. This involved updating the temperature at interior points based on the neighboring values and the physical properties such as thermal conductivity, density and specific heat. The code uses the following expression to update the temperature at interior point:

```
T_new[i] = T[i] + dt * (k / (rho * c_p)) * (
        (2 / r[i]) * (T[i+1] - T[i-1]) / (2*dr) +
        (T[i+1] - 2*T[i] + T[i-1]) / (dr**2)
    )
```

The expression accounts for heat conduction in the radial direction.

b) Boundary conditions, at the inner boundary r_i, heat is transferred from pap to the calabash material. At the outer boundary r_o, heat is lost through convection and rate of heat loss is influenced by the convective heat transfer coefficient h. The code uses the following expression for the inner boundary condition:

```
q_in = k * (T[0] - T[1]) / dr
dT_pap = -q_in * 4 * np.pi * r_i**2 * dt / (rho_pap * c_p_pap * V_pap)
T_new[0] += dT_pap
```

The heat flux from pap to calabash material is calculated using Fourier's law of conduction. The temperature change of the hot cooked pap is computed and temperature at the inner boundary is updated accordingly. The outer boundary conditions for convection:

```
T_new[-1] = (T[-2] + h * dr / k * T_inf) / (1 + h * dr / k)
```

This accounts for convective heat loss at the outer boundary, the heat loss rate Q_loss is also calculated every time step.

c) To track how much heat is lost through convection over time, we observed this by tracking the temperature at the outer boundary and calculated the rate of heat loss. The convective heat loss is calculated every time step:

```
Q_loss = h * 4 * np.pi * r_o**2 * (T_new[-1] - T_inf)
```

The heat loss over time is stored in an array can be used to analyze other factors.

d) The cooling rate of pap can be determined by calculating the change in temperature over time, it is observed by calculating the time derivative of the pap temperature. The cooling rate is calculated as:

```
cooling_rate = np.abs (np.diff(T_pap_history)/dt)
```

This calculates the rate of temperature change over each time step.

4.4 Experimental Procedure

The material used included

a) Calabash Shell: Pre-cleaned and hollowed to be used as a container.
b) Hot Pap: A cooked Substance that will be placed inside the Calabash to study heat preservation.
c) Thermometer: For measuring temperature at various points inside and outside the Calabash.
d) Data Logger: Notebook to record temperature changes over time.
e) Python Environment: To simulate the heat transfer process using numerical methods.
f) Insulated Chamber: To control environmental factors like ambient temperature and humidity.
g) Stop-watch: To ensure accurate time tracking of temperature measurements

The Calabash shell was cleaned and dried, ensuring that no moisture is present and that might interfere with the results. The cooked hot pap was cooked, and its temperature was measured, which will serve as the initial internal temperature for the experiment. The hot pap was poured into the hollowed calabash shell, and the thermometer was inserted into the shell to measure the internal temperature and measure temperature outside the shell. The shell filled with cooked hot pap was placed inside a room where environmental conditions such as ambient temperature and humidity will be kept constant to ensure that the heat loss occurs through the calabash not the external environment. The room temperature is assumed to be 25°C. The temperature readings from both the internal and external surface of the material were recorded for every minute for a duration of the internal environment temperature being equal to the external environment temperature or close to it. The temperature drops inside the calabash, as well as the corresponding temperature rise on its surface was recorded and logged in real time. The experiment was repeated at least three times to ensure that the results are consistent and reproducible.

Once the data was collected, the results were analyzed to determine the rate of temperature drop inside the Calabash. Assess the overall efficiency of calabash material as an insulator. Validate the python heat transfer model against real-world data. The analysis involved plotting temperature vs. time graphs to visualize how well the Calabash retains heat by observing the pap temperature over time, temperature vs radial direction to measure how heat is distributed within the material, the cooling rate of pap over time due to heat loss through convection and the rate of heat loss over time and comparing the results across different trials to ensure reliability.

V. Discussion and Results

5.1 Python modeling results

The results first obtained from the model offer insight into the distribution of temperature, cooling rate of the cooked hot pap and heat loss through convection. The model provides as with a theoretical understanding of materials potential as a natural insulator.

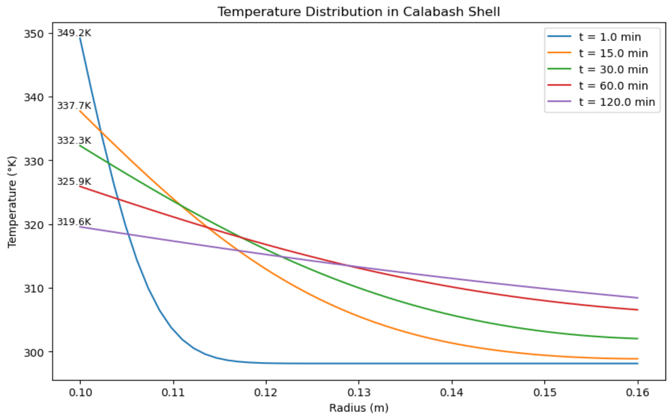

Fig.3: Temperature distribution on material at various times at specific temperature

5.1.1. Time Dependence of Temperature within the Calabash Shell Material

Hot cooked pap is the main source of heat, so the surface of the calabash (contact with heat source) starts at a higher temperature, while the outer surface of the shell remains close to the ambient temperature of 25°C. Figure 3 shows the highest temperature being above 349.2 K at the first minutes having a sharp temperature gradient indicating that heat highest on the side close to the heat source. As time goes on, heat begins to spread through the shell. The shell's thickness is about 1 cm thick when empty and is hard not easily broken. The temperature at each radial point slowly approaches equilibrium with the ambient environment. The temperature gradient decreases over time which suggests a decrease in heat transfer rate, as we approach ambient temperature conditions, the graphs for temperatures at different times become relatively uniform but higher than ambient conditions, showing slow cooling process.

5.1.2.Temperature of Hot pap in Calabash Shell Over Time

From the coded model thermal conductivity was varied to see its effects on the cooling rate of pap at constant h, figure 4 shows the findings

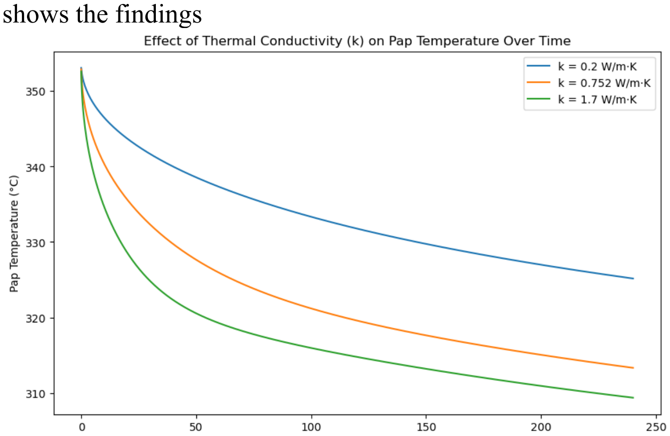

Fig.4: Pap temperature over time at varying thermal conductivity of calabash.

. When k = 1.7 W/m.K, it's observed that there is faster cooling and when k = 0.2 W/m.K showed slow cooling process. This is because higher thermal conductivity means faster cooling rate and the same otherwise .The thermal conductivity of calabash found to be 0.752. When the value was placed on the model where k = 0.752 W/m.K, the model showed a moderate decline when the model simulates for four hours.

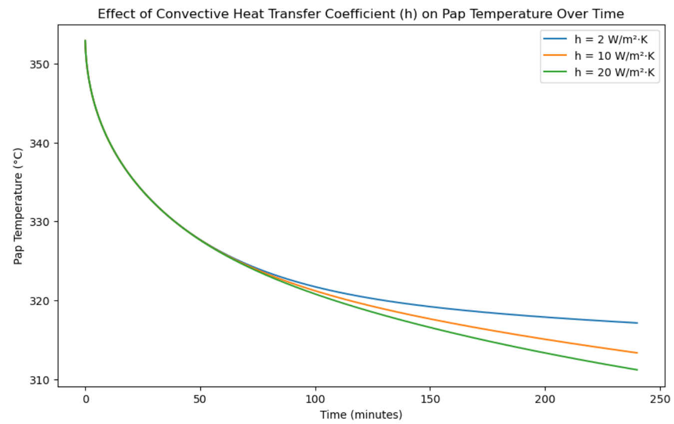

Fig. 5: Pap temperature over time at varying heat transfer coefficient.

When varying heat transfer coefficient while keeping k constant showed that when h = 20 W/m²·K showed the fasted cooling and when h = 2 W/m²·K showed slow cooling, figure 5 shows the findings. The heat transfer coefficient at room temperature is between 2-25 W/m²·K for natural convection. It was assumed that h is 10 W/m²·K for the sake of the experiment.

5.1.3.Heat loss of overtime through convection

From figure 6 when h = 20 W/m²·K shows the highest initial heat loss, peaking at t = 92.6 before gradually decreasing. The curve h = 10 W/m²·K and h = 5 W/m²·K follow the same trend but at lower magnitudes with the curve where h = 5 W/m²·K having the smallest heat loss

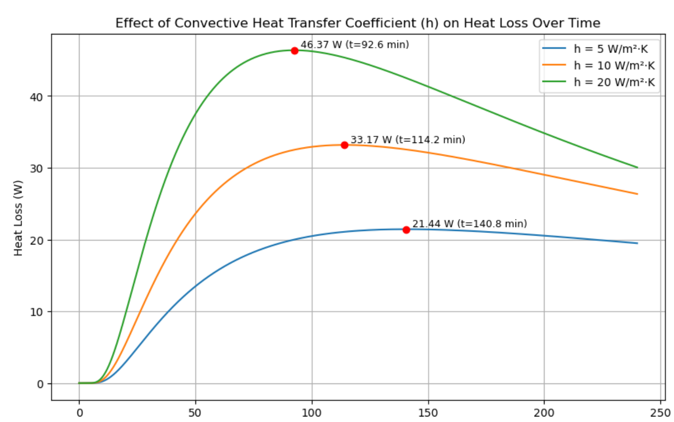

Fig. 6: Energy loss over time at varying heat transfer coefficient.

. Peak heat loss occurs early at higher value of h and takes time at lower values of h, this is because the system loses more energy to the environment and vise verse. After peaking the graphs decrease as the temperature difference between the internal environment and surroundings reduces, making the transfer rate slower. In an environment where there is high airflow will lose heat quickly.

VI. Conclusion

This paper simulated heat transfer through the *Lagenaria siceraria* calabash materials using a code written in Python. The models generated were validated with experimental data as laboratory cooked pap was conserved in the calabash cavity and temperature was measured in time and distance with respect to the calash external surface. A good correlation between the Python developed models and the experimental data was observed to the satisfaction of the researchers.

Appendix

The developed code is available on request.

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Data Availability Statement

The data presented in this study are available on request.

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Author Contributions

Conceptualization, Antoine F. Mulaba-Bafubiandi; Writing—original draft preparation, Samkelo Bhongoza; writing—review and initial editing: Antoine F. Mulaba-Bafubiandi; supervision: Antoine F. Mulaba-Bafubiandi; Inputs to discussions on growth, societal aspects and manufacturing: Moloko Ramaboea and Thusanang Matamela; Project administration: Antoine F. Mulaba-Bafubiandi and Samkelo Bhongoza; funding acquisition: Antoine F. Mulaba-Bafubiandi. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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