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Analysis of Natural Convection Heat Transfer in Barapen Cooking in Papua

Analisis Perpindahan Panas Konveksi Alami dalam Pemasakan dengan cara Barapen di Papua

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Abstract

Barapen, a cooking tradition in various indigenous Papuan communities. To date, various social science studies have been conducted to examine social values, business economics, and political economy. While research in the aspects of applied science has yet to be conducted to study the phenomenon of heat transfer by natural convection from hot stones to food in cooking packs, this research was conducted. The purpose of this research is to study the phenomenon of heat transfer by natural convection from hot stones to food in cooking packs. In this study, a square-shaped artificial pool (260 cm x 210 cm x 50 cm) with white batah stone walls was used to cook food in a barapen. On the four walls, a type K thermocouple is inserted to measure the temperature at 3 layers, which will be the object of research. The ingredients are vegetables, sweet potatoes, and chicken meat that has been cut and stoned. As a discussion, the temperature gradient between layers occurs due to the difference in the amount of volumetric heat against time in each layer. The difference in the amount of heat in each layer is due to the difference in the density of the hot vapor trapped in each layer. Thus, it can be said that the cooking of food in Barapen occurs due to natural heat convection.

Keywords: hot stones, cumulative heat, layers, vapor circulate.

***SDGs*:**

Abstrak

Barapen, tradisi memasak di berbagai komunitas adat Papua. Sampai hari ini berbagai penelitian sosial sains telah dilakukan untuk mengkaji nilai-nilai sosail, ekonomi bisnis dan ekonomi politik telah diteliti. Sementara penelitian dari aspek sains terapan belum ada. Tujuan penelitin ini, untuk mempelajari fenomena transfer panas secara konveksi alami dari batu panas ke makanan dalam bungkusan pemasakan. Penelitian ini dilakukan secara ekperimental di lingkungan laboratorium Teknik Mesin Universitas Cenderawasih. Dalam Penelitian ini menggunakan sebuah kolam buatan berbentuk persegi (260 x 210 x 50) cm dengan dinding batu batah putih yang digunakan untuk memasak makanan secara barapen. Pada keempat dinding dimasukan termokopel tipe K untuk mengukur suhu pada 3 Lapisan yang akan menjadi objek penelitian. Bahan-bahan masak adalah sayur, Ubi, daging ayam yang telah dipotong dan Batu. Sebagai pembahasan, Gradien Temperatur antara lapisan terjadi akibat perberbedaan jumlah energi panas terhadap waktu pada setiap lapisan. Perbedaan jumlah energi panas pada setiap layer adalah akibat pebedaan massa jenis uap panas yang terperangkap dalam setiap lapisan. Dengan demikian, dapat dikatakan bahwa pemasakan Makan dalam Barapen terjadi akibat konveksi Panas alami.

Kata Kunci: batu panas, panas kumulatif, lapisan, sirkulasi uap.

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1. INTRODUCTION

Barapen is a tradition of cooking food with hot steam that comes from hot stones that are burned manually. This tradition lives in the Papuan cultural community and Melanesia in general which has been passed down from generation to generation in the Melanesian region and Papua Island (Wenda and Purwanti, 2023). Barapen has philosophical, socio-economic and political functions that have helped drive Papuan civilisation until now (Tabuni, 2023).

Thermophysical phenomena in Barapen are an interesting research object to study because they come from local wisdom (Nipur, Rumampuk and Matheosz, 2022). The cooking process in Barapen occurs as a result of hot vapour sourced from hot stones that have been burned being transferred into the food by means of natural convection (see Figure 1(a)). Heat transfer by natural convection itself occurs through hot vapour (gas) accompanied by the transfer of intermediate particles due to differences in density at the bottom and top layers of the cooking pool (Marek and Nitsche, 2015; Warokka and Boedi, 2020). In addition to natural convection, transient conduction heat transfer at the stone surface temperature changes with time due to temperature distribution to the various layers of food in the cooking pond (Dewadi *et al.*, 2022). In addition, in the food that receives heat, pore opening occurs to receive and release heat into and out of the food in the cooking pond (Rooij *et al.*, 2022).

The majority of recent relevant research has come from the social sciences and anthropology (Manafe, Morib and Pelamonia, 2022). For example, research on Barapen by Flassy et al. in the Tehit tribe in South Sorong (Flassy, Saa and Frank, 2022). In American Indian tribes by Langley et al. (Langley *et al.*, 2023). The process of heat transfer from the hot stone inserted into the water inside the heated pig and queen sacks and then the hot water vapor cooking the food is comprehensively displayed. Traditional flavoring in Mozambique by Matavel et al., with a good stove and good food storage so as to avoid bacteria (Matavel *et al.*, 2022). The basic concept of heat transfer in the stone burning or Barapen process was introduced narratively to three high schools in Jayapura (Budiarti *et al.*, 2018).

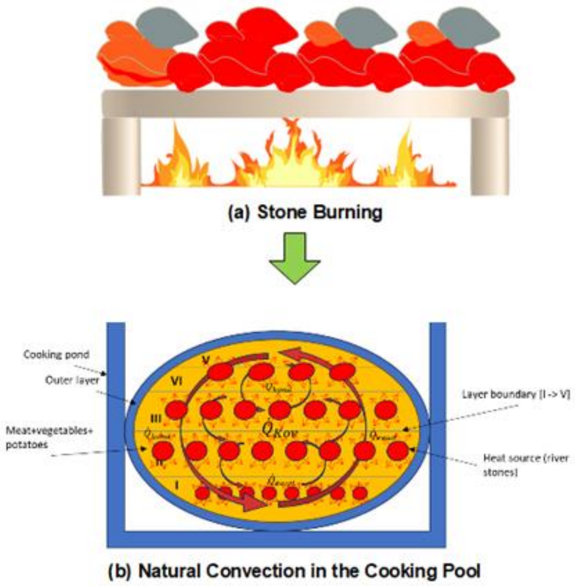

Figure 1. Barapen processes and thermophysical processes in the Barapen booklet.

Hot stone research has a lot to do with the medical world, especially in the aspect of body therapy to get optimal and effective sleep (Ghavami *et al.*, 2019; Radziejowski, 2021). Simulation of the temperature distribution of hot stones placed on the feet was also carried out, where heat enters through the pores of the human body (Kuge *et al.*, 2013). Meanwhile, in food preparation and storage, the hot steam from hot stones was also investigated (Sotome and Isobe, 2011). Changes in the mechanical characteristics of spaghetti-like meals where the higher the temperature of the hot steam, the smaller the young's modulus in real time (Akbar and Abdullah, 2021).

Based on the above research gap, several approaches will be taken in this experimental research:

1). Analyzing the temperature distribution in the cooking pond.
2). Calculating the amount of natural convective heat in the cooking pond in several layers.

The urgency of this research is to analyze and develop the potential of local wisdom to create appropriate technology in traditional cooking so that it can be used by people in the Land of Papua.

2. METHODOLOGY

Experimental research on barapen was carried out in the laboratory of the Department of Mechanical Engineering at Uncen in March-May 2024. In this study, four activities were carried out, namely preparation of tools and materials, collecting data, heat calculations such as calculating actual natural convective heat and calculating cumulative natural convective heat (see in Figure 2).

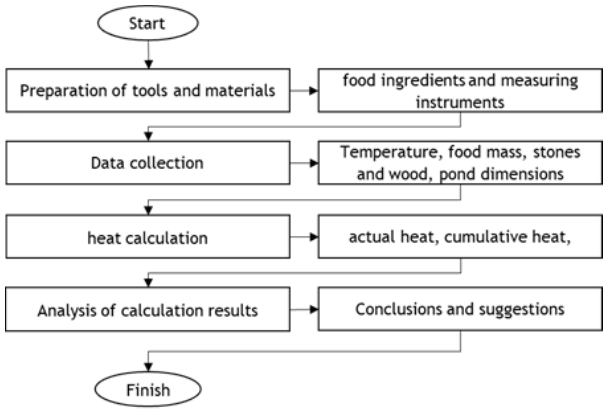

Figure 2. Research flow.

2.5. Tools and Materials

The river stone in Table 1 used in this Barapen is taken from the Kam Wolker river which originates from the Cyclops mountains. The cooking materials were taken randomly and heterogeneously. Table 2 shows the specifications of the tools used in this study.

Table 1. Cooking ingredients and stone.

Tools and materials	Mass (kg)
Meat (cutted chicken)	6
Vegetable (leafy)	5
Petatas (Ipomea batatas)	20
River stone	132
Firewood	67,24

Table 2. Measurement tools.

Measurement Tools	Volume	Specific
Termo Jet	1	Bosch GTC 400 C Thermal Camera
Thermocouples Type K	4	Thermocouple data logger based on the arduino platform
Tapes	1	Tapes 50 KRISBOW
Electronic Hanging Scale	1	Electronic Hanging ScaleMCS (CRANE SCALE)

2.6. Data Collection

The data collected in this experimental study are the heat temperature at four height positions with the same depth and divided into three layers in the cooking pond (see Figure 3) Besides the mass data of the feeding material, stones, firewood. The last are the dimensions of the cooking pond.

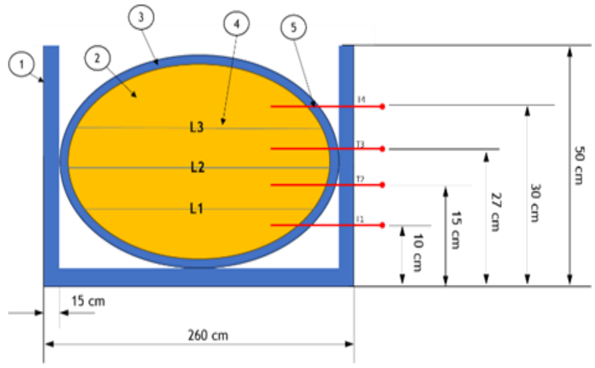

Figure 3. Cooking ponds and their dimensions.

2.3. Experiment Setting

The experiment was conducted in a pond with dimensions of (260 x 210 x 50) cm where the pond was built with white bricks without a cover (see Figure 3). In the cooking pool, there are four thermocouple positions (T1, T2, T3, T4) with different heights from four sides of the pool with almost the same thermocouple insertion depth. In the calculation of natural convective heat, there are three layers (L1 between T1 and T2, L2 between T2 and T3, L3 between T3 and T4).

Table 3 and Figure 3 show the components of the experiment and the dimensions of t he pools, thermocouple position and layer position in the Barapen bundle.

Table 3. Components of experiment.

No.	Components
1	Cooking pond
2	Packaged food chamber
3	Outer package
4	Boundary Layer
5	Position of the four Thermocouples

2.4. Mechanism of Calculation

To calculate the cumulative natural convective heat at each layer in the cooking pond, the mass of vapor in the cooking pond is first calculated using the density equation (1) (Kretzschmar and Kraft, 2011):

$$m_{steam} = \rho_i \cdot V_k \quad (1)$$

where:
ρ = density of hot vapor (kg/m^3)
msteam = mass of hot vapor in the pool (kg)
Vk = Volume of the cooking pond (m^3)

The density of hot vapor ρ_iis a function of temperature ρ = f(T), which is read and interpolated through the thermodynamic table (Kretzschmar and Wagner, 2019). The density values are then averaged using equation (2) (Kretzschmar and Kraft, 2022):

$$\rho_i = \frac{\rho(T_i) + \rho(T_{i+1})}{2} \quad (2)$$

where:
(T_i) = Density at Layer i (kg/m^3)

$\rho(T_{i+1})$ = Density in the leyer i+1 (kg/m^3)

Then the calculation continues by calculating the actual natural convective heat with equation (3) (Kretzschmar and Kraft, 2022):

$$Q_i = m_{steam} \cdot c_{p,i}\Big|_{T_i}^{T_{i+1}} \cdot \Delta T \quad (3)$$

where:
Q_i = actual natural convective heat (kJ)
$c_{p,i}\Big|_{T_i}^{T_{i+1}}$ = average heat capacity (kJ/(kg K)
ΔT = temperature difference at T_i and T_{i+1} (K)

Average heat capacity Cp $c_{p,i}\Big|_{T_i}^{T_{i+1}}$ calculated by formula (4). Both factors, $c_p(T_i)$ and $c_p(T_{i+1})$ interpolated first through the thermodynamic table (Kretzschmar and Wagner, 2019):

$$c_{p,i}\Big|_{T_i}^{T_{i+1}} = \frac{c_p(T_i) + c_p(T_{i+1})}{2} \quad (4)$$

where:
$c_{p,i}(T_i)$ = actual specific heat capacity (kJ/kg K)

$c_{p,i+1}(T_{i+1})$ = the following specific heat capacity (kJ/kg K)

Calculation of cumulative natural convective heat Q_kum can be done with equation (5) (Kretzschmar and Kraft, 2011):

$$Q_{kum} = \sum_{i}^{i-1} (Q_i + Q_{i-1}) \quad (5)$$

where:
Q_i = actual natural convective heat (kJ)
Q_{i-1} = natural convective heat before (kJ)

2.5. Mechanism of Research Result Analysis

This is done in three general stages, namely:

2.5.1. Preparation

At this stage, the cooking pool and temperature data collection position were made (see Figure 2). Then, materials and tools were prepared to conduct Barapan and collect temperature data in the cooking pond.

2.5.2. The Barapan

The Barapen process is divided into four parts. First, the process of cleaning the stones and the food to be cooked in the form of petatas, meat and vegetables. The second is the preparation of the stone kiln and the cooking pond, which is built with bricks with an open lid (see Figure 2). Then in the third stage, the burning of stones as a source of heat in Barapen. The last stage is cooking where the cooking is divided into three layers of cooking.

2.5.3. Temperature Distribution Analysis

Here the temperature movement that indicates heat transfer is analyzed from the aspect of logicality and rationality so that the data can be used in the calculation of actual heat and cumulative heat.

3. RESULTS AND DISCUSSION

3.1. Temperatur Distribution Analysis on Barapen

At this point the stone is removed, and the food is ready to be served and the temperature distribution can be seen in graph (1) below. In graph (1) it can be seen the first ±9 minutes (I) and the last ±19 minutes (III) the temperature is in the stationary position. In this state, the temperature rises significantly with time. Then within ±2 hours 12 minutes there is a stationary temperature distribution. In positions (I) and (III) there is a very significant natural convective heat transfer process and in position (II) the natural convective heat transfer conditions tend to be evenly distributed in each layer except in layer L3 where the temperature T4 experiences a drastic spike in the middle of cooking. This phenomenon occurs due to the accumulation of hot vapor in the uppermost layer due to the small density and large vapor pressure.

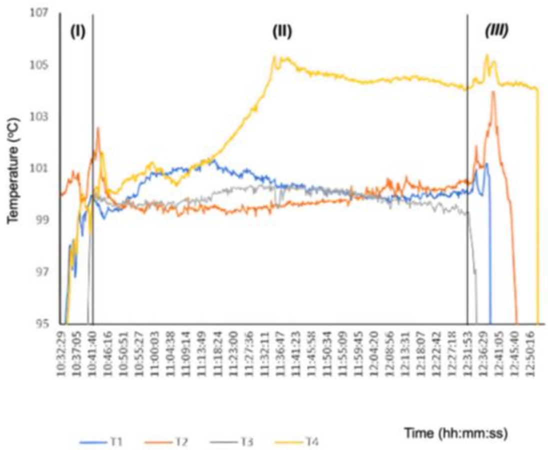

Figure 4. Temperature distribution in the cooking pond.

Langley et al.,also conducted an analysis of the temperature distribution against time T(t) while cooking 1000 mL of water with a 20 cm gap between the fireplace and the deer's stomach bag (Langley *et al.*, 2023). The water was cooked for 215 minutes, with an average temperature of 71.5 °C. In contrast, the average temperature in each layer during the heating process in this study is T1 = 99.82 °C, T2 = 101.0 °C, T3 = 99.81 °C, and T4 = 96.89 °C throughout layers one through four.

3.2. Actual Natural Convective Heat Analysis Results

In all three layers there is a change in natural convective heat in the middle of the cooking process as shown in Figure 5. In the first layer (I) (Q_T1T2), the natural convective heat decreases, meaning that the convective heat tends to receive heat due to temperature T2 being greater than temperature T1. The maximum value of convective heat is -0.347 kJ.

While in the second layer (II), (Q_T2T3) looks stationary or sloping due to no significant change in temperature difference. In this layer, the maximum value of natural convective heat is 2.54 kJ. In the third layer (III), (Q_T3T4) on the graph is stationary until the maximum convective heat value is 0.810 kJ. This is due to the constant temperature difference from time to time until the temperature stationary process (III) occurs.

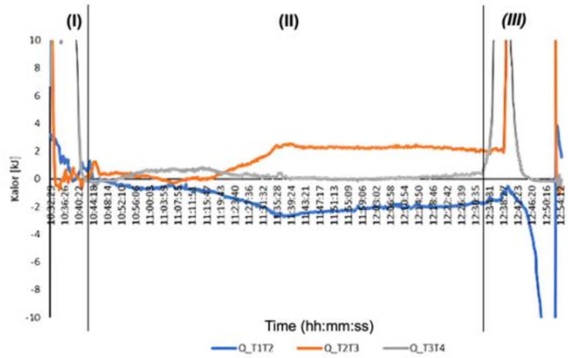

Figure 5. Actual natural convective Heat versus time.

3.3. Cumulative Natural Convective Heat Analysis Results

In Figure 6, at Layer I (Q_12), the natural convective cumulative heat decreases. This is in line with the negative temperature difference value or the temperature at position two which increases drastically with time. The maximum value of the cumulative natural convective heat is 57,929 kJ. At Layer I (Q_12), the natural convective cumulative heat decreases. This is in line with the negative temperature difference value or the temperature at position two which increases drastically with time. The maximum value of the cumulative natural convective heat is 57,929 kJ.

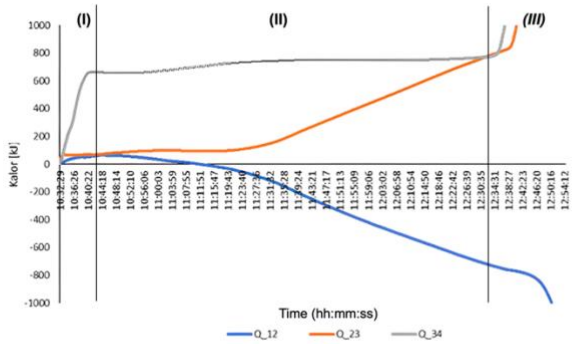

Figure 6. Cumulative natural convective heat.

While in Layer II (Q_23) the cumulative heat rises linearly in the middle of cooking with a maximum natural convective heat value of 724.87

kJ and in III (Q_34) the cumulative convective heat rises dramatically at the beginning of cooking and tends to be constant until the end of cooking which results in a cumulative natural convective value of 762.61 kJ.

3.4. Analysis of Calculation Results Convective Natural Displacement

From the results of the calculation of actual natural convective heat, the amount of natural convective heat starts from the middle layer (Q_T2T3), the upper layer (Q_T3T4) and the lower layer (Q_T1T2). Analogous also occurs in convective Cumulative Heat.

For comparison, the diagram of the amount of heat transferred against time in the heat storage and release experiment using PCM material looks the same. When the PCM melts (receives heat from the heat carrier medium), the heat received tends to be hotter. whereas when the PCM releases to the heat receiver medium which has a lower temperature, the heat transferred is lower on average (Hübner *et al.*, 2016; Leonhardt, 2016).

This process is analogous to the cooking process in barapen, where the food material receives heat at the beginning and when the heat gradian of the food becomes high, the food tends to release heat to the environment.

4. CONCLUSION

The conclusions of this study are that, first, the heat distribution coming from the hot stones in the pool determines the amount of natural convection heat in each layer. Furthermore, by demonstrating the existence of natural convection transfer in the cooking pond, it can be concluded that cooking occurs due to heat transfer from the hot stones through the feeding pores to the top and then trapped at the top of the cooking bundle. Finally, the highest cumulative natural convection heat of the three layers comes from the third layer (Q_34) at 762.87 kJ, which is due to the concentrated hot steam transferred by natural convection and circulation within the bundle.

For future research is expected to focus on the selection of rocks with large heat capacity and density to make them more reliable in their use at Barapen. In addition, analyze natural convection by using more regular layers and homogeneous cooking materials to be able to determine the heat distribution of the layer radius T(r).

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