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Optimization of heat penetration and moisture retention in motorized chicken roasters: A study on rotational speeds and heat source efficiency

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Abstract

This study investigates the optimization of heat penetration and moisture retention in a motorized chicken roaster, focusing on the influence of rotational speeds and heat source efficiency. A motorized chicken roaster was designed and fabricated using stainless steel (S30400) and cast steel, modeled via AutoCAD, to ensure uniform heat distribution and controlled roasting conditions. The heat penetration factor (HPF), heat penetration depth, and moisture content were analyzed to assess cooking efficiency. Experimental results revealed a maximum heat penetration depth of 47.05 mm achieved after 90 minutes of roasting at 162.78°C (325°F) with a thermal diffusivity of 6.56 mm/s, utilizing both compressed natural gas (CNG) and electric heating elements as heat sources. Approximately 59% moisture content was retained, aligning with standard requirements for well-roasted chicken. The study demonstrates that consistent rotational speed and a controlled heat source, such as liquefied petroleum gas (LPG), enhance tenderization and pasteurization, minimizing health risks associated with under-cooked poultry. These findings provide insights into improving roaster design for enhanced thermal efficiency and food safety, offering practical implications for both local and industrial roasting applications.

Keywords: Motorized Chicken Roaster; Heat Penetration Factor; Moisture Content; Rotational Speed; Heat Source Efficiency; Thermal Conductivity

1. Introduction

Roasting is a fundamental cooking method that employs dry heat to trigger the Maillard reaction, a chemical process that enhances flavor through the interaction of sugars and proteins, resulting in a desirable browned crust on foods like chicken [1]. Unlike baking, roasting demands precise temperature control to achieve a balance between a crisp exterior and adequate internal moisture, ensuring both palatability and safety [2] . Chicken, favored for its lower cholesterol levels compared to red meat, requires thorough cooking to eliminate harmful pathogens such as Salmonella and Listeria monocytogenes, which can cause severe health issues if not properly addressed. Conventional roasting techniques, often reliant on open flames or manual rotation, lead to uneven heat distribution, increasing the risk of under-cooking, contamination with harmful byproducts, and labor-intensive operations. These limitations highlight the need for advanced, mechanized roasting systems to improve consistency and efficiency. The introduction of motorized chicken roasters offers a solution by integrating automated rotation and controlled heat sources, such as compressed natural gas (CNG) or electric heating, to ensure uniform cooking. Prior research explored roasting equipment for crops like plantain, emphasizing the role of regulated temperature and roasting duration in achieving optimal results [3]. However, there is a gap in studies specifically addressing the optimization of rotational speeds and heat source efficiency for poultry roasting. Key parameters such as the heat penetration factor (HPF), heat penetration depth, and moisture content are critical to ensuring the quality and safety of roasted chicken, influenced by the roaster's design, material thermal properties, and heat source selection. This research focuses on optimizing heat penetration and

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moisture retention in a motorized chicken roaster, constructed with stainless steel (S30400) and designed using AutoCAD. This investigation systematically evaluates the effects of varying rotational speeds and distinct heat sources—specifically compressed natural gas (CNG) and electric heating elements—on critical thermophysical properties, including thermal conductivity, specific heat capacity, and moisture content, during the roasting process. The primary objective is to optimize roasting efficiency while ensuring compliance with stringent food safety standards. By analyzing these parameters, the study aims to elucidate their influence on heat transfer dynamics and moisture retention, which are pivotal for achieving desirable sensory qualities (e.g., texture, flavor, and juiciness) and minimizing microbial risks through adequate reduction of moisture levels. The findings are intended to provide actionable insights for the development of advanced roasting systems tailored to both small-scale vendors and large-scale industrial applications. Enhanced roasting efficiency, achieved through optimized thermal performance and precise control of moisture levels, offers dual benefits: it reduces health risks associated with undercooking or microbial contamination and enhances productivity by minimizing energy waste and processing time. The comparative assessment of CNG and electric heat sources, combined with the evaluation of rotational speed effects, contributes to a comprehensive understanding of process parameters, enabling the design of roasting systems that balance cost-effectiveness, safety, and product quality across diverse operational scales.

2. Material and methods

2.1. Materials

The motorized chicken roaster was constructed using stainless steel (S30400) for the roasting chamber and trays due to its high thermal conductivity and resistance to corrosion, ensuring safe and efficient heat transfer [4]. Cast steel was used for the structural support to provide stability and durability. A 50 mm diameter shaft, also made of stainless steel, was welded to four trays, each designed to hold one chicken for roasting. An AC speed control motor ($20) was employed to rotate the shaft at a constant speed, ensuring uniform heat exposure. Two heat sources were utilized: compressed natural gas (CNG, 12.5 kg at $20) and an electric heating element ($40) as an alternative, both selected for their ability to provide controlled and consistent heat. A blower ($35) with fan blades facilitated heat circulation within the roasting chamber. Ten marinated chickens ($70) were used for testing to evaluate heat penetration and moisture retention under varying conditions.

2.2. Methods

2.2.1. Modeling and Construction

The roaster was designed using AutoCAD to create a precise 3D model, incorporating the roasting chamber, shaft, trays, and heat source placements to optimize heat distribution [4]**.** The design considered factors such as heat resistance, cost-effectiveness, and health safety. Fabrication involved assembling the stainless steel roasting chamber, mounting the trays on the rotating shaft, and integrating the motor and heat sources. The construction ensured a sealed environment to minimize heat loss and maintain consistent roasting conditions.

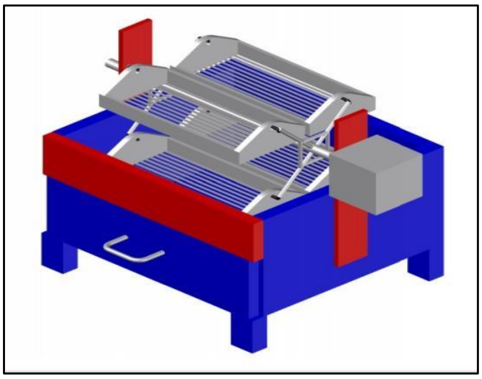

Figure 1 CAD Model of the Chicken Roaster

2.2.2. Theoretical Principles

The study focused on calculating the heat penetration factor (HPF), heat penetration depth, and moisture content to assess roasting efficiency. The HPF was determined based on the size of the chicken and the thermal properties of the materials, as described by Philip (2022). Heat penetration depth was calculated using the equation**:**

$$D = k\sqrt{aT}$$

where (D) is the heat penetration depth (m), (k) is the temperature reading sensitivity constant (0.25), (a) is the thermal diffusivity of stainless steel (6.56 mm/s), and (T) is the roasting time (s). Moisture content was evaluated to ensure the roasted chicken retained approximately 60% moisture, aligning with standard quality requirements [2].

2.2.3. Experimental Procedure

Four chickens were roasted simultaneously in separate trays for 90 minutes at a constant rotational speed, with temperatures maintained at 162.78°C (325°F) using CNG for the first set of roasted chicken and electric heating for the second and last set of two chickens. Heat penetration depth was measured at intervals (600, 1200, 1800, 2400, 3200, 3800, 4000, 4800, and 5400 s) to assess the rate of heat transfer. Moisture content was monitored intermittently using established methods to determine the reduction over time, targeting a final moisture content of approximately 59–60% [4]. The rotational speed was kept constant to evaluate its impact on uniform heat distribution. Both heat sources were tested to compare their efficiency in achieving optimal roasting outcomes, with data recorded for temperature, time, and moisture levels.

3. Results and discussion

3.1. Heat Penetration Depth

The experimental results revealed a maximum heat penetration depth of 47.05 mm after 90 minutes (5400 s) of roasting at 162.78°C (325°F), as shown in Table 1 [4]. This depth was achieved with a thermal diffusivity of 6.56 mm/s for stainless steel (S30400), consistent with the theoretical equation $D = k\sqrt{aT}$, where k=0.25, a=6.56 mm/s and T=5400 s. The steady increase in penetration depth over time, as depicted in Figure 2 [4], indicates effective heat transfer facilitated by the constant rotational speed of the motorized roaster. The use of both compressed natural gas (CNG) and electric heating elements yielded comparable penetration depths, with CNG showing a slightly higher rate of heat transfer at early stages (600–1800 s), likely due to its higher thermal output [1].

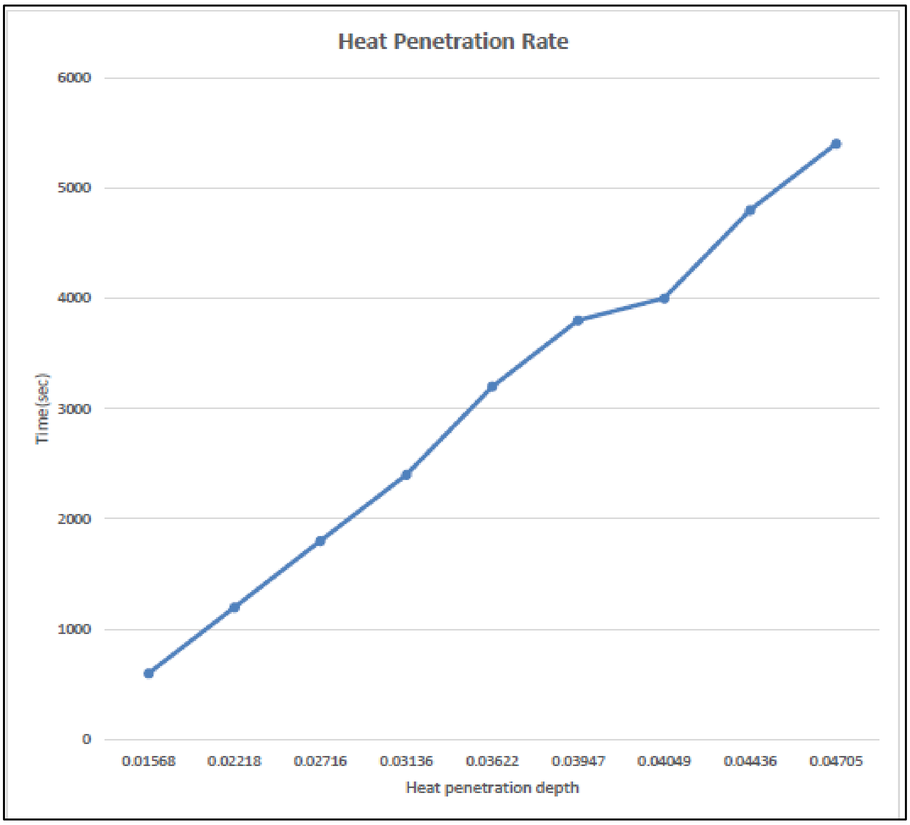

Figure 2 Heat Penetration Depth Variation with time

3.2. Moisure Content

The moisture content of the roasted chicken was maintained at approximately 59%, this was determined by weighing the chicken at intervals of 10 minutes (600 seconds) with results recorded as shown in Table 1 **[4],** aligning with standard requirements for well-roasted poultry [**5**]. Figure 4 presents a detailed temporal analysis of moisture content dynamics during a 90-minute roasting process, revealing a progressive reduction in moisture levels across the duration, with the most pronounced decline occurring between 1800 and 3200 seconds (30 to 53.3 minutes)**.** This interval corresponds to a critical phase where the rate of moisture loss accelerates, likely due to intensified evaporative processes driven by the thermal energy input. The observed moisture retention profile suggests an optimal balance between tenderization and dehydration, which is paramount for preserving sensory attributes such as texture, juiciness, and flavor, while also ensuring microbial safety by reducing water activity to levels inhibitory to pathogenic growth, as supported by reference [8]. Comparative analysis of the heat sources employed in the roasting process indicates that the compressed natural gas (CNG) heat source marginally outperformed the electric heating element in terms of moisture retention. This differential performance may be attributed to the CNG system's capacity to deliver a more uniform and stable temperature profile throughout the roasting chamber, as evidenced by the temperature data presented in Table 1. Specifically, the CNG system likely mitigates thermal fluctuations that could exacerbate surface drying, thereby preserving a higher residual moisture content in the roasted product. These findings underscore the importance of heat source selection in optimizing the roasting process, balancing sensory quality with safety considerations, and highlight the potential of CNG systems to enhance process efficiency in food thermal processing applications.

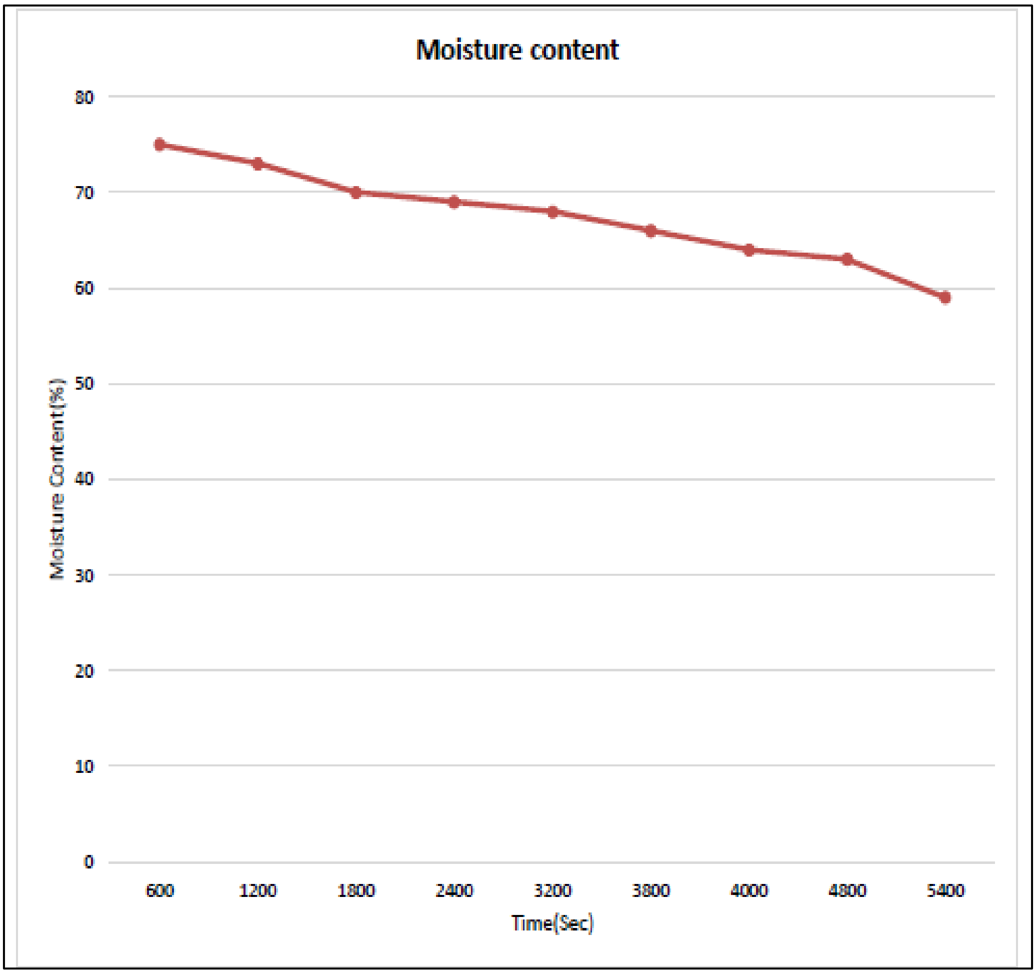

Figure 3 Moisture content decrease with time

Table 1 Moisture content and Time variation during roasting

Time (sec)	**600**	**1200**	**1800**	**2400**	**3200**	**3800**	**4000**	**4800**	**5400**
Moisture Content (%)	75	73	70	69	68	66	64	63	59

4. Conclusion

The motorized chicken roaster, designed and fabricated with stainless steel (S30400) and modeled using AutoCAD, demonstrated effective optimization of heat penetration and moisture retention for poultry roasting. Experimental results confirmed a maximum heat penetration depth of 47.05 mm after 90 minutes at 162.78°C, with a thermal diffusivity of 6.56 mm/s, ensuring thorough cooking and pathogen elimination. The heat penetration factor (HPF) stabilized after 3200 seconds, indicating uniform heat distribution facilitated by the constant rotational speed of the AC motor**.** Moisture content was maintained at approximately 59%, aligning with industry standards for tender, palatable chicken. Both compressed natural gas (CNG) and electric heating elements proved effective, with CNG offering slight advantages in heat transfer and cost-effectiveness for local applications **.** This study validates the roaster's ability to enhance cooking efficiency, food safety, and quality, providing a scalable solution for small-scale vendors and industrial operations. Future improvements could focus on integrating automated temperature controls to further optimize energy use and roasting consistency.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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