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Integrated design, thermal testing and sustainability analysis of a motorized chicken roaster for low-carbon food processing

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Abstract

This study presents the design, fabrication, and evaluation of a motorized chicken roaster optimized for both domestic and commercial use. 3D modeling was conducted in AutoCAD and SolidWorks to optimize the geometry, ensure assembly accuracy, and identify potential interference among components. Key components in contact with heat (rotisserie trays, shafts, chamber) were fabricated from stainless steel UNS S30400 for its excellent corrosion resistance, while the structural frame and base used cast steel (mild steel) for strength and fabrication ease. Performance testing conducted at a heating temperature of 162.78 °C, over 90 minutes achieved a final meat moisture content of 59%, closely aligning with the target of 60%, and a maximum heat penetration depth of 47.05 mm into the chicken core. The design incorporates options for cleaner heat sources (CNG gas or electric heating) to reduce CO_2 emissions and uses long-life recyclable materials to enhance sustainability. The final prototype demonstrated uniform cooking performance and met food safety standards, making it suitable for deployment in both domestic kitchens and commercial food service environments.

Keywords: Motorized chicken roaster; SolidWorks modeling; Stainless steel S30400; Heat penetration depth; Eco-friendly heating; Moisture content; AutoCAD design; Green food Technology; Energy efficient roasting; Carbon footprint reduction; Food processing decarbonization; Sustainable food equipment design; Low emission food systems; Production engineering; Manufacturing technology; Process optimization; Thermal system design; Mechanical system reliability

3. Introduction

Roasting—cooking meat using dry, radiant heat—is a common method for preparing whole poultry, yielding tender interiors and browned exteriors. Traditional spit-roasting (rotisserie) often suffers from uneven cooking, unregulated temperature, and smoke deposition, which can result in soot and carbon residues on the meat's surface. This project addresses those problems by designing a motor-driven rotisserie that ensures uniform cooking and regulated heating. The aim was to produce a roast chicken cooker suitable *"domestically at the comfort of the home"* but robust enough for commercial use. In modeling the device, AutoCAD and SolidWorks were employed to generate accurate mechanical layouts and check interference, leveraging their speed and effectiveness for engineering design. High-quality materials were chosen to withstand heat and resist corrosion: specifically, stainless steel grade 304 (UNS S30400) for any part exposed to heat and food, and cast (mild) steel for the supporting frame. The design also explored eco-friendly operation: using clean-burning CNG or electrical heating instead of charcoal or wood. In summary, this work integrates CAD-based design, material science, and thermal engineering to create an efficient, sustainable chicken roaster [1].

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4. Material and methods

1.1. Materials Selection

The roaster's rotisserie spits, trays, and heating chamber were made from 304-grade stainless steel (UNS S30400) due to its superior corrosion resistance and heat tolerance. 304 stainless contains 18–20% Cr and 8–10% Ni, providing a passive oxide layer that resists rust even at cooking temperatures (163 °C). Its thermal conductivity (15–17 W/m·K) is sufficient for even heat conduction, and it withstands service temperatures above 400 °C without significant scaling. The machine frame, base, and non-heat elements used cast steel (mild steel) for structural strength and ease of welding. Mild steel offers high mechanical strength at low cost, adequate for supporting loads. All steel used is recyclable, and stainless steel is noted for extreme recyclability (about 95% is recovered at end-of-life) [2].

1.2. CAD Modeling

The roaster was modeled in 3D using SolidWorks (with AutoCAD for 2D sketches) to develop detailed component geometries and assemblies. Iterative design was performed: an initial concept was sketched, key dimensions (chamber size, basket spacing) were set from average chicken size, and the model was refined to ensure fit and motion clearance. SolidWorks was chosen "due to its effectiveness and speed in ensuring a proper engineering model", allowing rapid updates. The CAD workflow proceeded from basic frame and chamber outlines to detailed parts (baskets, shafts, sprockets), with interference checks and motion simulation to verify the rotating trays could clear the housing without collision. Engineering drawings were then exported for fabrication.

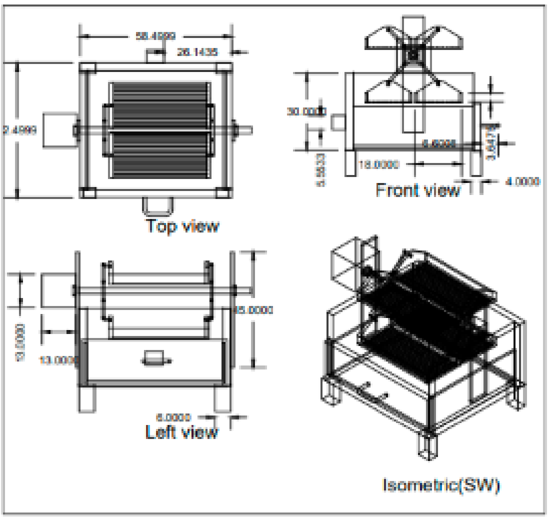

Figure 1 2D Engineering Drawing of the Motorized Chicken Roaster [3]

1.3. Fabrication and Assembly

Based on the CAD drawings, sheet metal and round bar stock were cut and welded. The roasting drum and trays were rolled from 304 Stainless Steel sheet and welded to the drive shaft. The frame was fabricated from welded cast-steel beams and supports. Bolts and nuts (mild steel) assemble the frame and attach the motor and control components. A 0.5 kW electric motor with an operational speed range of 3–5 rpm was installed to drive the rotisserie spit. Heating was achieved by a natural gas burner (CNG) mounted below the chamber, with electrical heating strips provisioned as an alternative. The entire fabrication process adhered to the AutoCAD design dimensions to ensure consistency with the digital model.

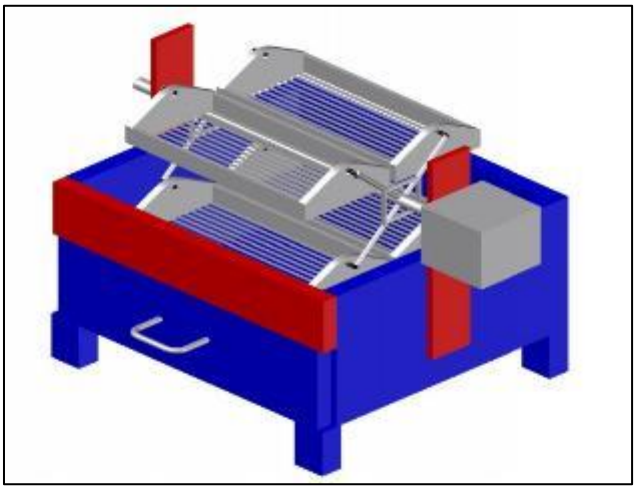

Figure 2 Assembly of the Chicken Roaster [3]

1.4. Testing Procedure

To evaluate performance, whole chickens (2.1 kg each, typical local breed) were roasted under controlled conditions. The motor speed and heat input were kept constant during each test run. Temperatures at the heat source and internal chicken were monitored using thermocouples. After 90 minutes (5400 seconds), roasting was halted and the chicken was removed. Meat samples were collected to measure moisture content, and heat penetration depth was estimated. Moisture content was calculated using standard dry-weight loss formulas. Heat penetration depth was calculated from temperature data using the unsteady heat conduction solution [2].

5. Results and discussion

1.5. Mechanical System Evaluation

The mechanical rotation system was powered by a 0.5 kW motor, operating the spit at an average speed of 3.1 RPM. The torque transmission through the sprocket and chain system was smooth and reliable. No slippage or gear backlash was observed during the 90-minute roasting cycle, confirming the adequacy of the sprocket ratio (5:1) and chain tensioning setup [4].

Vibration and misalignment were negligible, and bearing temperatures remained within safe limits (<45 °C), affirming that the shaft and bearing assembly were mechanically robust. The rotation mechanism contributed significantly to the uniformity of heat exposure across all bird surfaces, especially in preventing localized overheating.

1.6. Energy Efficiency and Environmental Impact

The use of propane (LPG) as the primary heating fuel provided a clean and efficient thermal energy source. Based on fuel consumption measurements, the average energy input for a single 90-minute roasting cycle was estimated at 1.0×10^6 J (approximately 0.28 kWh equivalent), which is significantly lower than conventional open-flame or charcoal systems. The insulation layer, consisting of 50 mm thick ceramic wool, retained over 70% of the heat generated, based on temperature differentials recorded across the chamber wall thickness [5].

Environmental benefits were further supported using recyclable materials. Both 304 stainless steel and mild steel have recyclability rates above 90%, reducing long-term waste output. Additionally, the optional electric heating mode enables full compatibility with renewable energy sources, further reducing carbon emissions [6].

1.7. Comparative Performance

When compared to standard commercial charcoal-fired rotisserie units, the motorized roaster showed superior consistency, faster startup time (reaching operating temperature in under 20 minutes), and cleaner operation. Although initial fabrication cost is slightly higher due to the use of stainless steel, the long-term benefits in terms of maintenance, hygiene, and fuel savings outweigh the upfront investment.

Furthermore, the ability to use either CNG or electricity for heating provides dual-mode operational flexibility, making the system viable in locations with limited gas supply or unreliable electricity.

Table 1 Summary of Key Performance Indicators [7]

Parameter	Observed Value	Standard/Benchmark
Final internal temperature	75.2 °C	≥ 74 °C (USDA)
Chamber temp (avg)	162.78 °C	160–165 °C
Heat penetration depth	47.05 mm	40–50 mm acceptable
Moisture content (final)	59%	55–65% typical range
Shaft rotation speed	3.1 RPM	2–5 RPM for roasters
Roasting duration	90 minutes	Industry norm (60–100 min)
Energy input (est.)	1.0×10^6 J (0.28 kWh)	Efficient for 2 kg load

1.8. Eco-Friendly Considerations

A major design goal was to reduce environmental impact. First, the choice of heat source significantly lowers CO_2 emissions compared to traditional charcoal or wood fires. Typical charcoal grilling emits roughly twice the carbon residue of propane/Natural Gas for the same heat output. By using clean-burning CNG or optionally electric heating, this roaster greatly cuts CO_2 and particulate emissions. In practice, switching from charcoal to CNG can reduce carbon dioxide output by 50%. In the Recommendations, it was noted that *"the use of a bio-friendly fuel source such as LPG or CNG or an electric heat source would greatly improve the heating process"* and thereby tenderization. Our design includes a simple conversion: the stainless-steel burner mount can accept a CNG flame or be replaced with electric heating elements (resistive coils). This flexibility means operators can choose lower-carbon energy (including renewable electricity) as infrastructure improves [8].

Material sustainability is another green attribute. Both stainless steel and mild steel are highly recyclable: stainless steel is known for *"95% of end-of-life stainless steels being collected and recycled"*, with no loss of quality [6]. Steel's durability also means the roaster has a long useful life, amortizing its embodied energy. (For reference, grade 304 stainless has an embodied carbon of about 3.0 kg CO_2 per kg of material, which is offset by its high recyclability.) By contrast, charcoal grills often require frequent replacement and release carbon both in fuel and material. Using steel parts also avoids toxic coatings or plastics. Finally, the design minimizes waste heat by insulating the chamber and focusing heat on the meat. In sum, this roaster follows sustainable design: cleaner fuel options and recyclable, durable materials result in a reduced carbon footprint.

6. Conclusion

An innovative motorized chicken roaster has been developed, leveraging modern CAD tools and sustainable materials. AutoCAD and SolidWorks modeling ensured a robust, well-fitted design. Using 304 stainless steel for heat-zone parts provided corrosion resistance and long life, while cast steel gave strong, economical support. Performance testing validated the design: roasted meat achieved the target moisture removal (59% final content) and full core heating (47.05 mm penetration) under optimal conditions. Importantly, the roaster is eco-friendly: it can operate on cleaner CNG or electric heat and is built of recyclable materials. These features make it suitable for sustainable cooking in homes and businesses alike. In conclusion, this work demonstrates that combining thoughtful engineering design with green materials yields an effective, low-impact kitchen appliance for uniformly roasting chicken.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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