Research Article
Numerical Modeling of a Hot Plate Stove for Peanut Roasting

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1.Introduction

Peanut or groundnut (Arachis hypogaea) is a very valuable food crop and is mainly cultivated in the tropical and subtropical regions in Africa, America, and Asia [1]. The dry-roasted peanut kernels without salt are very rich in fatty acids (50%), proteins (25%), fiber, vitamin B6, vitamin E, niacin, and minerals. The minerals include manganese, magnesium, potassium, copper, and phosphorus [2]. Peanut is the richest nut in terms of protein and vitamin B3 (niacin) content [2], and it contains very high-quality oil. Its oil has a high smoke point and is, therefore, ideal for cooking or frying at high temperatures [2, 3].

Production of oil from peanuts involves the processing of groundnut by shelling, roasting, and pressing [4]. It is also used in making soap, cosmetics, furniture cream, shaving cream, fuel, and lubricants. Due to the fact that peanut is produced in the tropics where temperature and humidity are usually high, and also as a result of poor processing procedures, it is often associated with infestation with different species of fungus and formation of mycotoxins [5, 6]. Among these are aflatoxins (AFs), which are very dangerous to animal and human health [6, 7]. Heating can reduce the level of aflatoxin contamination in contaminated seeds, as revealed by different studies. Lee et al. [8] reported that the concentration of AFB1 could be reduced by about 80% by roasting peanuts for 30 min at 150°C. This makes roasting as a peanut processing method very important. Roasting is very important for making different nut products [9]. The peanut roaster is used to process other nut products as well, which in the process results in the development of color, flavor, and texture of the final product through several complex chemical reactions, heat transfer, and drying processes [10]. Roasting should be given special attention since it is used to improve food safety, introduce desired flavor, color, and texture and to improve and preserve food crops like grains, cocoa, coffee, and peanuts [9, 11]. The process of roasting also makes processed foods, especially nuts, more palatable.
and acceptable [12]. It has been observed that the improved taste, color, and texture of the processed food, and for that matter peanut, depend mainly on the roasting process [13].

Kita and Figiel [14] characterize roasting methods into two main groupings, namely, roasting in oil and dry roasting in air methods. Generally, the roasting process changes the microstructure of the nuts to develop the peculiar crunchy and crispy texture of the nuts and reduces the possible presence of poisonous fungi in peanut kernels and ultimately brings down the level of aflatoxins [15]. In dry roasting, two main methods are employed: the microwave and convection methods. The microwave roasting involves placing the peanut in a microwave oven and heating it for a few minutes [16]. In the convection method, peanuts are heated on a plate or by allowing air at a determined elevated temperature to flow at a given speed through the nuts to roast them [17]. Roasting on a heated plate is the most common method used in Ghana.

Proper roasting process is very important for the development of taste, color, and texture of the final product [13]. Lykomitos et al. [18] discovered that the flavor and color of roasted peanuts have a strong impact on consumer acceptance of the product. In a study to investigate the effect of different roasting methods of peanut on peanut color, flavor, and lipid oxidation values, Smith [19] did it for different time and temperature combinations using oven, microwave, and combination roasting technologies and observed that the method was not significant but rather the temperature and time of roasting were most essential.

Different time periods and temperatures are used to roast peanuts to obtain some specific product qualities for a specific market segment [16]. Specific time-temperature combinations used during peanut roasting have been observed to produce the same surface color [10]. It is, therefore, necessary to know the temperature-time combinations needed to roast for the best-desired peanut characteristics. Davids [20] reported a temperature-time combination of 240–275°C for the duration between 3 and 30 minutes, for some roasters. Raemy and Lamblet [21] found out that roasting starts as an endothermic reaction but later turns into an exothermic reaction at a roasting temperature of about 175°C, that is, the products being roasted heat themselves up in the process.

Some roasters are electrically powered but are mostly combined with an extractor [22]. This kind of combination makes the machines more complex and expensive for peanut vendors who are small-scale enterprises (SMEs). Peanut seeds are traditionally roasted by constantly stirring the groundnut seeds in an open mild steel pan over an open wood fire. Often, small open sand bath pan roasters, which are not efficient and hygienic, are used to roast the nuts [23]. Peanut, which indisputably is a valuable crop, is unfortunately associated with drudgery and bad hygiene in the developing world, which could be a source of physical and microbial contamination to the product [24]. This technique is rather hazardous and causes a great deal of discomfort to the operator due to constant contact with heat and smoke from the fire. Peanut processors who use this method need a roaster that would be user-friendly and easily maintained at a relatively lower cost. Therefore, this study proposes a groundnut roaster that is economical, efficient, and ergonomically suitable for SMEs that will be fueled with biofuel.

Biofuel, unfortunately, has its own demerits. Over 69% of the population in Africa use biomass as a traditional and most reliable fuel source of energy used for cooking. However, the effects of these demerits could be drastically reduced if more efficient and improved stoves are used. A study in India found that, if improved biomass cookstoves were widely accepted and implemented, it would have very significant benefits for health; for example, if theoretically 150 million cleaner burning improved biomass cookstoves were introduced and used over a period of ten years, about 2.2 million deaths could be avoided [25]. That is very significant. The hot plate roaster under study is an improved version of the traditional open mild steel pan over an open wood fire. This study considered the use of the computational fluid dynamics (CFD) approach to study the thermal performance of different fin configurations introduced in the hot plate roaster.

2. Experimental Setup

The hot plate stove consists of a brick structure, which is the main insulating material housing the roaster components. The rocket stove profile (cavity) from inlet (air and fuel) to outlet was designed and constructed using bricks. A stainless steel pan was fixed at the top of the brick structure to serve as a hot plate for the peanut roasting. Figure 1 shows a photograph of the roaster, while Figure 2 shows its CAD model. The roaster was equipped with a K-type thermocouple, which was used to measure the ambient, flame tip, and hot plate surface temperatures. The temperature measurement was taken at 5-minute intervals during the experiment. The K-type thermocouples have a temperature range from −200 to 1260°C and a sensitivity of 41 µV/°C. The flame tip and the hot plate surface temperatures were measured throughout the roasting period.

3. Computational Fluid Dynamics (CFD) Analysis

ANSYS Fluent 14.5 was used to simulate the three-dimensional (3D) stove geometry. The geometry was created in SpaceClaim 2020 R1 software as shown in Figure 2(a). The geometry was discretized into a finite volume mesh with 3.05 × 10^5 nodes and 1.14 × 10^6 elements. Figure 2(b) presents an image of the meshed volume. The fluid and component material properties that include air, brick, and stainless steel are shown in Table 1. These fluid and material properties were assigned to the model to describe the physical system (hot plate roaster) under consideration. The ANSYS Fluent solver was used for the numerical computations. The pressure-based solver, which represents an implicit solution approach that features the momentum and pressure correction as its primary variables, was used due to its unique applicability in solving a range of flow regimes ranging from low-speed incompressible flow to high-speed compressible flows, while expending less computer memory.
Figure 1: Hot plate roaster.

Figure 2: Hot plate roaster boundary specifications.
and storage. The model validation was carried out using the mean absolute error (MAE), Nash–Sutcliffe efficiency (NSE), root mean square error-to-observation standard deviation ratio (RSR), and the percent bias models to check the goodness of fit. This was performed by comparing the simulated results with the experimental results in accordance with the literature [26–31].

3.1. Boundary Conditions. Figure 2(c), Figure 3, and Tables 2 and 3 present the boundary condition assignment details and the flame tip input data used in the simulation. The flame tip temperature was measured using a K-type thermocouple from the roasters’ combustion chamber and used as an input in the Fluent simulation. This was conducted in order to ensure that both experimental and numerical simulations had the same input conditions. The transient setting in the Fluent environment was selected, and the time-dependent temperature (flame tip temperature) of the flue gas was prepared as an input text file, which was imported into the Fluent environment. The inlet velocity of the flue gas was 0.3 m/s, and the ambient temperature was 30.1 °C. As the flue gas rises, it flows beneath the hot plate and transfers heat to it by convection. The flue gas then moves toward the chimney and escapes into the environment. The walls of the hot plate roaster were assigned a no-slip boundary condition.

3.2. Constitutive CFD Model Setup. The governing equations of mass, momentum, and energy conservation of the heat transfer sequence were used to model, using the continuity, Navier–Stokes, and the energy equations, respectively. \( k \) and \( \varepsilon \) turbulent models were used in this study, where \( k \) is the turbulent kinetic energy and \( \varepsilon \) is the representation of the rate of dissipation. Equations (1)–(3) show the continuity, momentum, and the turbulent model equations used in this study:

Continuity equation:

\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0.
\]

Momentum equation:

\[
\frac{\partial (\rho u_i)}{\partial t} + \frac{\partial (\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu_{eff} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] - \rho g \delta_{ij}.
\]

Here, effective viscosity is the sum of laminar viscosity and turbulence viscosity \( \mu_{eff} = \mu_i + \mu_t \). The gravity is active in negative \( z \) direction as the Kronecker delta operator \( \delta_{ij} \) indicates.

Turbulence model:

\[
\mu_t = \rho C_p \frac{k^2}{\varepsilon}
\]

where \( C_p = 0.09 \) (Launder and Spalding, 1974). \( k \) and \( \varepsilon \) are turbulence kinetic energy and turbulence kinetic energy dissipation rate, respectively [32–35].

4. Results and Discussion

4.1. Grid Independence and Convergence Tests. A mesh convergence and independence test depict computing a numerical solution on successively finer grids. The numerical results are improved by using successively smaller cell sizes for the computation. A grid independence test was carried out by varying the refined mesh element size from 25 mm to 10 mm for the hot plate stove model before carrying out the full-scale fluid simulation. All solutions converged for the various mesh sizes. The results presented in Figure 4 show an insignificant change in temperature after varying or reducing the element size from 20 mm to 10 mm. Results from Figure 4(a) indicate that the element sizes between 10 mm and 20 mm reached numerical stability, with no significant change in the hot plate surface temperature below a mesh size of 15 mm. The results from the element size of between 25 mm and 10 mm indicate that the appropriate definition and mesh refinement are essential in obtaining accurate numerical simulation results. Therefore, a mesh element size of 10 mm was chosen for the simulation.

4.2. Study of the Hot Plate Temperature. The surface temperatures of the hot plate are shown in Table 4 and Figure 5 for the experimental and predicted conditions. The surface temperature results present a maximum difference of 33.3°C after 95 minutes, a minimum difference of 0.00°C at the onset, and an average difference of 16.51°C. The surface temperatures for the two conditions attained maximum temperatures of 133.7°C and 143.847°C at the end of the roasting period (3 hours). The surface temperature difference (for both test conditions) at the end of the roasting period was about 10°C. Furthermore, the experimental and predicted test conditions presented in Figure 5 show very similar results (line patterns), which confirm the prediction capabilities of using the model and Fluent software. The results demonstrate that CFD can be used to improve cookstove design as it is cost-effective and allows several

### Table 1: Material properties of roaster components.

| Material properties | Air          | Brick        | Stainless steel |
|---------------------|--------------|--------------|-----------------|
| Material type       | Fluid        | Solid        | Solid           |
| Density (kg/m³)     | 1.225        | 2100         | 8030            |
| Thermal conductivity (W/m·K) | 0.0242      | 0.73         | 16.27           |
| Specific heat (J/kg·K) | 1006.43      | 850          | 502.48          |
| Viscosity (kg/m·s)  | 1.7894       | —            | —               |

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design iterations without the need of developing several physical models or prototypes.

4.3. Model Validation Results. The model validation was performed using the mean absolute error (MAE), Nash–Sutcliffe efficiency (NSE), root mean square error-to-observation standard deviation ratio (RSR), and the percent bias (PBIAS) models to check the goodness of fit. This was performed by comparing the simulated results with the experimental results:

The mean absolute error (MAE): MAE as given in equation (4), which gives how closely the observed and modeled datasets agree. It evaluates the magnitudes of the deviations of modeled datasets from the observed
Figure 4: Grid independence test.

Table 4: Hot plate surface temperature versus time.

| No. | Time (min) | Experimental (°C) | Predicted (°C) | No. | Time (min) | Experimental (°C) | Predicted (°C) |
|-----|------------|-------------------|----------------|-----|------------|-------------------|----------------|
| 1   | 0          | 30.1              | 30.1           | 20  | 95         | 110               | 143.3          |
| 2   | 5          | 42.3              | 50.8           | 21  | 100        | 110.9             | 142.1          |
| 3   | 10         | 47.0              | 67.2           | 22  | 105        | 115.3             | 141.5          |
| 4   | 15         | 57.4              | 70.7           | 23  | 110        | 120.6             | 148.1          |
| 5   | 20         | 55.3              | 69.3           | 24  | 115        | 118.4             | 144.8          |
| 6   | 25         | 64.1              | 78.5           | 25  | 120        | 111.7             | 133.90         |
| 7   | 30         | 66.7              | 78.0           | 26  | 125        | 121.3             | 132.5          |
| 8   | 35         | 69.3              | 75.4           | 27  | 130        | 126.1             | 142.2          |
| 9   | 40         | 66.3              | 71.1           | 28  | 135        | 129.5             | 150.4          |
| 10  | 45         | 79.0              | 79.2           | 29  | 140        | 131.1             | 152.6          |
| 11  | 50         | 76.3              | 81.1           | 30  | 145        | 124.4             | 152.0          |
| 12  | 55         | 78.2              | 86.4           | 31  | 150        | 133               | 153.2          |
| 13  | 60         | 83.2              | 97.5           | 32  | 155        | 131.5             | 151.8          |
| 14  | 65         | 90.4              | 110.9          | 33  | 160        | 128.4             | 144.0          |
| 15  | 70         | 88.9              | 109.6          | 34  | 165        | 135.5             | 150.2          |
| 16  | 75         | 83.7              | 107.4          | 35  | 170        | 138               | 154.4          |
| 17  | 80         | 101.1             | 126.4          | 36  | 175        | 135.4             | 149.9          |
| 18  | 85         | 107.4             | 134.9          | 37  | 180        | 133.7             | 143.9          |
| 19  | 90         | 108.7             | 139.0          |     |            |                   |                |

Figure 5: Hot plate surface temperature for the experimental and predicted conditions.
values in real units, irrespective of the magnitude of the event [36].

\[
\text{MAE} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{Y_i^{\text{obs}} - Y_i^{\text{sim}}}{Y_i^{\text{mean}}} \right|
\]

(4)

where \( n \) = samples used; \( Y_i^{\text{obs}} \) = measured parameter (from observation); and \( Y_i^{\text{sim}} \) = calculated parameter (from simulation).

The root mean square error (RMSE)-to-observation standard deviation ratio (RSR): RSR uses error index statistics and a scale/normalization factor and, therefore, makes it possible for the statistic and reported values from it to apply different parameters. RSR values range from zero (0) to a large positive value. The optimum value is zero (0), which indicates a perfect simulation model. Equation (5) gives the mathematical formula for RSR [37].

\[
\text{RSR} = \frac{\text{RMSE}}{\text{STDEV}_{\text{obs}}} = \sqrt{\frac{\sum_{i=1}^{n} \left( Y_i^{\text{obs}} - Y_i^{\text{sim}} \right)^2}{\sum_{i=1}^{n} \left( Y_i^{\text{obs}} - Y_i^{\text{mean}} \right)^2}}
\]

(5)

where \( Y_i^{\text{obs}} = i^{\text{th}} \) observation; \( Y_i^{\text{sim}} = i^{\text{th}} \) simulated value; \( Y_i^{\text{mean}} = \text{mean of observed data} \); and \( n = \text{total number of observations} \).

Nash–Sutcliffe Efficiency (NSE): the Nash–Sutcliffe efficiency (NSE) is a normalized statistic that gives a comparison of the magnitude of the residual variance (the "noise") to the measured data variance (the "information") [38]. NSE can be mathematically represented by the following equation:

\[
\text{NSE} = 1 - \frac{\sum_{i=1}^{n} \left( Y_i^{\text{obs}} - Y_i^{\text{mean}} \right)^2}{\sum_{i=1}^{n} \left( Y_i^{\text{obs}} - Y_i^{\text{mean}} \right)^2}
\]

(6)

where \( Y_i^{\text{obs}} = i^{\text{th}} \) observation; \( Y_i^{\text{sim}} = i^{\text{th}} \) simulated value; \( Y_i^{\text{mean}} = \text{mean of observed data} \); and \( n = \text{total number of observations} \).

Percent Bias (PBIAS): percent bias (PBIAS) represents the tendency of the simulated data to be larger or smaller than their observed data as a percentage [39]. 0.0 is the optimal value of PBIAS. Lower values of the magnitude show that the accuracy of the model simulation is better. PBIAS is mathematically represented by the following equation:

\[
\text{PBIAS} = \left( \frac{\sum_{i=1}^{n} \left( Y_i^{\text{obs}} - Y_i^{\text{sim}} \right)}{\sum_{i=1}^{n} \left( Y_i^{\text{obs}} \right)} \times (100) \right)
\]

(7)

where \( Y_i^{\text{obs}} = i^{\text{th}} \) observation; \( Y_i^{\text{sim}} = i^{\text{th}} \) simulated value; and \( n = \text{total number of observations} \).

The mean absolute error (MAE) value for the study was 17.4048, indicating an error of about 17.4°C. The Nash–Sutcliffe efficiency (NSE) value was 0.5976, which from Table 5 indicates that the simulated model just satisfactorily fits the experimental data, since NSE is an indicator of how well the plot of observed versus simulated data fits. The RMSE-to-observation standard deviation ratio (RSR) value was 0.4024, showing that the model simulation performance was very good. The percent bias (PBIAS) value was -17.6423. Negative values of PBIAS indicate model overestimation bias. From Table 6, the PBIAS value shows that the accuracy of the model simulation was only satisfactory. RSR, NSE, and PBIAS results show that the use of the CFD modeling approach is good and can be effectively used to model and conduct design improvements for roasters.

### 4.4. Thermal Performance Analysis of the Hot Plate Roaster Model with Different Heat Exchange (Fins) Configurations

In this section, the effect of the addition of fins to improve the thermal performance of the hot plate was analyzed. The hot plate was modified to include two different fin configurations. These fin configurations are rod (12.7 mm diameter) and honeycomb (made with 2mm thick steel plate) as shown in Figure 6. Tables 7 and 6 present the surface temperatures for the experimental and predicted conditions with different fin configurations. The results show a maximum surface temperatures of 133°C, 153.25°C, 310.63°C, and 265.07°C after 180 minutes (three hours) for experimental (without fins), predicted (without fins), predicted (with rod fins), and predicted (with honeycomb fins), respectively. The average hot plate surface temperature results for experimental (without fins), predicted (without fins), predicted (with rod fins), and predicted (with honeycomb fins) were 93.1°C, 111.0°C, 169.64°C, and 139.46°C, respectively. From the presented results, the addition of fins to the hot plate leads to a significant increase in temperature with a maximum difference of 132.07°C and 177.63°C for predicted (hot plate with honeycomb fins) and predicted (hot plate with rod fins), respectively. Higher hot plate surface temperatures are desirable as it reduces the level of aflatoxin contamination in contaminated seeds [8]. Rod fins attained higher temperatures than honeycomb fins, which may be attributed to the high level of obstructions (in the honeycomb cells), which produced a temperature gradient leading to a reduction in heat transfer during the flow of the hot flue gases [40]. Figures 7 and 8 show the geometric models and temperature contour plots of the hot plate fin configurations (original plate without fins, hot plate with honeycomb fins, and hot plate with rod fins). The development of the cookstove prototype with the analyzed fins is recommended to validate the numerical results. There were 115.34% and 143.03% increase in hot plate surface temperatures for the honeycomb and rod fin modified hot plates over the original roaster, which is in agreement with Shashidhar’s [41] findings. Thus, honeycomb and rod fins can be introduced to increase the thermal performance of the roaster plate.
Table 6: Validation statistics.

| Performance rating      | RSR       | NSE       | PBIAS     |
|-------------------------|-----------|-----------|-----------|
| Very good               | 0 ≤ RSR ≤ 0.5 | 0.75 < NSE ≤ 1 | PBIAS < ±10 |
| Good                    | 0.5 < RSR ≤ 0.6 | 0.65 < NSE ≤ 0.75 | ±≤ 10 PBIAS < ±15 |
| Satisfactory            | 0.6 < RSR ≤ 0.7 | 0.5 < NSE ≤ 0.65 | ±15 ≤ PBIAS < ±25 |
| Unsatisfactory          | RSR > 0.7   | NSE ≤ 0.5  | PBIAS > ±25 |

Source: [31].

Figure 6: Hot plate surface temperature for the experimental and predicted conditions at different fin configurations.

Table 7: Hot plate surface temperature for the experimental and predicted conditions at different fin configurations versus time.

| Time (s) | Hot plate (without fins) experimental (°C) | Hot plate (without fins) predicted (°C) | Hot plate with rod fins predicted (°C) | Hot plate with honeycomb fins predicted (°C) |
|----------|------------------------------------------|----------------------------------------|---------------------------------------|---------------------------------------------|
| 0        | 30.1                                     | 30.1                                   | 30.1                                  | 30.1                                        |
| 300      | 42.3                                     | 50.83688                               | 40.52949                              | 37.42657                                    |
| 600      | 47                                       | 67.20928                               | 53.49955                              | 45.85424                                    |
| 900      | 57.4                                     | 70.70168                               | 62.17645                              | 51.75321                                    |
| 1200     | 55.3                                     | 69.30462                               | 67.21052                              | 55.5708                                     |
| 1500     | 64.1                                     | 78.50634                               | 76.67397                              | 62.32829                                    |
| 1800     | 66.7                                     | 78.10656                               | 83.56199                              | 67.47927                                    |
| 2100     | 69.3                                     | 75.38275                               | 87.29558                              | 70.79904                                    |
| 2400     | 66.3                                     | 70.98046                               | 89.95532                              | 73.46316                                    |
| 2700     | 79                                       | 79.12975                               | 97.17179                              | 79.0695                                     |
| 3000     | 76.3                                     | 81.09478                               | 103.7069                              | 84.29769                                    |
| 3300     | 78.2                                     | 86.40991                               | 110.8094                              | 90.05375                                    |
| 3600     | 83.2                                     | 97.53341                               | 121.8798                              | 98.34925                                    |
| 3900     | 90.4                                     | 110.9372                               | 135.6838                              | 108.5371                                    |
| 4200     | 88.9                                     | 109.6522                               | 144.5668                              | 115.765                                     |
| 4500     | 83.7                                     | 107.1539                               | 151.1753                              | 121.7142                                    |
| 4800     | 101.1                                    | 126.4397                               | 167.0472                              | 133.6128                                    |
| 5100     | 107.4                                    | 134.8871                               | 182.9843                              | 145.6897                                    |
| 5400     | 108.7                                    | 138.9646                               | 196.2829                              | 156.3919                                    |
| 5700     | 110                                      | 143.3                                  | 209.8445                              | 167.4088                                    |
| 6000     | 110.9                                    | 142.1373                               | 221.0136                              | 177.0444                                    |
| 6300     | 115.3                                    | 141.5335                               | 231.034                               | 186.078                                     |
| 6600     | 120.6                                    | 148.1008                               | 243.6005                              | 196.81                                      |
| 6900     | 118.4                                    | 144.8226                               | 252.6613                              | 205.347                                     |
Table 7: Continued.

| Time (s) | Hot plate (without fins) experimental (°C) | Hot plate (without fins) predicted (°C) | Hot plate with rod fins predicted (°C) | Hot plate with honeycomb fins predicted (°C) |
|----------|------------------------------------------|----------------------------------------|--------------------------------------|--------------------------------------------|
| 7200     | 111.7                                    | 133.9076                               | 255.5703                             | 209.997                                    |
| 7500     | 121.3                                    | 132.4922                               | 259.7463                             | 215.5144                                   |
| 7800     | 126.1                                    | 142.2089                               | 269.4999                             | 224.5233                                   |
| 8100     | 129.5                                    | 150.4031                               | 280.9035                             | 234.5581                                   |
| 8400     | 131.1                                    | 152.6216                               | 289.9701                             | 243.198                                    |
| 8700     | 124.4                                    | 151.9939                               | 297.073                              | 250.6639                                   |
| 9000     | 133                                       | 153.2493                               | 304.587                              | 258.3506                                   |
| 9300     | 131.5                                     | 151.835                                | 310.6253                             | 265.0674                                   |
| 9600     | 128.4                                     | 143.9568                               | 312.6161                             | 269.2107                                   |
| 9900     | 135.5                                     | 150.2267                               | 318.7322                             | 275.9133                                   |
| 10200    | 138                                       | 154.3543                               | 325.557                              | 282.9557                                   |
| 10500    | 135.4                                     | 149.8572                               | 327.0896                             | 286.6313                                   |
| 10800    | 133.7                                     | 143.8465                               | 324.9341                             | 287.9087                                   |

Figure 7: Hot plate surface geometric models with design modification (different fin configurations).
Figure 8: Temperature contour plot of a hot plate with different fin configurations (original plate without fins, hot plate with honeycomb fins, and hot plate with rod fins).
5. Conclusions

CFD simulation was used to analyze a biomass-fueled peanut roaster to improve its effectiveness and propose design improvement to reduce the harmful effects of biomass-powered stoves. The K-type thermocouple was used to measure the ambient, flame tip, and hot plate surface temperatures during the experiment at 5-minute interval during the experiment. ANSYS Fluent 14.5 was used to simulate the three-dimensional (3D) stove geometry. The experimental results were compared with the simulated results. Model validation was carried out using the mean absolute error (MAE), Nash–Sutcliffe efficiency (NSE), root mean square error-to-observation standard deviation ratio (RSR), and the percent bias (PBIAS) models to check the goodness of fit. The model fitted the experimental data well.

The effect of the addition of fins at the bottom of the hot plate to improve its thermal performance was studied. For the two (2) different fin configurations studied, i.e., rod (12.7 mm diameter) and honeycomb (made with 2 mm thick steel plate), maximum surface temperatures of 133°C, 153.25°C, 310.63°C, and 265.07°C were obtained after 180 minutes (three hours) for experimental (without fins), predicted (without fins), predicted (with rod fins), and predicted (with honeycomb fins), respectively. The results show that the addition of rod fins to the hot plate leads to the highest temperature. The introduction of honeycomb and rod fins on the roster plate increased temperatures by 115.34% and 143.03% of the original roaster hot plate temperature, which can drastically reduce the possible aflatoxin contamination effect. Thus, a design with rod fins added to the hot plate could improve its thermal performance and hence reduce harmful effects of the burning of its biofuels in support of the United Nations’ Sustainable Development Goals (SDGs) 3, 7, 12, and 13.

Data Availability

The data gathered and used in this study are privately kept at the laboratory of the authors and can be made available upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors’ Contributions

Michael Kweku Commeh took part in the design of the roaster. Anthony Agyei-Agyemang, Michael Kweku Commeh, and Benjamin Atribawuni Asaaga carried out the experiments. Anthony Agyei-Agyemang and Benjamin Atribawuni Asaaga carried out the modeling work. Anthony Agyei-Agyemang and Benjamin Atribawuni Asaaga were involved in the data analysis. Peter Oppong Tawiah played a supervisory role and was also involved in editing.

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