Temperature coverage simulation of horizontal cylinder type coffee roasting machine

F Fachruddin*1,2, S Syafriandi1,3, R Fadhil1,3

1Department of Agricultural Engineering, Universitas Syiah Kuala, Indonesia
2Aceh Climate Change Initiative (ACCI), Universitas Syiah Kuala, Indonesia
3Agricultural Mechanization Research Centre, Universitas Syiah Kuala, Indonesia

*Email: fachruddin@unsyiah.ac.id

Abstract. This study aims to simulate the temperature distribution of coffee roasting machines and study the profile of coffee beans roasted using a horizontal cylinder-type roaster. The coffee used in this study is arabica. The simulation method for the temperature estimation in the coffee roasting process uses the Solidworks Flow Simulation 2016 software, while the actual temperature measurement using a thermocouple is simulated with the Surfer software version 16. Furthermore, each stage of the coffee roasting process has been carried out, including the weight of the material, the roasting temperature, and the bulk density. The final step is to observe the profile of the roasted coffee beans at every minute of treatment. The study results indicate a difference between the approximate temperature simulation (top 176.85°C, bottom 191.97°C) and the actual temperature measured results (upper 214°C, bottom 220°C). The weight of the material (coffee green bean), the roasting temperature, and the bulk density during the test experienced regular movements from the beginning to the end of the treatment. The profile of roasted coffee beans shows a darker color movement along with the longer roasting time used. The profile of the roasted coffee beans will be beneficial in determining at which level of roasting you want (light, medium, medium-dark, dark).

1. Introduction

Coffee is one of Indonesia's priority commodities for food and agriculture development [1, 2]. Indonesia's natural coffee exports reach five continents, namely Asia, Africa, Australia, America, and Europe, with the leading share in Europe. The top five countries Indonesian natural coffee importers are the United States (13.52 %), Germany (9.56 %), Malaysia (9.22 %), Italy (8.15 %), and Russia (7.89 %) [3]. Coffee products exported by Indonesia are dominated by coffee with a medium to high quality. Improvements in coffee quality must always be pursued so that the quality of exported coffee is by consumer preferences [4].

World coffee consumption from year to year continues to increase; data from 2001 to 2008 shows the increase in world coffee consumption reached an average of about 2%. World coffee consumption in 2008 is estimated at 7,680 tons, consisting of 4,909 tons of Arabica coffee and 2,771 tons of Robusta coffee. The increase in world coffee consumption is due to coffee consumption in coffee-producing countries proliferating and consumers experiencing an increase. According to Consultant International Coffee Organization (ICO), P & A Marketing International estimates global coffee consumption growth in the 2005-2015 period increased by 35% [5].
The increasing value of coffee consumption is a driving force for the coffee processing industry to increase its production. The quality of coffee beans is highly dependent on the proper post-harvest handling process. One of them is in the roasting process, where there is a change in the level of water content and acidity as well as the development of the aroma and taste of coffee depending on the temperature and roasting time [6]. Roasting with an adequate time and temperature can reduce acrylamide formation in coffee, but it needs ongoing studies related to the coffee process, especially in the roasting stage [7].

According to Sulistyowati [8], several factors significantly affect the taste of brewing coffee, one of which is the coffee roasting technique. The results of traditional roasting are generally done openly with a frying pan made of earth, iron, or steel. This method is relatively straightforward but has many drawbacks, such as low roasting capacity, long time required, a lot of heat energy is wasted so that it wastes fuel, the level of ripeness (maturity) of coffee beans is not uniform, and the level of ergonomics is low. This condition will reduce the quality and quantity so that the added value of production is not maximized. Therefore, the existence of a coffee roaster that can produce high-quality brewed coffee is essential. The horizontal cylinder type coffee roaster is believed to overcome the shortcomings in the coffee roasting process. The use of this tool can produce a better coffee taste.

The manufacture of a cylindrical coffee roaster equipped with a two-axis gas stove is expected to reduce the roasting process time, save fuel, and overcome maturity to make it more even. The addition of a stirrer in it is expected to maintain the quality of the coffee in the roasting process. The mechanism of the stirrer section serves to prevent the coffee beans from piling directly with the main cylinder when roasting. Most drying occurs during this process, where the solid is in contact with gas or hot air [9].

The roasting process is the process of forming the taste and aroma of coffee beans. The roasting process will be relatively easier to control if the coffee beans have uniformity in size, specific gravity, texture, moisture content, and chemical structure. Therefore, it is necessary to roast coffee that is appropriate to the temperature and duration of roasting [10].

The degree of roasting affects the flavor characteristics of the coffee extract produced. The degree of roasting can be seen from the color of the coffee that has been roasted. The color of roasted coffee also affects the percent loss (rate of failure) of the ingredients in coffee, such as light roast of about 3-5% loss, medium roast of about 5-8% loss, and a dark roast of about 8-14% loss (including the level of roasting) water in rice coffee). This clearly shows that the chemical composition of both volatile and non-volatile coffee is affected by the degree of roasting [11]. Batubara [12] mentioned that coffee roasting methods could be divided into light, medium, and dark roast.

The roaster can be an oven that operates continuously, where heating is carried out at atmospheric pressure with hot media or combustion gases. Heating can also be accomplished by making contact with a heated surface and in some heater designs. This is a determining factor in heating. The most common technique that can be adapted for continuous roasting is a rotating horizontal drum. Generally, the coffee beans are poured parallel with hot air through this drum, except in some roasters where cross-flow with hot air is possible [13].

There are many coffee bean roasting machines with various brands and different specifications. Along with technological developments, coffee roasting machines continue to be developed to get more quality coffee beans. A horizontal cylindrical roasting machine is one of the machines used in the coffee roasting process to produce coffee quality with a high taste. The study results [14] stated that the treatment temperature and roasting time significantly affected the yield of roasted Arabica coffee beans and the acidity of steeping coffee. Still, the roasting temperature treatment did not affect moisture content and color value L's (Lightness).

This study aims to simulate the temperature distribution of coffee roasting machines and study the profile of coffee beans roasted using a horizontal cylinder-type roaster. The research results are expected to contribute to the development of coffee roasting machines, especially related to the roasting temperature and profile of the coffee produced from the roasting process.
2. Research Methods

2.1. Coffee Roaster Design
The design of the coffee roaster with a cylindrical type is has been made so that it can be opened and closed for easy maintenance of the tool. Furthermore, to support the process of reversing the coffee ingredients, a stirrer is used in the drum (roasting chamber). The materials used for the roaster are made of stainless steel, heating using a gas stove, an electric motor to regulate the mixing and dispensing system, a stainless steel stirrer system using an ergonomic intake and output system. The tool's specifications have a length of 140 cm, a width of 60 cm, a height of 110 cm. The tube/drum has a length of 75 cm, a diameter of 45 cm, a motor that drives 1 HP, and a capacity of 5 kg. Details and design of the tool can be seen in Figures 1 and Figure 2.

Figure 1. Coffee Roast Machine Design

Figure 2. Design of Coffee Roasting Machine Technology
2.2. Tools and materials
The coffee used for the actual test is arabica coffee for testing as much as 5 kg of coffee beans, while the tool designed is a cylindrical type roasting machine. Furthermore, complementary equipment is a laptop unit that has been installed with Solidwork Flow Simulation 2016 Software and Golden Google Surfer Software version 16.

2.3. Research Stages
The roasting machine temperature simulation is carried out using Solidwork software. Furthermore, the spread validation and roasting temperature measurements have been carried out using a thermocouple, and a temperature distribution display using the Golden Software Surfer has been presented. Data collection on the quality of the coffee beans produced included the average material weight (gr), sangria temperature (°C), average Kamba density (gr/l), and roasted profile. Data were collected every 3 minutes with 3 repetitions.

3. Results and Discussion
3.1. Temperature Spread Simulation
The simulation results of the temperature distribution of the roasted coffee show that the lowest temperature occurs at the top of the roasting drum, reaching 176.85 °C, while the highest temperature is at the bottom of the roasting drum with a temperature of 191.97 °C (Figure 3). This data shows that the temperature range in this roasting drum is +15.12 °C, where the median temperature is 184.41 °C.

![Figure 3. Simulated Roasting Machine Using Solidwork](image)

3.2. Temperature Measurement
Temperature measurement using a thermocouple and data processing using Surfer software shows that the lowest temperature is 214°C, while the highest temperature is at the bottom of the roasting drum, with a temperature reaching 220°C. Details of the roasting temperature distribution are validated in the form of temperature distribution in Figure 4. In addition, the roasting machine is also installed with a temperature sensor so that the highest temperature will be controlled only, reaching 220°C. It is
essential to maintain this temperature so that the coffee roasting process does not exceed the allowed temperature, scorching the coffee's outer surface quickly while the inside is not fully cooked.

![Figure 4. Spread of Roast Temperature Using Thermocouple](image)

The results also show that the highest temperature source is at the bottom of the roasting drum because it is close to the heat energy source of the roasting machine. Of course, this is by the principle of heat that moves from the gas stove to the drum (cylindrical tube) made of stainless steel and will then be absorbed by the Arabica coffee material. The contours generally occur in the temperature distribution, where the closer to the heating energy, the higher the temperature. Conversely, if the position with the stove is away, then the temperature of the roast will decrease. The roasting machine can still function because there is a stirrer on the inside, making the ingredients evenly receive heating energy well.

### 3.3. Product Quality

In the roasting test of arabica coffee beans, it can be seen that the weight of the material and the average density of the material decreases over time due to the transfer of water vapor from the material. Likewise, the energy released, the longer the increase occurs, from 180°C to 218°C (Table 1), so that more water is evaporated and reduces the weight of the material. This result is similar to the research results by [15], where the longer the time spent in the roasting process, the energy released by the drying media is the greater, so more water evaporates.

**Table 1. Quality of Coffee Beans and Roasting Temperature**

| Coffee Ingredients | 0   | 3   | 6   | 9   | 15  | 18  | 21  |
|--------------------|-----|-----|-----|-----|-----|-----|-----|
| Average Material Weight (gr) in a volume of 160 ml | 102.4 | 88.8 | 83.8 | 75.1 | 65.5 | 57.6 | 55.0 |
| Roast Temperature (°C) | 180 | 175-178 | 179-183 | 184-195 | 196-210 | 210-215 | 215-218 |
| Average density of kamba (gr/l) | 0.64 | 0.55 | 0.52 | 0.46 | 0.40 | 0.36 | 0.30 |
3.4. Roasting Profile

In coffee, maturity in the roasting process is usually indicated by the presence of a first crack, which is splitting the coffee beans in the yellowing process due to a mixture of carbon dioxide gas and water that both evaporate in the coffee beans. This process can be recognized by the presence of a crisp sound like the sound of peanuts breaking [16]. This process is fundamental because all the characters and flavors of the coffee beans begin to develop and form.

The test results show that the first crack in the study occurred at a temperature of 200°C and ended at 205°C. The research results are close to Sasongko and Rivai's [17] research result, where the first crack occurs at a temperature range of 200°C to 210°C and ends at a temperature of 225°C. Furthermore, the second crack appeared at a temperature of 215°C to 218°C. This is a slightly higher temperature with the results of the study Roasting coffee beans [18]. The second crack occurred at a temperature of 200°C and was somewhat lower than the study results[19], where the second crack is at a temperature of about 240 °C. Therefore, in general, the relationship between one study and another related to first crack and second crack is above 200 °C. The profile of the roasted Arabica coffee is as shown in Table 2 so that under what circumstances the desired coffee color can be determined based on the length of the roasting time. For example, for dark roasting results, the final time reaches 21 minutes for testing as much as 5 kg of coffee beans.

| Table 2. Profile of Arabica Coffee Roast |
|-----------------------------------------|
| Treatment | Time (minute) |
| 0 | 3 | 6 | 9 | 12 | 15 | 18 | 21 |
| 1 | ![Image of coffee beans at different times](image1.png) |
| 2 | ![Image of coffee beans at different times](image2.png) |
| 3 | ![Image of coffee beans at different times](image3.png) |

4. Conclusions

Some of the conclusions from this research include: First, There is a slight difference between the actual measurement results and the simulated temperature. The temperature in the simulation process is lower than the measurement validation results using a thermocouple temperature sensor. Secondly, there are similarities in the results of temperature distribution based on simulation and validation of roasting technology. The roaster's highest temperature is at the bottom due to the roasting room's position and the roasting machine's heat energy source. Third, The roasting machine test results show that the machine's ability is good in the roasting process where the results are uniform, and it takes 21 minutes to test 5 kg.
Acknowledgments
The author would like to express his gratitude and highest appreciation to KEMENRISTEK BRIN and LPPM Unsyiah for supporting the INSINAS research for the 2021 fiscal year Number 15/E1/KPT/2021.

References
[1] Sulaiman A A, Simatupang P, Subagyono K, Suwandi, Setiawan B I, Andayani A, Hermanto, Herodian S and Hakim L. 2017. Merah Putih Swasembada Pangan: Menghapus Ego Sektoral. IAARD Press, Jakarta.
[2] Fadhil R, Nurba D. 2019. Comparison of Gayo Arabica coffee taste sensory scoring system between Eckenrode and Fuzzy-Eckenrode methods. International Conference on Agricultural Technology and Engineering, and Environmental Sciences (ICATES) 2019. IOP Conf. Series: Earth and Environmental Science, 365, 012040.
[3] Statistik BP. 2017. Statistik Kopi Indonesia 2017. Kementan RI.
[4] Kustiari R. 2007. Perkembangan Pasar Kopi Dunia dan Implikasinya bagi Indonesia (Market Development of World Coffee and Its Implication for Indonesia). Forum Penelitian Agro Ekonomi, 25(1), 43-55. (in Indonesian)
[5] Departemen Perindustrian. 2009. Peran Industri Kopi bagi Peningkatan Kontribusi GPD Indonesia. Temu Karya Kopi VI, Jakarta
[6] Yusdiali W. 2013. Pengaruh Suhu dan Lama Penyangraian Terhadap Tingkat Kadar Air Dan Keasaman Kopi Robusta (Coffea robusta) (The Effect of Temperature and Long Roasting Against Moisture levels and acidity of Coffee robusta). Tugas Pengolahan II. (in Indonesian)
[7] Fadri RA, Sayuti K, Nazir N, Suliansyah I. 2019. Review of Coffee Roasting Process and Formation of Acrylamide Related to Health. Journal of Applied Agricultural Science and Technology, 3(1), 129-145.
[8] Sulistyowati S. 2002. Faktor-faktor yang Berpengaruh Terhadap Cita Rasa Seduhan Kopi. Materi Pelatihan Uji Rasa Kopi, Jember: Pusat Penelitian Kopi dan Kakao Indonesia.
[9] Yliniemi L. 1999. Advanced Control of A Rotary Dryer. Finland: Departement of Process Engineering, University of Oulu.
[10] Nugroho WKJ, Rahayee S, Meliala EA. 2009. Effect of Time Temperature History on Coffee Aroma During Roasting with Heat Conduction. Proceedings of the 10th International Agricultural Engineering Conference, Bangkok, Thailand, 7-10 December, 2009.
[11] Varnam HA, Sutherland JP. 1994. Beverages: Technology, Chemistry and Microbiology. London: Chapman and Hall.
[12] Batubara A, Widyasanti A, Yusuf A. 2019. Uji Kinerja dan Analisis Ekonomi Mesin Roasting Kopi: Studi Kasus di Taman Teknologi Pertanian Cikajang – Garut. Jurnal Teknotan, 13, 1–7
[13] Ciptadi W, Nasution MZ. 1985. Pengolahan Kopi. Bogor: Fakultas Teknologi Pertanian. Institut Pertanian Bogor.
[14] Pumamayanti NPA, Gunadnya IBP, Arda G. 2017. Pengaruh Suhu dan Lama Penyangraian terhadap Karakteristik Fisik dan Mutu Sensori Kopi Arabika (Coffea arabica L) (The Effects of Roasting Temperature and Roasting Duration on Physical Characteristics and Sensory Quality of Arabica Coffee (Coffea arabica L)). Jurnal BETA (Biosistem dan Teknik Pertanian), 5(2), 39-48.
[15] Sarastuti M, Yuwono SS. 2014. Pengaruh Pengovenan Dan Pemanasan Terhadap Sifat-Sifat Bumbu Rujak Cingur Instan Selama Penyimpanan (The Effect of Oven and Heating Time on Rujak Cingur Instant Seasonings’s Characteristics During Storage). Jurnal Pangan dan Agroindustri, 3(2), 464–475.
[16] Herawati D, Giriwono PE, Dewi FNA, Kashiwagi T, Andarwulan N. 2019. Critical roasting level determines bioactive content and antioxidant activity of Robusta coffee beans. Food Science and Biotechnology, 28, 7–14.
[17] Sasongko IJ, Rivai M. 2018. Mesin Pemanggang Biji Kopi dengan Suhu Terkendali Menggunakan Arduino Due. *Jurnal Teknis ITS*, 7(2), 39–44.

[18] ICCRI-TC [Indonesian Coffee and Cocoa Research Institute-Training Center]. 2021. *Penyangraian Biji Kopi*. https://tc.iccri.net/en/.

[19] Dinas Perkebunan Jawa Barat. 2016. *Proses dan Tingkatan Roasting Kopi*. Disbun Jawa Barat.