https://doi.org/10.17221/69/2022-RAE

Design and construction of coffee roasting machine with rounding cylinder tube using electric heat source

Andriani Lubis, Syafriandi Syafriandi, Muhammad Idkham, Ari Maulana*

Department of Agricultural Engineering, Faculty of Agriculture, Syiah Kuala University, Banda Aceh, Aceh Province, Indonesia

**Corresponding author: andriani_loebis@unsyiah.ac.id*

Citation: Lubis A., Syafriandi S., Idkham M., Maulana A. (2023): Design and construction of coffee roasting machine with rounding cylinder tube using electric heat source. Res. Agr. Eng., 69: 118–123.

Abstract: The purpose of this research is to design a rounding cylinder tube on a coffee roaster using an electric heating element that will be used to roast coffee. The roasting process also uses an electric motor to rotate the cylindrical drum so that the stirring process becomes even. The research was conducted using engineering methods including identification of problems, roasting machine design formulation, prototyping, functional testing, and performance testing. The data analysed are roasting capacity, roasting temperature and the need for electrical energy used. The results showed that the roasting capacity was 2.3 kg·h^{-1}. The serving of coffee for dark roast maturity levels can be ended when the temperature has reached a temperature of 201 °C. The need for electrical energy in the heater for roasting arabica coffee beans with a maturity level of a dark roast for 1 hour 54 minutes obtained an average value of 3.4 kWh, with the need for electrical energy for roasting arabica coffee beans which is 1.35 kWh.

Keywords: coffee beans; dark roast; electrical energy; electric motor; roasting temperature

Coffee is one of the plantation commodities that has an important role in economic activities in Indonesia. Coffee is also one of Indonesia's export commodities as a foreign exchange earner in addition to oil and gas. In addition to increasingly open export opportunities, the domestic coffee market is still quite large. Coffee production from 2018 to 2020 fluctuated. In 2018 coffee production amounted to 756.05 thousand tons, which decreased to 752.51 thousand tons in 2019, or a decrease of 0.47%. In 2020 coffee production rose to 762.38 housand tons or an increase of 1.31% (BPS 2020).

The growth of the coffee industry and the current high price of coffee show that coffee farming can make a major contribution to the household income of coffee farmers in Indonesia. But in reality, the impact of this growth has not been felt by coffee farmers who have technological limitations, especially in the roasting process, which still uses wok and wood-fired media. The uneven distribution of heat and the unknown temperature in the traditional roasting process causes the roasted coffee beans to be scorched so that the coffee beans can only be marketed as raw beans (green beans). This will certainly affect the income earned by coffee farmers.

According to Dutra et al. (2001), the quality of coffee drinks is influenced by many factors such as altitude, soil, climate, processing procedures, roasting temperature, and brewing method. Of all these factors, roasting is important in determining the quality of coffee drinks. Sofi'i (2014) states that in general coffee processing, the roasting process is carried out in the traditional way using simple tools. On a fairly large scale, coffee processing uses a roasting coffee machine.

https://doi.org/10.17221/69/2022-RAE

In accordance with the opinion of Suryadi et al. (2022), the roasting process with a roasting machine is carried out in a closed manner using a cylindrical tube given a rotary force. This aims to get even heat in the tube.

The aroma and taste of coffee are highly dependent on roasting. Roasting is a process that determines the physicochemical properties of coffee beans such as taste and aroma (Ridwan et al. 2018). The biggest problem in general during the roasting process is the instability of the roasting process (Getaneh et al. 2020). The business of designing a coffee roaster is one of the efforts to overcome the main problems faced by the coffee industry, namely to increase the productivity of coffee beans. With this roasting machine, it is hoped that the coffee bean roasting process can be carried out as efficiently as possible to minimize the costs incurred.

The purpose of this study was to design a coffee roaster with a capacity of ±10 kg per process using an electric heating element with a rounding cylindrical tube and test the performance of the roaster that has been made.

MATERIAL AND METHODS

The tools used in this study include tools for making coffee roasting machines, namely grinding machines, drilling machines, lathes, electric welding machines, hammers, meters, and other tools. The materials used in this study include stainless steel plate, iron plate, U iron, gear, bearing, axle shaft, gearbox, chain, motor drive and the material used as the tested material is arabica coffee beans. The procedure in this study starts with identifying the problem and formulating a design concept for a coffee bean roaster with a rotating cylindrical. After getting the formulation of the design concept, then a design analysis will be carried out which will be used for making working drawings. The machine assembly will be carried out and a work test of the tool in the form of structural and functional tests will be carried out to determine the performance of the tool working properly when roasting coffee beans. The data analyzed are roasting capacity, roasting temperature and the need for electrical energy used.

In making working drawings, machine design is carried out first using the SketchUp software (version 2021 PRO) application to simplify the design process. Based on the results of the design analysis, a working drawing will be made in accordance with the concept that has been created. The design of the working drawing of the coffee roaster can be seen in Figure 1. The structural approach is to determine the type of material and the construction dimensions of each main part of the roaster. The following in Table 1 can be seen from the description of the construction of the coffee bean roasting machine and its dimensions as shown in Figure 2. The functional approach is a review of the components of a coffee bean roaster to determine the function of several main parts. The following can be seen in Table 2 a description of some of the functional parts of a coffee bean roaster.

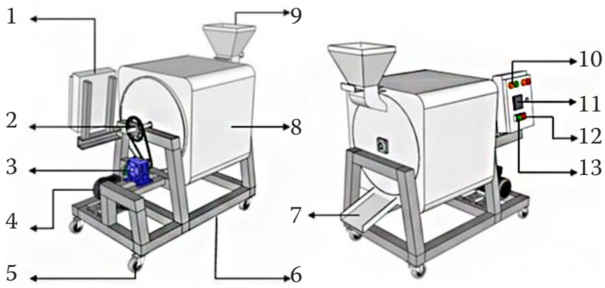

Figure 1. Design working drawing of coffee roaster

1 – control panel box; 2 – gear; 3 – gearbox; 4 – electromotor machine; 5 – wheel; 6 – engine frame; 7. – output hopper; 8 – heating drum; 9 – input hopper; 10 – indicator lamp; 11 – electric panel; 12 – switch-off; 13 – switch-on

Calculated parameters

Tube volume. The coffee bean roasting tube volume in Figure 3 can be calculated using Equation (1).

$$V = \pi \times r^2 \times p \tag{1}$$

where: V – volume of the cylinder (cm^3); r – radius of the circle (cm); p – length of a cylindrical tube.

Roaster working capacity (kg·h^{-1}). According to Sutarski et al. (2010), to calculate the working capacity of the roaster using Equation (2).

$$KW = \frac{BK}{w} \tag{2}$$

where: KW – working capacity of the tool (kg·h^{-1}); BK – the weight of coffee beans (kg); w – roasting time (h).

Roasting temperature. Temperature measurement is carried out when the coffee roasting process takes place in a roasting tube using a temperature thermostat

https://doi.org/10.17221/69/2022-RAE

Table 1. Criteria for component dimensions of the main parts of the coffee bean roaster

No.	Main section	Component	Dimensions
1.	frame	C channel iron	40 × 40 cm as much as 1 stick
		seat cushion	size 7/8 inch as much as 2 units
2.	drive	electric motor	capacity 1 horsepower as much as 1 unit
3	heating drum	outside drum	1 unit of 3 mm thick iron plate
		inner drum	diameter 45 cm and length 43 as much as 1 unit
		outboard bearing	size 7/8 inch as much as 1 unit
		heater	capacity 250 w/220 v as much as 1 unit
		thermocople	size 250 v/10 A/120 °C as much as 1 unit
4.	control panel	iron plate	2 mm thickness one piece
		electrical panel box	size 20 × 30 cm
		switch on-off	capacity 10A/220 v as much as 1 unit
		miniature circuit breaker	capacity 6 A as much as 1 unit
		relay	capacity 220 v/AC current as much as 1 unit
		indicator lamp	capacity 10 A LED type as many as five units
		converter AC to DC	capacity 60 A/220 v as much as one unit
		earth leakage circuit breaker	low sensitive 30 A as much as one unit

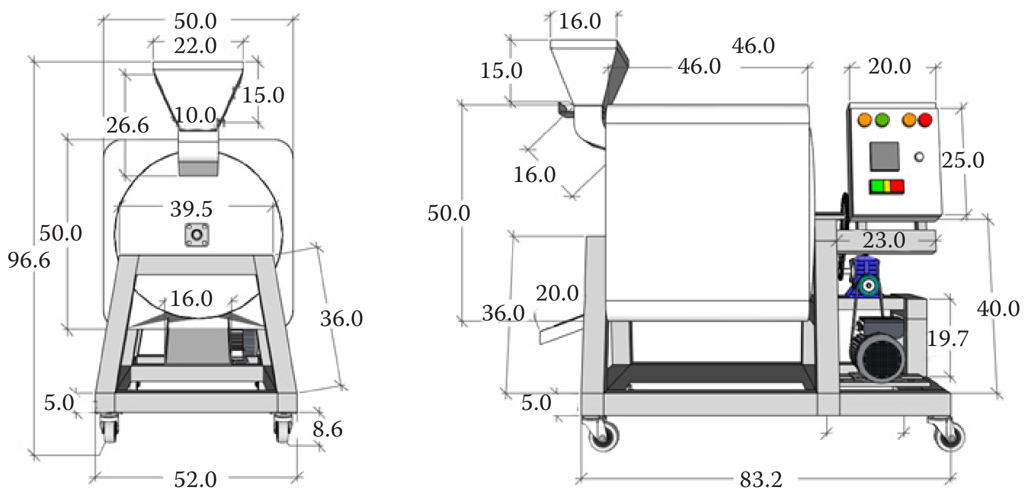

Figure 2. Dimensions of the coffee bean roaster machine (values are given in cm)
values are given in cm

which functions to regulate the temperature in the roasting tube chamber in order to obtain temperature measurement results. The temperature observed is the temperature in the roasting tube chamber. All measurements were carried out in three repetitions and the average value was taken.

Electrical energy needs. Electrical energy results from changing mechanical energy (motion) into electrical energy. The existence of electrical energy can be utilized as much as possible. The uses of electrical energy in everyday life are lighting, heating, electric motors, and so on. The energy used by an electric tool is the rate of use of energy (power) multiplied by the time during which the tool is used. According to Sutarski et al. (2010), the need for electrical power can be calculated by Equation (3).

$$W = v \times I \times t \tag{3}$$

where: W – electrical energy (J); v – voltage (V); I – strong electric current (A); t – time (s).

https://doi.org/10.17221/69/2022-RAE

Table 2. Functional criteria of components of the main parts of the coffee bean roaster

No.	Main parts of the roaster	Function
1.	frame	place to attach all components of a coffee bean roaster
2.	drive motor	
3.	heating drum	place to attach the heater and a place the heating process occurs during roasting
4.	panel control	place for electrical components such as electricity box panels, on/off buttons, miniature circuit breaker 16 A, 220 V relay, and indicator light.
5.	roasting cylinder tube	container for coffee beans and a place for the roasting process to occur until ripe

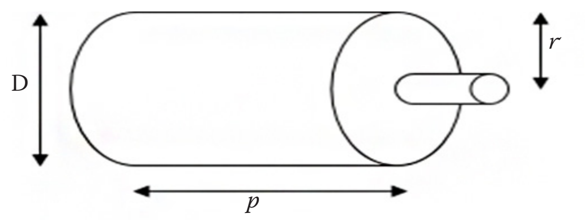

Figure 3. The equation of the volume of the coffee bean roasting tubeparts of the coffee bean roaster

D – diameter of the circle (cm); *r* – radius of the circle (cm); *p* – length of a cylindrical tube

Figure 4. Coffee bean roast machine with rotating cylinder type

RESULTS AND DISCUSSION

The size and dimensions of the roasted coffee beans are measured on a cm scale. There are six parts in the design of a coffee bean roaster machine, including in Table 3. The coffee bean roaster machine, as shown in Figure 4, was made after the calculation of the design drawings and technical analysis was completed. Each component is assembled and arranged according to the design drawings made, while the frame is made of angle iron to withstand the load when the machine is operating. Furthermore, function and performance tests are carried out to ensure whether the machine has been successfully made according to the initial design or still requires some improvements. If the result is good, then the performance is complete. Functional tests are carried out to determine whether the components/parts of the roasting machine are working properly. Field observations indicate that all parts/components have been functioning properly.

Table 3. Size and dimensions of the coffee bean roaster

Components		Length	Width	Height
Frame		83.2	52.0	45.0
Heating drum		46.0	50.0	50.0
Stirring cylinder		44.0	46.0	46.0
Panel control		20.0	10.0	25.0
Hopper	input	16.0	22.0	26.6
	output	20.0	16.0	10.0

measurements are in cm

The volume of the coffee bean roaster tube is made of stainless material which has a diameter and length of 46 and 44 cm, respectively. Hence, the volume obtained is 73.086 cm^3 with the bulk density of coffee beans being 0.735 $kg \cdot cm^{-3}$, if the tube is filled with 1/3 tubes, the resulting tube capacity is 24.362 cm^3 which is equal to 17.906 kg

Roast working capacity. The calculation of the working capacity of the tool is done by dividing the initial weight of the roasted coffee beans by the time required during the roasting process. Equation (2) is used to calculate the working capacity of the roaster. Based on the calculation of the volume of the tube, the maximum capacity of this machine is 18 kg process. In this study, the weight of the coffee used was 3 kg with a temperature of 205 °C and the time required for the roasting process was 78 minutes. So that the working capacity of the roaster with an initial weight of 3 kg of coffee beans which are roasted until cooked or until the coffee beans are dark roasted with a roasting time of 78 minutes, the result is 2.3 $kg \cdot h^{-1}$.

https://doi.org/10.17221/69/2022-RAE

According to Bakara and Daryanto (2022), the capacity of the dryer and the coffee roaster was 3.6 kg in one process. Batubara et al. (2019) stated that a theoretical capacity of 5 kg per process and an actual capacity of 0.752 kg·h^{-1} could be obtained on the SGR-5 Coffee Roasting Machine (CRM).

Roasting temperature. In Figure 5 it can be seen that the roasting temperature of arabica coffee beans was measured by heating the roasting machine at 6 minutes, namely at a temperature of 69 °C (the temperature before the coffee beans are added). Then for 36 minutes, the heating process took place, at 36 minutes the temperature rose to 201 °C (the initial temperature of arabica coffee beans was added) then the temperature in the roasting room dropped to 156 °C. This happens because of the mixing of the temperature of the coffee beans with the temperature of the roasting tube. Furthermore, from the 48th minute to the 114th minute the temperature increased again. In the 114th minute at a temperature of 201 °C ripe coffee was suitable for the dark roast level and was removed from the roasting tube.

Based on the statement above, it can be concluded that in the coffee bean roasting process, the temperature rises and falls in the roasting tube and the roasting can be ended if the colour of the coffee is in accordance with the desired level of maturity. Fadri et al. (2021) stated that the most important variables for each roasting were the type of roasting, the roasting temperature of the coffee beans, and the length of the roasting process. According to Purnamayanti et al. (2017) stated that roasting coffee using high temperatures will evaporate more water content and volatile compounds (caffeine, acetic acid, propionic, butyric, and valeric) present in coffee beans than roasting coffee using low temperatures.

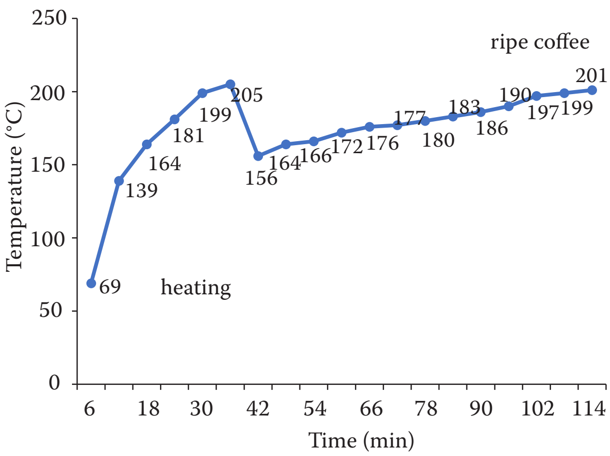

Figure 5. Coffee roasting temperature against time

According to Afriliana (2018), coffee roasting for dark roast maturity level can be ended when the temperature has reached a temperature of 123 to 221 °C. The roasting time of arabica coffee beans for 78 minutes produces coffee with a dark roast maturity level. Meanwhile, Bicho et al. (2012) reported that coffee beans are roasted at temperatures ranging from 180 to 250 °C for varying lengths of time. Laukaleja et al. (2019) stated that in value-adding coffee, roasting is an energy-intensive unit operation when green coffee beans are subjected to heat treatment with high temperatures of more than 200 °C at a certain time to achieve colour, aroma, and taste. Syafriandi et al. (2021) reported that the roasting process of coffee beans requires a high enough temperature to be roasted until cooked, above 200 °C. The higher the temperature causes the faster the roasting rate.

Coffee bean roaster electrical energy needs. The roasting process of arabica coffee beans with a dark roast maturity level takes 1 hour and 54 minutes. Testing the electrical energy requirements of arabica coffee beans was carried out three times by going through a roasting process of 3 kg for each repetition. Collecting data on electrical energy needs is done manually, which is observed in the control panel box. The demand for electrical energy can be calculated using the formula of Equation (3). The graph of the need for electrical energy can be seen in Figure 6 as follows.

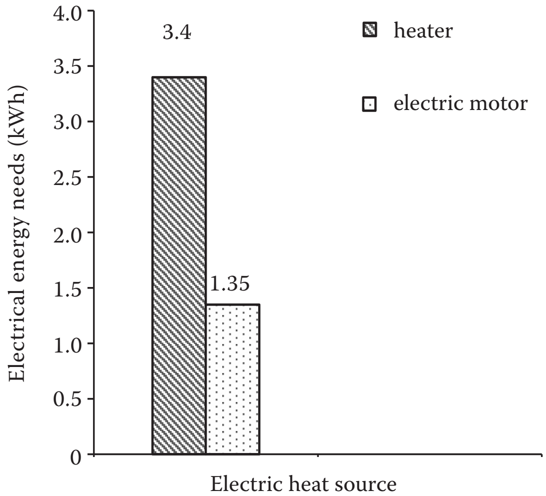

Figure 6. The electrical energy demand of heater and electric motor

https://doi.org/10.17221/69/2022-RAE

Figure 6 shows that the electrical energy requirement of the heater for roasting arabica coffee beans with a dark roast maturity level of 1 hour 54 minutes obtained an average value of 3.4 kWh, with the electrical energy requirement of the machine for roasting arabica coffee beans which is 1.35 kWh.

Based on the above statement, the need for electrical energy in the heater is greater than that in the engine. This is because, at the beginning of the testing process, the heater is turned on first to heat the air in the heating drum until the temperature reaches 205 °C. In contrast, the dynamo machine is only turned on when the coffee beans are inserted into the roasting cylinder tube. The analysis of electrical energy requirements testing in the coffee bean roasting process concluded that the electrical energy needs would be greater if the temperature used for roasting was higher. Nugroho et al. (2009) determined that roasted coffee needs to be roasted according to the temperature and duration of roasting.

CONCLUSION

This research was a success to design and construction of a coffee roasting machine with a tube volume made of a stainless material that has a diameter of 46 cm and a length of 44 cm so that a volume of 73.086 cm^3 was obtained with a specific gravity of coffee beans of 0.735 $kg \cdot cm^{-3}$. The performance of the working capacity of the roaster on the rounding cylinder tube coffee machine was 2.3 $kg \cdot h^{-1}$. The roasting process was carried out with a total time needed of 1 hour 54 minutes using 3.4 kWh of electricity on the heater. The coffee bean roasting machine was capable of roasting according to the maturity level of dark roast when the temperature reaches 201°C.

REFERENCES

Afriliana A. (2018): Teknologi Pengolahan Kopi Terkini. Yogyakarta, Deepublish.

Bakara A.A., Daryanto E. (2022): Rancang bangun mesin pengering kopi tipe rak dan penyangrai kopi tipe roaster dengan pemanas kompor gas. Jurnal Engineering Development, 2: 1–7.

BPS (2020): Badan Pusat Statistik. Jakarta, Produksi kopi di Indonesia.

Batubara A., Widyasanti A., Yusuf A. (2019): Uji kinerja dan analisis ekonomi mesin roasting kopi (studi kasus di taman teknologi pertanian cikajang-garut). Teknotan: Jurnal Industri Teknologi Pertanian, 13: 1–7.

Bicho N.C., Leitao A.E., Ramalho J.C., Lidon F.C. (2012): Use of colour parameters for roasted coffee assessment. Ciência e Tecnologia de Alimentos, 32: 436–442.

Dutra E.R., Oliveira L.S., Franca A.S., Ferraz V.P., Afonso R.J.C.F. (2001): A preliminary study on the feasibility of using the composition of coffee roasting ex-haust gas for the determination of the degree of roast. Journal of Food Engineering, 47: 241–246.

Fadri R.A., Sayuti K., Nazir N., Suliansyah I. (2021): Sensory quality profile of ranah minang arabica coffee specialty. International Journal on Advanced Science, Engineering and Information Technology, 11: 281–290.

Getaneh E., Fanta S.W., Satheesh N. (2020): Effect of broken coffee beans particle size, roasting temperature, and roasting time on quality of coffee beverage. Journal of Food Quality, 2020: 1–15.

Laukaleja I., Kruma Z. (2019): Influence of the roasting process on bioactive compounds and aroma profile in speciality coffee: A review. 13th Baltic Conference on Food Science and Technology and North and East European Congress on Food. In: Jelgava, May 2–3, 2019.

Nugroho W.K.J., Rahayoe S., Meliala E.A. (2009): Effect of time temperature history on coffee aroma during roasting with heat conduction. Proceedings of the 10th International Agricultural Engineering Conference. In: Bangkok, Dec 7–10, 2009.

Purnamayanti P., Gunadnya I., Arda (2017): Pengaruh suhu dan lama penyangraian terhadap karakteristik fisik dan mutu sensori kopi arabika (*Coffea arabica L.*). Jurnal of BETA (Biosistem dan Teknik Pertanian), 5: 39–48.

Ridwan F., Novison R. (2018): Characterization of roasted coffee aroma by optimizing roaster parameters. Borneo Journal of Resource Science and Technology, 8: 23–29.

Sofi'i I. (2014): Coffees roaster design machine with rotating mixer. Jurnal Ilmiah Teknik Pertanian, Politeknik Negeri Lampung, 6: 34–45.

Suryadi D., Anugraha B., Suryono A.F., Suandi A., Daratha N. (2022): Optimalisasi dimensi tabung roasting kopi kapasitas 2 kg dengan pendekatan model elemen hingga. METAL: Jurnal Sistem Mekanik dan Termal, 6: 1–7.

Sutarsi, Soekarno S.,Widyotomo S. (2010): Performance evaluation of rotating cylinder type coffee bean roaster. Journal of Keteknikan Pertanian, 24: 33–38.

Syafriandi, Fachruddin, Lubis A., Maulina H., Nazura P. (2021): Testing coffee roasting machine with electric heater as energy source. Proceeding of the 3rd ICATES 2021 Conference. Series: Earth and Environmental Science. In: Banda Aceh, Sept 21–22: 1–7.

Received: September 13, 2022
Accepted: February 7, 2023
Published online: August 2, 2023