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Design and manufacture of portable coffee roaster with LPG heater system

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Abstract

Bengkulu Province is one of Indonesia's top coffee producers. However, coffee processing is still done traditionally. Therefore, modern processing is required, particularly in the roasting process, which is vital in deciding the flavor of the coffee. This study aims to design, build, and test a low-energy coffee roaster with a capacity of 2 kg. The components of a coffee roaster are designed according to the demands and relevant standards, such as drum volume, drum material, shaft size, pulley size, belt, burner stove, and motor parameters. The coffee roaster is then tested by altering the distance between the fire holes to 10, 15, and 20 mm with a diameter of 3 mm, as well as varying the rotating speed of the drum to 60, 65, and 70 rpm and varying the coffee varieties, namely Robusta and Arabica. The testing of coffee roasting equipment with a capacity of 2 kg went smoothly. The results show that the ideal distance of the stove burner hole to attain 200 °C was discovered at a distance of 10 mm and a distance of the stove to the drum of 10 mm with a time of 17.24 minutes. For Robusta and Arabica coffee beans testing, the light roast should be roasted for 10 minutes. The medium roast requires 15 minutes of roasting time. And the dark roast requires a 20-minute roasting process. Furthermore, the rotating speed of the drum has little influence on the character of roasted coffee beans

Keywords:
coffee bean, burner stove, coffee roaster, mechanical design, roasting time

1 Introduction

Indonesia is one of the largest coffee-producing countries globally [1]. However, many coffee producers, especially in Bengkulu province, carry out traditional processing and roasting of green coffee beans. This traditional roasting process still uses a frying pan and firewood for heating. Therefore, it takes long roasting times and wastes energy during the roasting process [2]. This roasting process is critical compared to all phases of coffee processing because it determines the taste of the coffee [3]. Factors that affect coffee quality during the roasting process include operator skill, agitation of coffee beans in the drum, air temperature in the roasting drum, and heating source used [4].

Recently, a coffee roaster is required to simplify the coffee roasting process [5]. Many researchers have conducted developing coffee roasters. Generally, the roaster consists of six main parts: the roasting drum, the outer frame of the drum with the coffee inlet and outlet hoppers, the main motor driver, the heater, the cooler, and the temperature controller [6]. Several parameters should be considered to obtain the best roaster design, such as the drum dimensions and material [7], temperature, roasting time, efficiency in induction heating roasters [8], the number of holes, and burner diameter [9].

Some commercial coffee roasters using electric heaters for the home industry are widely used [10]. However, they still have some disadvantages; high energy consumption and expensive [6]. The coffee roaster also needs the proper process parameters. Those parameters affect the heat transfer rate in coffee beans during the roasting process [11]. The process must be precisely controlled to improve roasting performance and achieve a homogeneous profile. Various studies have been conducted experimentally evaluating the quality of roasted coffee based on parameters such as aroma, taste, color, bean temperature, pH, and chemical composition [12]. The results showed that parameters significantly impact the processing efficiency and quality of roasted coffee beans [13].

Since the high energy consumption of coffee roasters is also one of the reasons for the lack of public interest in automatic coffee roasters. In this research, the improvement of a potable coffee roaster with energy-efficient is proposed in which a gas stove with a burner is designed to provide the best heater. The capacity of the roasting drum is 2kg. Here, three components are considered to be implemented more efficiently; the design of the driver motor, burner, and rotation speed of the roasting drum. Therefore, energy-efficient and the cheaper production cost of roasters will be obtained.

2 Research methods

This research proposes an energy-efficient coffee roaster design. The design step includes the mechanical design of the coffee roaster, the design of the heating system using LPG, and the performance test of the coffee roaster. The manufactured coffee roaster is experimentally tested for both Robusta and Arabica coffee beans.

2.1 Design of coffee roaster for a capacity of 2kg

A coffee roaster is designed to obtain the best result that fits the needs, criteria, and standards. Before conducting roaster design, machine capacity is needed. In this study, a capacity of 2kg is considered.

2.1.1 Dimensions coffee roaster drum

A roaster drum is one of the main components of a coffee roaster that is based on the required capacity. The dimension of the roaster drum for a coffee capacity of 2kg can be calculated by the steps.

1. Volume of the roaster drum is determined by using Eq. (1) where m is Mass of coffee beans (kg), ρ is Density of coffee beans (kg/m^3) and V_{coffee} = Volume (m^3).

$$V_{coffee} = \frac{m}{\rho} \quad (1)$$

Since only 1/3 of the roaster drum volume can be used for the roasting process [14], the volume of the roaster drum is three times the volume of coffee beans (Vdrum=3xVcoffee).

2. In addition, the diameter of the roaster drum (D) can be calculated using Eq. (2), where V_{drum} is Volume of roaster drum (m^3), D is Drum Diameter (m) and t is Drum Length (m)

$$D = \sqrt{\frac{4V_{drum}}{\pi t}} \quad (2)$$

2.1.2 Design of the shaft of the drum

The shaft design is initiated by selecting the appropriate shaft material. In this study, Stainless steel is chosen as a material for the roaster shaft. Because it has some advantages; more corrosion resistant, heat resistant, hygienic, strong, and long service life [15]. After selecting the material, the optimum shaft diameter of the shaft roaster is calculated. The stage for the design of the shaft diameter is:

1. Torque applied on the shaft is based on the coffee weight and drum radius of the coffee roaster. Torque is calculated by using Eq. (3),. where T = Torque (N. m), F = Loads (N), and r = Radius of drum roaster (m).

$$T = F.r \tag{3}$$

2. The power calculation determines the nominal output power of the driving motor. It is can be calculated using Eq. (4), where P is Power (kW), n is Rotational speed (rpm) and T is Torque (N. m)

$$P = \frac{2.\pi.n.T}{6000} \tag{4}$$

3. The actual power is calculated by using Eq. (5). The actual power is the power that is transmitted from the main engine to the driven shaft. where P_d is Actual power (kW) , f_c is Correction factor and P *is* Power (kW).

$$P_d = f_c.P \tag{5}$$

4. The next step is calculating the torsional moment using Eq. (6), where T is torsional moment (N. m), P_d is actual power (kW) and n_1 is rotational speed (rpm).

$$T = 9{,}74 \times 10^5 \frac{P_d}{n} \tag{6}$$

5. The desired shear stress on the shaft is determined by using Eq. (7), where: τ_a is The desired shear stress $\left(\frac{kg}{mm^2}\right)$, σ_B is Tensile strength $\left(\frac{kg}{mm^2}\right)$ *and* Sf_1, Sf_2 = safety factors.

$$\tau_a = \sigma_B/(Sf_1 \times Sf_2) \tag{7}$$

6. The last step is designing the diameter of the shaft. It can be calculated using Eq. (8), where d_s is Diameter of Shaft (mm), τ_a = the desired shear stress $\left(\frac{kg}{mm^2}\right)$, K_t = ratio correction factor for torsional, C_b = ratio correction factor for bending and T = torsional moment (N. m)

$$d_s = [\frac{5{,}1}{\tau_a} K_t \times C_b \times T]^{1/3} \tag{8}$$

2.1.3 Selection of motor driver and pulley

Motor Driver for the coffee roaster is carried out based on the required torque and rpm specifications. In this study, the selection of the motor refers to the ABB motor datasheet. Moreover, transmitting power from the motor to the shaft is using V-belt with a width of type A. Inner diameter of pulley and outer diameter of the pulley are calculated using eq. (9) and (10), respectively. Where D_p= Inner diameter of pulley (mm), d_{min} *is* Minimum diameter (mm), i is rotational speed ratio and d_k *is* $d_p + 2 \times 5.5$. Secondly D_k is Outer diameter of pulley 1 (mm), d_k is outer diameter of *pulley* 2 (mm), D_p is Diameter of pulley (mm) and d_p*is* Minimum Diameter (mm)

$$D_p = d_{min} \times i \tag{9}$$

$$D_k = D_p + 2 \times 5.5 \tag{10}$$

After obtaining the diameter of the pulley, then determine the length of the belt required to transmit power from the motor to the drive shaft. The calculation of the size of the circumference of this belt can be used in eq. (11), where L is Length of belt circumference (mm), r_1 is Minimum radius of the pulley (mm), r_2 is radius of the *pulley* (mm) and x is distance of each shaft axis (mm).

$$L = \pi(r_1 + r_2) + 2\,.x + \frac{(r_1 + r_2)^2}{x} \tag{11}$$

2.2 Design of heating system

In this study, a gas stove is chosen as a heater for the coffee roaster instead of an electric heater due to its energy efficiency. Therefore, optimizing the dimensions and performance of gas stoves needs to be designed to get maximum results. This design includes the design of the venturi, nozzle, and the distance of the fire hole.

Venturi and nozzle are the important components of this burner stove which is located at the inlet pipe. This tool serves to supply air and spray fuel (LPG) into the burner pipe. To get a good fire (blue), it is essential to pay attention to the design of the venturi and nozzle. The venturi and nozzle design scheme can be seen in Fig 1.

The next step to getting good heating quality in the roasting process is optimizing the dimensions of the heating pipe. The dimensions of the heating pipe used in this coffee roaster are 25.4 mm in diameter, 370 mm in total length, and a stove fire hole diameter of 3 mm. The fire pits are spread horizontally on the surface of the heating pipe. To produce a constant temperature in the tube of 200oC, the distance of the fire pit was varied with a length of 10 mm, 15 mm, and 20 mm. Meanwhile, the stove had a distance private d the tube ranged between 5, 10, 15, 20, 25, and 30 mm. The design of the coffee roasting heating stove in Fig 2.

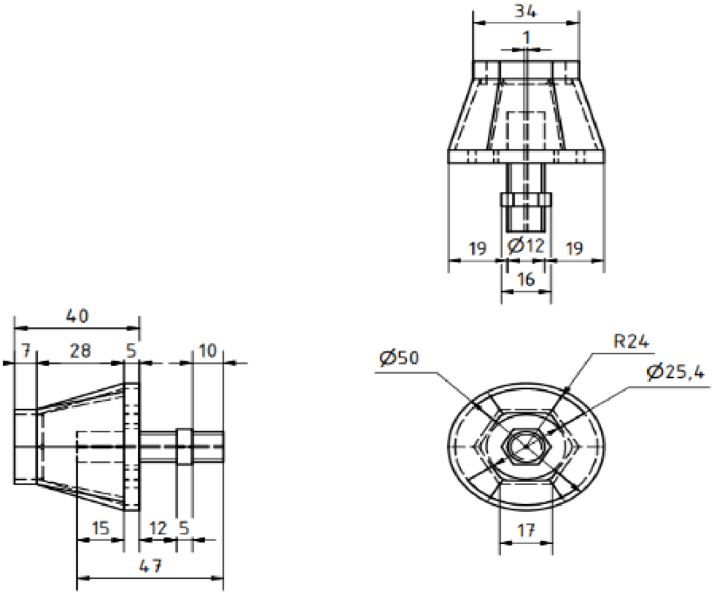

Fig 1. Venturi and Nozzle design scheme

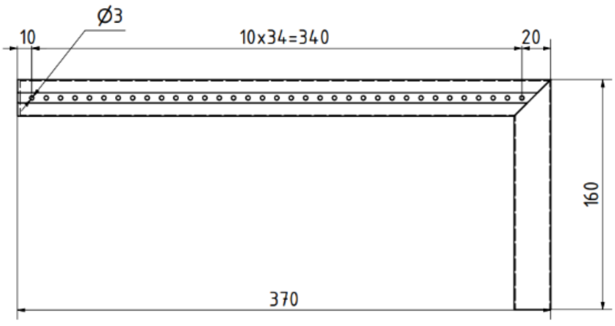

Fig 2. Design of the Stove

3 Results and discussion

3.1 Specification of designed coffee roaster with capacity of 2kg

A coffee roaster has been successfully designed for a capacity of 2kg. It has a total length of 850 mm, a width of 300 mm, a height of 800mm, and a total weight of 27kg. In general, this machine consists of main components, such as a roaster tube, inlet, blade, agitator, shaft, pulley, coffee holder, stir, casing, motor, and gas stove. The material of coffee roasters generally is stainless steel. The detailed design results are presented in Table 1.

After obtaining the design results in the form of specifications for a coffee roaster with a capacity of 2 kg, the manufacturing process is carried out using conventional machining processes. The dimensions and specifications of the roaster made according to the design results are presented in Table 1. The designed coffee roaster is shown in Fig 3. The manufacturing roaster in Fig 4.

Table 1. Results of Designed coffee roaster and its specifications

Part	Material	Specification		
Coffee roaster	-	Capacity	:	2 kg
		Length	:	850 mm
		Width	:	300 mm
		Height	:	800 mm
Drum	Stainless Steel	Length	:	350 mm
		Diameter	:	200 mm
Blade	Stainless Steel	Length	:	350 mm
		Width	:	25 mm
		Elongation	:	25°
Shaft	Stainless Steel	Length	:	505 mm
		Diameter	:	25,4 mm
Drum Frame	Steel Plate	Width	:	5 mm
		Length	:	300 mm
		Height	:	300 mm
Main Frame	Steel	Length	:	430 mm
		Width	:	300 mm
		Height	:	250 mm
Coffee container	Aluminum	Width	:	300 mm
		Height	:	300 mm
Inlet	Galvanized iron	Panjang	:	150 mm
		Lebar	:	150 mm
Outlet	Steel Plate	Width	:	135 mm
		Height	:	70 mm
Bearing	-	Trade mark	:	ASB
		Type	:	UFC 205
		Inner Diameter	:	25,4 mm
Pulley 1	Aluminum	Type	:	V
		Diameter	:	50,8 mm
Pulley 2	Aluminum	Type	:	V
		Diameter	:	101,6 mm
V-Belt	Rubber	Type	:	A
		Dimension	:	A-36
Electrical Motor	-	Power	:	250 watt
		Speed	:	2700 rpm
Stove	Galvanized iron	Panjang	:	370 mm
		Diameter	:	25,4 mm
		Diameter Fire Hole	:	3 mm
Body	Stainless Steel	Lebar	:	400 mm
		Tebal	:	1 mm

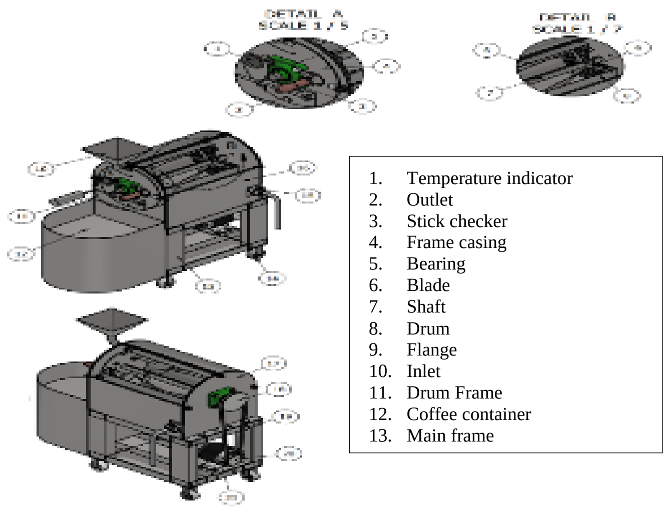

Fig 3. Detail of the designed coffee roaster capacity of 2kg

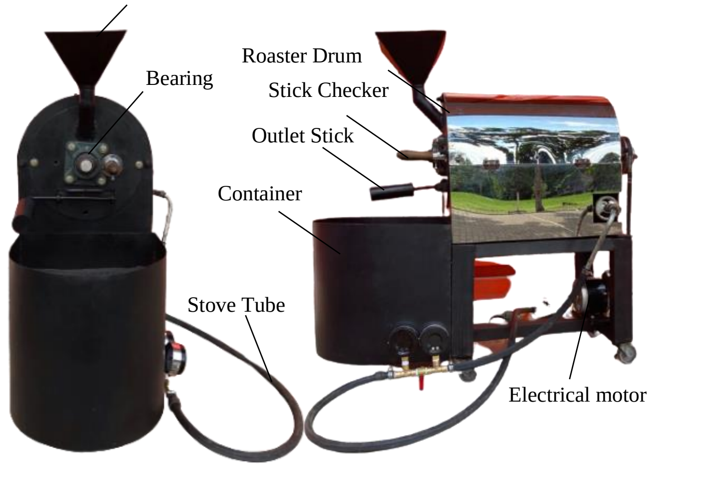

Fig 4. Manufacturing Result of the coffee roaster capacity of 2 kg

3.2 Heating system performance

The heating system is the most significant component of this coffee roaster. The quality of the stove is evaluated by adjusting the distance between the fire pits and the distance from the furnace to the roaster tube. The fuel utilized in this test is gas, with a constant pressure of 0.5 psi and a rotation speed of 65 rpm. To achieve high-quality roasted coffee, the temperature in the tube is kept constant at 200°C.

Fig 5 shows a graph indicating the relationship between the distance from the stove to the tube and the heating time for three different fire pit distances. The distance from the furnace to the tube is varied between 5mm, 10mm, 15mm, 20mm, 25mm, and 30mm. At the same time, the variations in the distance between the fire pits are 10mm, 15mm, and 20mm. Based on Fig 5, the distance between the fire holes of 10mm requires a faster time to heat the tube to a temperature of 200oC. At the same time, the distance of the fire pit of 15mm takes the longest time for the heating process. It appears that the distance between the stove to the drum and the distance between the holes in the stove were varied in the study, and the results showed that the distance between the holes in the stove had an impact on the time required to heat the drum. The results also showed that, in general, the distance of the stove to the drum has an inverse relationship with the time required to heat the drum, except at a distance of 5mm. At this distance, the heat from the stove is not distributed evenly across the drum. Based on the results of the study, it seems that the optimal distance of the stove to the drum for achieving a temperature of 200°C is 10mm

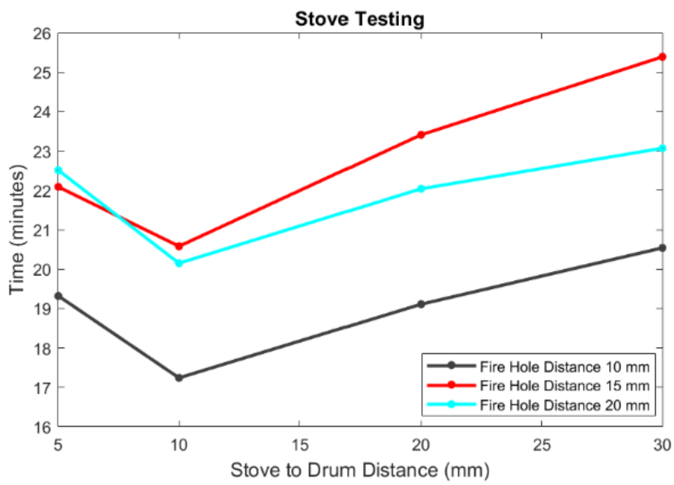

Fig 5. Relationship between the distance from the stove to the tube and the heating time

Fig. 6 shows the fuel consumption test in the form of a comparison graph between the distance of the stove fire hole and the distance from the stove to the tube to fuel consumption. Fig 6 shows the lowest value of fuel consumption is 0.04 kg. Namely, the stove's distance to the tube is 10 mm, and the distance from the stove fire hole is 10 mm. While the highest value of fuel consumption is 0.11 kg, it is found at the length of the stove to the tube of 30 mm and the distance of the stove fire hole of 15 mm. Based on these results, the optimal heating stove is one that has a distance of 10mm from the fire hole to the tube and a distance of 10mm from the stove to the tube, as this results in the lowest fuel consumption of 0.04kg. This is more efficient than using aluminum foil insulators, which result in fuel consumption of 0.05kg [5].

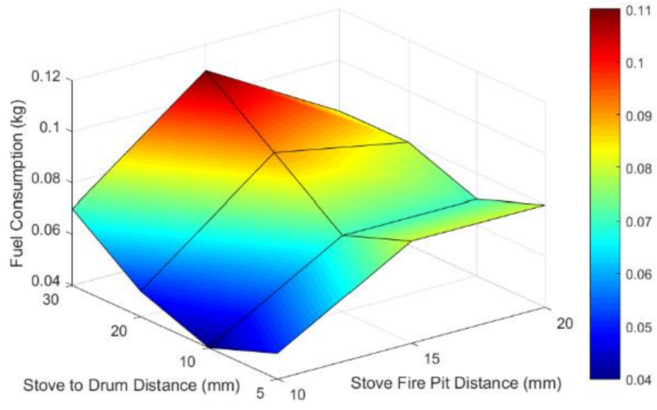

Fig 6. Relationship between the distance of the stove fire hole and the distance from the stove to the tube to fuel consumption.

3.3 A Coffee roaster machine performance Test

The next step in this study is to test the overall quality of a coffee roasting machine. The water content of Robusta and Arabica coffee is tested during the roasting process by controlling the temperature in the range of 180-200°C. The test is being conducted by varying the roasting time to 10, 15, and 20 minutes and varying the tube rotation to 60, 65, and 70 rpm for Robusta and Arabica coffee. This is being done in order to create a coffee roast profile based on the moisture content of the coffee before and after roasting. This information will help to understand how the roasting process affects the water content of the coffee and how different roasting conditions impact the final product.

Fig 7 shows a graph of the relationship between the roasting time and the water content of Robusta coffee, with variations in drum rotation. The graph shows that, overall, the water content of Robusta coffee is inversely related to the roasting time, meaning that as the roasting time increases, the water content decreases. The graph also shows that the drum rotation has an impact on the roasting process. A drum rotation of 70 rpm results in a water content of 9%, which is slightly higher than the water content produced by a drum rotation of 60 rpm or 65 rpm. This is likely due to the influence of forced convective heat transfer.

Fig 8 shows a graph of the relationship between the roasting time and the water content of Arabica coffee, with variations in drum rotation. Like the testing of Robusta coffee, the results for Arabica coffee also show an inverse relationship between the roasting time and the water content. In this testing of Arabica coffee, the lowest water content after testing occurred at drum rotations of 60rpm and 65rpm at roasting times of 20 minutes, while the highest water content occurred at a drum rotation of 70rpm at a roasting time of 10 minutes.

The testing conducted with roasting times of 10, 15, and 20 minutes for Robusta and Arabica coffee resulted in roast profiles based on the water content of the coffee. A light roast was produced with a roasting time of 10 minutes, a medium roast was obtained with a roasting time of 15 minutes, and a dark roast was produced with a roasting time of 20 minutes. Based on the testing results, the drum rotation does not have a significant impact on the roast profile of the coffee. The visual roast profiles of the tested Robusta and Arabica coffee in Figs 9 and 10.

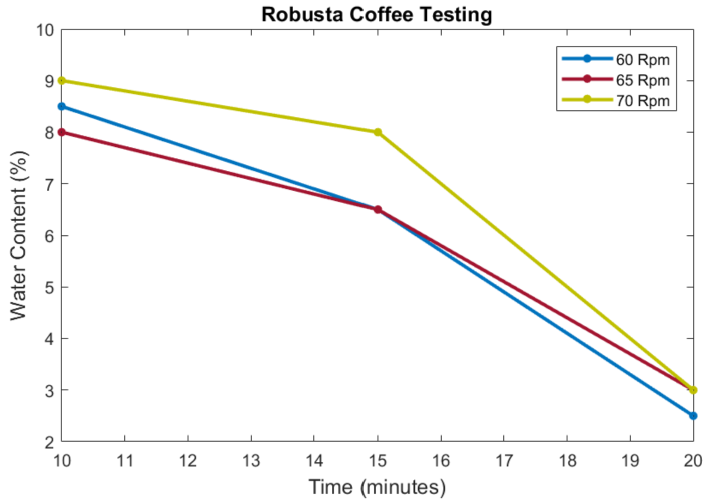

Fig 7. The curve of relationship heating time with respect to the water content of the Robusta coffee beans

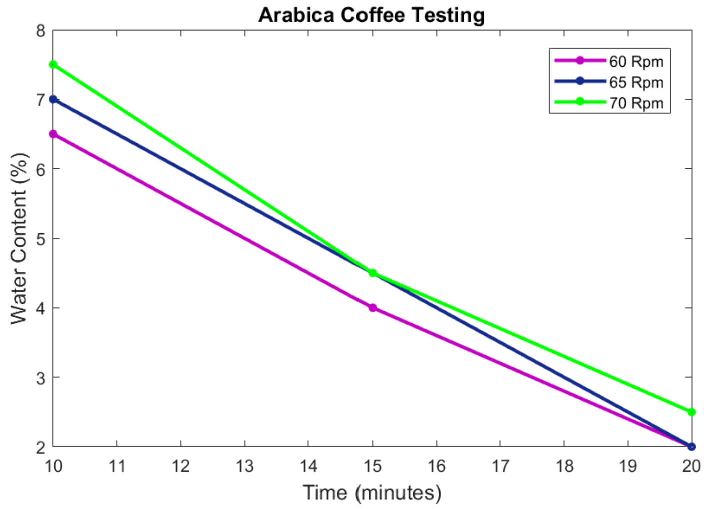

Fig 8. The curve of relationship heating time with respect to the water content of the Arabica coffee beans

4 Conclusions

The conclusion of this research is a coffee roaster with a capacity of 2 kg has been successfully made with a total length of 850 mm, a width of 300 mm, and a height of 800 mm. The main components of this roaster are a tube, stirrer, shaft, driver motor, pulley, v-belt, and heater. This roaster could be operated easily. Coffee roaster has a heat source from LPG fuel. The specifications of the stove are a fire pipe length of 370mm, a pipe diameter of 25.4mm, and a diameter of the fire pit of 3mm. The temperature can be adjusted. Based on the performance test shows that the potable roaster works well. The roaster can roast the green coffee beans until reaching the target of light, medium, and dark for both Arabica and Robusta coffee. The heating times are 10 minutes, 15 minutes, and 20 minutes for a light roast, medium roast, and dark roast, respectively.

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