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Redesign of Horizontal Coffee Roasters with Temperature, Time and Rotation Controls

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***Abstract*—Traditional coffee roasting is still done using traditional tools, usually of clay or steel pan and stirrer, as well as a stove and firewood, before roasting, the wet process is carried out for the coffee cherries. National coffee bean production which 600,000 tons per year, only 20% can be processed and marketed in secondary products, including roasted coffee, ground coffee, fast-food coffee, and several types derived from their derivatives and processing. Temperature and roasting time affect changes in the mechanical physical properties of the coffee, namely a faster decrease in water content, an increase in brittleness, and accelerate the change in dark color. The previous design has produced a horizontal roaster prototype while still use the traditional method with temperature and time controls, but to increase product creation, a rotary control function is added to adjust the stirrer speed. At a temperature of 120^0 - 160^0 C the coffee has not shown a level of maturity where the aroma has not been smelled and the weight loss has not been so good. The ripeness of the roast occurs when the temperature is 180^0 - 220^0C for 15 – 30 minutes with a rotation of 100 - 150 RPM where the coffee aroma has been smelled strong and there is a significant reduction in weight in 50%. The reverse occurs when the temperature is set to 240^0 C even though the time and rotation are varied, resulting in coffee that is burnt and not fully ripe, indicated by a weight loss of only 33%. This shows that temperature, time and rotation greatly affect the quality of roasting results.**

***Keywords*—roaster, coffee, rotation, time**

I. Introduction

National coffee bean production which 600,000 tons per year, only 20% of which can be processed and marketed in the form of secondary products, including roasted coffee, ground coffee, fast-food coffee, and several types of secondary coffee derivatives and processing [1,2]. For some agricultural products, roasting is needed to produce a distinctive aroma and facilitate the grinding process. Most of the smallholder plantations sell dry coffee beans at a relative price [1]. However, there are also smallholder plantations that sell coffee beans that have been roasted manually at a higher price. This manual roasting is very inefficient in terms of power.

Roasting a very important role in the result of coffee (brewed coffee). That factor to be considered when roasting include the roasting machine system, roasting tube plate material, the stability of the fire. In addition to that factor of the roasting tool, other important aspects are temperature, time, skill, and roasting technique with a tool designed to have a length of 50 cm, a width of 45 cm and a height of 110 cm [1,3,4]. Coffee is roasted using a Teflon pan with a diameter of 25 cm and a Teflon skillet with a lid with a diameter of 16 cm which treatments studied in temperature about 180 to 215^0C with a roasting time of 12 minutes [5]. The results showed that the roasting process using conduction heat with a roaster with a lid causes the heat to spread evenly so that the roasting process runs faster. Temperature treatment and roasting time have an effect on changes in the mechanical physical properties of the coffee, namely a faster decrease in water content, an increase in brittleness and an accelerated change in the color of darkness [2]. That three studies stated the quality of coffee bean roast was determined in terms of roasting, method as well as temperature and time, but the tools used still had large dimensions and a relatively high price where the roasting pan used Teflon.

This automatic roaster and grinder uses a microcontroller its electric controller [6]. A microcontroller roaster based on gas fuel is made with only 3 settings for the coffee profile results, namely light, medium and dark with a light time of 12.8 minutes, medium 17 minutes and dark 25 minutes with a temperature setting of 245 degrees Celsius [7] . This research has applied an automatic system based on a microcontroller so that the desired profile quality can be determined.

Roasting plays an important role in the final result of coffee (brewed coffee). There are several factors that need to be considered when roasting, including the roasting machine system, roasting tube material, the stability of the fire source of the roasting tube, and the type of coffee raw material and its characteristics. Apart from the roasting equipment factor, other aspects that are also important are temperature, time, expertise, and roasting techniques [1].

Coffee roasting is a very important unitary operation to develop specific organoleptic properties (taste, aroma and color) that underlie the quality of coffee and guarantee a good cup of coffee. However, this process is very complex, as the amount of heat transferred to the seeds is very important. During coffee roasting, moisture loss and chemical reactions (oxidation, reduction, hydrolysis, polymerization, decarboxylation and many other chemical changes), as well as major changes (color, volume (swell), mass, shape, pop bean, pH, density and volatile components) occurs, and the resulting CO2 [8].

The roaster tool in previous research has functioned as needed by getting roasting results in a maximum of 30 minutes and an international standard coffee profile [9]. Seeing the prototype of the tool that has been made, there are still weakness in the lid construction. Constructions made with a vertical model experience problems when opening or closing. This construction does not provide free space in pouring or taking coffee. This construction also has an impact on the preheating time lag of the pan, that it make an affects the roast time and quality. The shape that resembles a tube is also not optimal because the coffee is not stirred evenly. So in this study, the lid will be redesigned and change the shape of the pot into a semicircle in order to reduce the time lag that occurs and the turbulence of stirring the coffee beans. This tool will add a stirrer rotation control to be able to stir evenly and get the quality profile of coffee.

II. Research Methods

A. Design

Redesign is done on the lid and roasting pan so that the roaster process will be more optimal (See Figure 1).

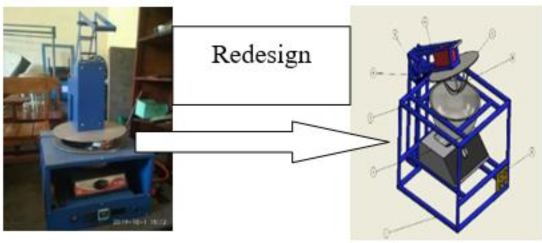

Fig. 1. Redesign roaster tool.

Tests are carried out to see the effect of temperature, time and rotation on roasted results. The fixed variable is the weight of copies per process, while the independent variables are temperature, time and rotation.

Design of the tool was made with small dimensions (50 cm high, 40 cm wide and 40 cm long and a 30 cm diameter pan to accommodate 1 kg of coffee). Wok uses steel with temperature control to adjust the flame so the temperature in the pan can be controlled. Time control to be able to adjust the duration of the roast process. Speed control to adjust stirrer rotation.

B. Research Instrument

This study was experimental study with literature approach conducting and making observations about this horizontal type mechanical coffee roaster. Then do the design of the shape and manufacture / assembly of the components of the roaster. Makes a horizontal type mechanical coffee roaster. After that, the tools were tested and observed the parameters.

In this study, a horizontal coffee roaster prototype was redesigned with temperature, time and rotation control. Tests were carried out to see the effect of temperature, time and rotation on roast results. The fixed variable is the number of copies per process, while the independent variables are temperature, time and rotation.

Manufacturing and testing of coffee roaster was done at the Mechanical Workshop of the Mechanical Engineering Department Politeknik Negeri Bali in Indonesia. Coffee samples were taken from Pupuan Tabanan regency. Retrieval of data was done by looking at the roast result profile based on variable temperature 120^0 C - 240^0 C, the time setting is 15 - 30 minutes and the rotation is 100 - 150 RPM.

C. The Construction Coffee Roaster

The steps taken to construct the coffee roaster are as follows:

1) Making a design drawing: Design drawings are made to simplify the process of cutting and assembling research tools.

2) Material cutting: Cutting materials using a cutting machine in a mechanical workshop. Cutting is done to get the basic shape of the research tool. In addition, the drilling process is also carried out according to the drawing.

3) Form making: Making shapes is done using tools in a mechanical workshop. The shapes are made like rolling to get a cylindrical pattern.

4) Connection: The connection is done using a special Shield Metal Arc Welding (SMAW) welding process for materials made of stainless steel. For other materials, the connection is carried out using glue and bolt joints in order to make it easier to do the unloading and maintenance of the tool.

5) Assembly: The assembly process is carried out on all components of the research tool that have been completed.

6) Testing: The trial stage is carried out to find out that the planned system is running according to expectations and to recheck the possibility of leakage or damage due to wrong processing.

7) Finishing: The finishing stage will be carried out after the research tool does not experience problems during the trial.

III. Results and Discussion

A. Result of Data

The test is carried out several times according to the method. The type of coffee used is Robusta from the Pupuan Tabanan regency. In the test with a temperature of 120^0 - 160^0

C for 15-30 minutes and a variation of RPM in 100-150, the results obtained by the coffee were almost fully cooked, the smell became strong for ripe coffee and the water content decreased by 33%. This proves that the coffee is not perfectly ripe. The rotation remains at a low temperature so that the coffee is not maximally hot (See Figure 2).

Fig. 2. Visual coffee at 120^0 – 160^0 C, 15 – 30 minute and RPM 100 – 150.

In the test with a temperature of 180^0 - 220^0 C for 15-30 minutes and a variation of RPM 100 - 150, the results obtained were perfectly mature coffee, strong smell of ripe coffee and 50% decreased water content. This proves that the coffee is perfectly ripe (See Figure 3).

When the rotation is low, the temperature must be low in a fixed time. When the rotation is high, the temperature must be high too for a fixed time. Temperature affects to the roasting room therefore that it affects the contact process between the coffee and the plate.

Fig. 3. Visual coffee at 180^0 – 220^0 C, 15 – 30 minute and RPM 100 – 150.

In testing with a temperature of 240^0 C for 15 - 30 minutes and a variation of RPM 100 - 150, the results obtained by the coffee became dark black, the smell of burnt coffee was strong and the water content decreased by 33%. This proves that the coffee is not ripe, only burnt on the outer skin and still raw on the inside. The rotation that remains at a high temperature makes the coffee heat up too quickly (See Figure 4).

Fig. 4. Visual coffee at 240^0 C, 15 – 30 minute and RPM 100 – 15.

B. Discussion

The parameters that was identified in this study were temperature, machine rotation, and duration of roasting time. This study was evaluate the influence of those parameters towards the coffee quality descriptively. According to the data, all of the parameters affect the product of the coffee quality. This test proves that RPM affects the maturity of coffee.

The combination of rotation, temperature and time in the roasting process is highly influential factors. When a system has a temperature gradient, or when two systems with different temperatures are touched, energy transfer will occur. The process by which energy transfer takes place is called heat transfer. Heat transfer is an important transfer process in mechanical engineering besides momentum transfer and mass transfer. Heat transfer is basically the accumulation of transfer of heat and energy from one place to another. Heat transfer often occurs in combination with other operating units such as distillation, evaporation, drying and others. Heat transfer will occur when there is a temperature difference between the 2 parts of the object. Heat will move from a high temperature to a lower temperature [10].

Heat can move in 3 ways, namely conduction, convection, and radiation. In the event of conduction, heat will move without being followed by the flow of the heat transfer medium. Heat will be transferred in a relay from one particle to another in the medium. In convection events, heat transfer occurs due to the flow of fluid. Thermodynamically, convection is expressed as enthalpy flow, not heat flow. In the event of radiation, energy travels by means of electromagnetic waves [10].

The cylindrical chamber gets heat energy through two heat transfer media. First, heat transfer by convection free of hot smoke resulting from heating reaction which is in direct contact with the entire surface of the cylinder wall. Second, radiated heat transfer from the surface of the high temperature flame to the lower surface of the cylinder wall. The heat energy from these two sources then propagates through the outer cylinder wall in a conduction manner and then heats the space in the cylinder evenly. This heat transfer mechanism causes a temperature gradient [11].

When the rotation is low, the temperature must be low in a fixed time. When the rotation is high, the temperature must be high too for a fixed time. Temperature affects to the roasting room therefore that it affects the contact process between the coffee and the plate. Rotation make it affect to the rotation speed of the coffee thus that the contact process between the coffee and the plate can be adjusted [10].

The shaft is one of the most important engine parts of any machine [12]. Almost all engines transmit power together with rotation. The main role in transmitting power is the shaft. Shafts for transmitting power are classified according to their loadings as follows. Shafts of this kind are subjected to pure torsional or twisting and bending loads. Power is transmitted to these shafts via couplings, gears, belt pulleys or chain sprocket etc. A relatively short transmission shaft, such as the main shaft of a machine tool, where the main load is torsion, is called a spindle. The conditions that this axis fulfills are that the deformation must be small and the shape and size must be precise. An axle such as that is installed between the wheels of a freight train, which does not receive a torsional load, is sometimes not allowed to rotate, is called an axle, this axle only gets bending loads, unless it is moved by the initial drive which will also experience torsional loads [4,13].

A transmission shaft can experience torsional or bending loads or a combination of twisting and bending as described above. There are also shafts that are subjected to a tensile or compressive load such as a ship's propeller or turbine shaft, and others. Fatigue, collision or the effect of stress concentration when the shaft diameter is reduced (supported shaft) or if the shaft has keyway, must be considered. a shaft must be planned so that it is strong enough to withstand the load. Even though a shaft has sufficient strength, if the bending or torsional deflection is too large it will result in inaccuracies in machine tools or vibrations and sounds (for example in turbines and gearboxes) [4,12–14].

When the speed of an engine is increased, at a certain rate of rotation, an enormous vibration can occur. This round is called a critical turn. This can happen to turbines, electric motors etc., and can result in damage to shafts and other parts. If possible, the shaft should be planned so that its working speed is lower than its critical speed [4,13].

Corrosion resistant materials (including plastics) should be selected for propeller shafts and pumps when they come into contact with corrosive fluids. Likewise for axles that are threatened with cavitation, and engine shafts that often stop for a long time. To some extent protection against corrosion can be provided. Shafts for machining are typically made of cold-worked steel and carbon steel. And if needed to be able to withstand shock loads, hardness and high stress, carbon steel is used [4,13].

Combination of the three variables is done to get a variety of coffee roasting profiles [1,13]. The maturity level of coffee can be seen from the visual color and the stronger aroma of the coffee. Maturity level can also be measured by the reduced moisture content of coffee before and after processing [11]. The water content indicates the overall maturity of the coffee to the inside of the bean [9].

The roasting process uses conduction heat with a tool roaster with a lid causes the heat to spread evenly so the roasting process runs faster. Temperature treatment and roasting time have an effect on changes in the mechanical physical properties of the coffee, namely a faster decrease in water content, an increase in brittleness and accelerate the change in dark color [15]. Temperature treatment and roasting time significantly affected the yield of roasted Arabica coffee beans and the acidity of the coffee brew, but roasting temperature treatment had no effect on moisture content and color value (Lightness). The interaction of temperature treatment and roasting time significantly affected the level of yield, moisture content, color value, acidity and acceptant of the aroma, taste and color of steeping roasted coffee [2].

Maturity level can also be measured by the reduced moisture content of coffee before and after processing. This study found that different temperature and roasted duration affect the water content of the roasted coffee (33-55%). The water content in food ingredients will affect the resistance of foodstuffs to microbial attack, which can be used by microorganisms for their growth. The greater the value of water activity, the smaller the durability of foodstuffs, and vice versa, the smaller the value of water activity, the longer the shelf life of these foodstuffs and this water activity is closely related with moisture content in the material [16].

With reduced water content in the material, its physical and thermal properties also change, so that the temperature increase will be slower. Thermal conductivity is a constant whose value depends on the type of material. In most materials, the thermal conductivity increases with increasing temperature, but the variation is very small and negligible. If the value of the object's conductivity is large, it is easy for heat energy to pass and vice versa, if the conductivity is small, then the object is difficult for heat energy to pass [17].

This study found that the coffee roaster that was made, could produce coffee product with the different quality. The quality that evaluate in this study only for the aroma, color and water content. The limitations of this study was the roasted coffee quality only observed descriptively. Further studies are needed regarding these parameters statistically. Furthermore future study needed towards the chemical compound of the coffee after hearing process. Some chemical compound is affected by the temperature and duration of the roasting process. The limitless of this coffee roaster was the maximum capacity, which is limited only 2 kg.

IV. Conclusion

The test results by redesigning the roaster show that the temperature, time and rotation of the stirrer can make an affect the quality of roasting results.

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