

The Development of Coffee Bean Drying Process Technology – A Review

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ABSTRACT

Coffee is an important export commodity for Indonesia. Coffee drying is post-harvest processing that greatly determines the coffee quality and microbiological safety. Conventional/sun drying is time-consuming, depending on the weather, and can potentially contaminate coffee beans by dust and moisture readsorption under high relative humidity. These problems could be avoided by employing artificial drying. This literature review aims to identify the current status of coffee drying technology, its advantages and limitations, to obtain coffee beans with the desired quality, duration of drying time, and energy consumption for processing. From the three types of thermal radiation dryers being reviewed, namely tray dryer, rotary dryer, and fluidized bed dryer, it was concluded that the drying air temperature and relative humidity must be selected properly to obtain the microbiological safety and the quality of the coffee brew. Efficient energy consumption requires a balance between the rate of water evaporation inside the coffee grain and the rate of water vapor removal from the solid surface by the air stream. The most efficient coffee drying is achieved at an air temperature of 50°C, resulting in drying time and energy consumption of 65%, and 50% lower than that of 40°C, with a good quality of the coffee brew. Fluidized bed drying combined with zeolite adsorption is potential to reduce the drying time due to an enhancement of air capacity to absorb water vapor. Application of microwave for coffee drying resulting in much shorter drying time than conventional thermal drying, but has a drawback of un-uniform grain temperature. A hybrid drying system could be implemented by using microwave and thermal oven.

Keywords: Drying techniques, Fluidized bed, Microwave, Rotary, Tray dryer.

1. INTRODUCTION

In 2020, Indonesia is the fourth largest coffee producer in the world, with the production of 726,000 tons and export of 404,000 tons, but the value of coffee exports is ranked 9th in the world, decreasing by USD 821,937, from 2019[1]. Brazil still dominates the global coffee trade with a world market share of around 14.3%, with a value of 4.3 billion USD. In fact, some countries that are not coffee producers are able to outperform Indonesian exports, such as Germany, Switzerland, Italy, France, etc. This is because these countries are powerful to control the coffee roasting and other processing industries.

The efficiency of Indonesian coffee production is much lower than that of other countries since 90% of coffee production is dominated by small farmers who applied the dry processing[2]. Most of the Indonesian coffee production is from the Robusta variety. Meanwhile, coffee consumption in developed countries is mostly Arabica coffee, which is considered to have higher quality. Teuber [3] highlights that coffee

consumer from developed countries are very concerned at food safety, quality, and origin of coffee producers. Several types of Indonesian Robusta coffee are considered specialty coffee, while the quality of Indonesian Arabica coffee is also recognized as being able to compete with Brazilian Arabica coffee. These are advantages that coffee bean from other countries does not have, so it needs to be maintained along with optimum coffee post-harvesting and management [4]. One of the shortcomings of Indonesia's coffee export quality is the Ochratoxin A. (OTA) contamination.

OTA is a mycotoxin produced by fungi belonging to the genera *Aspergillus* and *Penicillium*. Several studies have reported the presence of OTA in foods and beverages including coffee [5]. Indonesia Robusta coffee was contaminated by 0.2-1.0 µg/kg of OTA, which is very good and ranked 10th compared to coffee from other countries [6]. Research by Rosavani et al. [7] shown 9 of 10 samples of green coffee beans from Jember, East Java, Indonesia was detected OTA with the highest concentration was 0.4319ppm, and the lowest concentration was 0.0146ppm. OTA growth is

mainly resulted from poor post-harvest handling of coffee beans, including poor drying method.

Lilia et al. [8] found that sun-dried coffee bean from South Ogan Komering Ulu Regency, South Sumatra, Indonesia, was contaminated with OTA due to high moisture content (13.97%). The solution to the coffee post-harvesting problem is determining optimal drying operation conditions that minimize energy consumption and maintain the bean's quality.

The purpose of this literature review is to identify the current status of coffee drying technology, its advantages and limitations, to obtain coffee beans with the desired quality (safety and sensory characteristics), and energy consumption for processing.

2. METHODS

This study is based on literature primarily found in the databases Google Scholar and Scopus. The selected articles are published within 20 years, from 2001-2021, to give a current view of the research on mechanical coffee drying. Search terms associated with coffee post-harvest ("coffee drying", "mechanical coffee drying", "coffee drying and characteristics") were combined with the search terms of "nutritional value" and "applications of drying method". Data on legislation refer to the Food Agriculture Organization (FAO) and the Indonesian Ministry of Agriculture. The selection of the papers to be included in the review was performed after a careful study of their content, which resulted in the identification of 30 eligible research articles and websites.

3. RESULTS AND DISCUSSION

3.1. Coffee Post-Harvesting

Based on the Regulation of Indonesian Minister of Agriculture No 52/Permentan/OT.140/9/2012, coffee post-harvesting is a series of activities consisting of fruit sorting, peeling, fermentation, washing, drying, beans sorting, packaging, storage, and quality standardization [9]. The coffee/green bean drying process aims to meet the quality of coffee beans, namely the maximum water content of 12.5% (w.b.) according to SNI No. 01-2907-2008 concerning General Requirements for Coffee Bean Quality. The most critical post-harvesting activity of coffee beans is the drying process. The coffee cherries are dried immediately after harvest, under sun light on a clean dry cemented floor or on mats. The bed depth of less than 40mm, need to be turned over frequently to avoid fermentation or discoloration. However, there are problems associated with this method of drying, namely dirt blown onto the product, weather fluctuation that can spoil the bean very quickly. The problems in natural drying that are very time consuming, labour intensive, the presence of impurities from surrounding dust, water content and homogeneity are hard to be controlled.

Coffee bean processed by the wet method is considered to have less body, higher acidity, and more aromatic than coffee produced by the dry method, resulting in a higher consumer acceptance. And finally, it obtain higher price when traded [10].

3.2 Principles of Drying: Heat and Mass Transfer

Dried foods are generally containing less than 25% of moisture. The drying process involves the application of heat to vaporize water inside the grain and water vapor removal after its separation from food tissues. Therefore, it is a simultaneous heat and mass transfer operation that requires a supply of energy. Airflow is the common medium for transferring heat to drying tissue and removing water vapor. The two phenomena of mass transfer during grain drying are:

- Transfer of water from internal tissue to the surface of dried material.
- The removal of water vapor from the surface to environment.

One of the most important factors to prevent the growth of fungi in dried food during storage is the relative humidity of the air in the storage area.

In order to obtain effective drying, air should have sufficiently high temperature, low relative humidity, and flowing. These factors are interrelated that need to be maintained properly. The following are the factors that affect the drying process of grain:

- a) Temperature: The greater the temperature differences between the heating medium and the food tissue, the greater the rate of heat transfer into the food which provides the driving force for moisture evaporation.
- b) Surface area: the greater the contact surface area between the grain and the drying air, the greater the water vapor removal from the solid surface.
- c) Air relative humidity: The lower the relative humidity of the drying air, the greater the capacity of the air to absorb moisture from the solid surface. The higher temperature of the air will reduce the relative humidity and allow the air to carry more water vapor. The relationship between temperature and relative humidity is presented on a *psychrometric* chart[11].

Drying at a lower temperature and high relative humidity will give a slow drying rate and provide microbial growth. On the contrary, if the air temperature is too high at the beginning of the process, a hard shell will be developed on the surface of the food that traps the moisture inside the food material, known as case hardening. Too high a temperature at the end of drying results in scorch and brittle solid.

Air temperature for drying of fruits and vegetables is recommended between 49°C to 60°C. Temperature up to 65°C may be used at the initial stage of drying but should be decreased as food begins to dry. During the

termination of the drying period, the temperature should be less than 55°C [12].

3.3 Existing Coffee Bean Drying Technology

Currently, various research on coffee bean drying has been carried out by utilizing various drying processes, such as tray dryer, rotary dryer, fluidized dryer, and microwaves dryer with various process modifications and supporting materials [13].

3.3.1. Coffee Drying by Using Tray Dryer

Drying of the parchment coffee was carried out in a laboratory tray dryer under controlled air temperature and relative humidity. One hundred grams of parchment coffee was placed on a tray as a thin layer inside the dryer. The drying was conducted at a constant air velocity of 1 m/s, air temperature and relative humidity of 50–70°C and 10%–30%, respectively. The coffee parchment with initial moisture of 122% d.b was dried to achieve final moisture content in a range of 12.5% d.b. to 4.5% d.b. The shortest drying time of 8h was achieved at the highest temperature of 70°C and the lowest relative humidity of 10%, due to increasing the kinetic energy of the water molecule to break the cohesive force. The Higher drying temperature is sufficient to evaporate more water in products than the lower temperature. The temperature of saturated water within the coffee bean was affected by the water vapor pressure of the drying air, which results in faster evaporation of water inside the produce [14]. Vibrated bed dryer is one of the coffee drying methods to obtain uniform drying distribution. Therefore, the dispersion coefficient of coffee should be investigated[15]. Coffee cherries drying through vibrating tray dryer was conducted to promote the improvement in flavor and aroma of coffee beverages through controlled operating conditions with associated vibration. The work was aimed to compare drying performance at two different temperatures, namely 45°C and 60°C to obtain the mass transfer coefficients. Two pieces of the perforated tray are arranged inside the steel structures and connected to the electromagnetic vibrator. The ripe coffee cherry of Arabica variety with initial moisture of 68.75% w.b. was put in two trays, with bed porosity (ϵ) of 0.38, then introduced into the dryer in the upper and lower positions, respectively. Their positions were reversed every 30min with the complete cycle of 2 hours. The drying air was injected by blower from the bottom of column. The result obtained that drying with air temperature of 45°C to a moisture content of 13-13.5% w.b. in non-vibrated system is achieved within 27 hours, while drying with vibration takes less time, which is 24 hours. Vibration-assisted coffee drying reduces the drying time by three hours (11.1 %) compared with the non-vibrated system. Vibration increases the diffusional transportation of moisture inside the coffee cherries enhances drying. Vibration also increases the bed porosity, thereby improving the contact between the

coffee beans and the drying air, increasing the drying rate. But for the drying temperature of 60°C obtained a total drying time of 6.5 hours, which means operation at a higher air temperature depleted the influence of vibration on the drying time. The final average moisture contents for vibrated and non-vibrated drying were 11.6% and 12.3% respectively. For both the operation at an air temperature of 45°C and 60°C, the mass transfer coefficients were greater in the vibrated system than that of the non-vibrated system, namely 0.001 - 0.003 kg H₂O/m²s and 0.001 kg H₂O/m²s respectively. The experimental results show that the temperature difference gives a significant difference in drying time which are 24 hours and 6.5 hours for temperatures of 60°C and 45°C respectively[15]. This means that drying at 60°C takes 65% less drying time than that of 45°C.

At a high drying temperature, the effect of vibration on water molecule mobility inside the coffee cherries is inferior compared with the driving force generated by temperature which accelerates the water evaporation rate.

The effect of air flow rate on single-layer drying is also being concerned with air velocity ranging between 0.5 -1.8 ms⁻¹[16]. The drying temperature was selected in the range of the recommended level between 45°C to 55°C. The air velocity was selected according to the range commonly used for thin layer drying process. The result showed that increasing air velocity from 0.5 ms⁻¹ to 1.8 ms⁻¹ failed to improve the drying rate, although the paired Γ -test indicated that their moisture ratios were statistically different. The moisture content curves resulting from the three levels of air velocity across the drying time coincide with each other, especially at the drying time longer than 10 hours [17]. This phenomenon occurred because, at a temperature of 47°C, the rate of water evaporation inside the coffee beans is probably equivalent to the mass transfer rate of water vapor from the surface of the coffee beans to the drying air (at an air velocity of 0.5 m/s and actual air relative humidity). By increasing air velocity above 0.5 m/s, air capacity to catch moisture will be enhanced, higher than the water evaporation rate. Under these conditions, the drying rate will not increase but only wastes energy for the blower and air heater.

3.3.2 Coffee Drying by Using Rotary Dryer

A rotary dryer is one strategy of using low drying temperatures with high air mass flows to decrease the product moisture content without harming the grains temperatures [18]. The ‘Guardiola’ cylindrical rotary batch dryer was used in coffee processing. The dryer is equipped with a hot drying air circulation system through axial conducts and perforated steel walls allowing wet air to escape. The total drying time (τ) varied according to the beans initial moisture ($X_{\beta 0}$) and load (m_{β}), as well as the air drying flux (G_{γ}) and temperature (T_{γ}) [19]. The optimization criteria were to

determine the value of the independent variables (x) that minimized the energy consumption (Q), and maximized the thermal efficiency; fixing as restrictions: a_w of less than 11% or X_b of $0.13 \text{ kg (kg of dry matter)}^{-1}$, grains temperature lower than 45°C . Produce size was fixed at 2,675 kg of wet green coffee beans. The drying air temperature was varied between 60°C - 80°C ; the air rate was 5,000; 7,000; and 14,000 kg/h.

In each experiment, three zones of drying rate occurred, namely the initiation stage, constant drying rate, and falling rate. At the beginning of the process, there was a rapid increase in bean temperature until equilibrium was established, then a constant drying rate was started, until most of the unbound water was eliminated, which is known as a critical point. After critical moisture content is reached (moisture content $0.17 \text{ kg /kg of dry solid}$), more energy is needed to remove the remaining bound water and therefore, the drying rate decreases. At the same air flow rate, the higher the temperature results in a shorter drying time. For air flow rate of 5,000 kg/h, a temperature of 60°C , 70°C and 80°C , the drying rate is 0.02; 0.025; and 0.03 $\text{kg H}_2\text{O (kg solid. hour)}^{-1}$, and drying time of 49 h, 38 h and 31 h, respectively.

For the same gas flow rate, the temperature difference has no effect on efficiency. The greater the gas flow rate, there is a decrease in efficiency, although not too significant. Flow rate of 5,000 kg/h; 7,200 kg/h and 14,000 kg/h give an efficiency of 70-75%, 67-72% and 67% respectively.

The gas flow rate greatly affects the drying rate. At 60°C , the air flow rate of 5,000 kg/h; 7,200 kg/h; and 14,000 kg/h giving a drying rate of 0.02; 0.03; and 0.05 $\text{kg H}_2\text{O (kg solid. hour)}^{-1}$, respectively.

The response resulted from these conditions are energy consumption of 3.53 MJ/kg and efficiency of 78%. Implementing the optimized process conditions, a 15.80% reduction in energy consumption is achieved. The strategy of applying low drying temperatures with high mass flows to reduce the grains moisture content without harming the grains temperatures is thermally inefficient. The grains saturation air flow is reached at 6,560 kg/h, which means that higher mass flows failed to enhance the drying velocity but increase energy consumption [19].

Parchment coffee drying using a rotary dryer completed with a diffusion system was conducted to reduce the moisture content from 40% w.b. to 10.56 %. The operating condition is drying temperature of 40°C and 60°C , air flow rate, air velocity, and grain temperature are controlled by $80 \text{ m}^3\text{min}^{-1}$, 28 m s^{-1} and 45°C respectively. At the beginning of drying, the coffee temperatures are constantly lower than the hot air due to the evaporation of the moisture content. In the longer drying time, the drying rate increased, and energy consumption reduced by two-third of conventional drying. The average drying time of coffee

parchment at 60°C and 40°C were 1.5 h, and 2.1 h respectively. When the drying is reaching a more advanced stage, the air and grain temperatures coincide with each other, inhibiting moisture migration from the internal parts to the outside of the grain. The mass transfer process will stop when the water vapor pressure at the product surface becomes equal to the water vapor pressure of the drying air, thus entering hygroscopic equilibrium. Therefore, the proper selection of drying air temperature is essential for drying parchment coffee [20]. Enhancement of drying rate in such conditions can be achieved by reducing air relative humidity. Sensory analysis performed by the Q - grader group, the city of Alfenas-MG, Brazil obtained: coffee drying at 40°C and 60°C gains scores of 84.33, and 74.67 respectively (maximum score is 100).

Due to the limited data of energy requirement on a mechanical coffee dryer, a study was conducted to find information on the energy requirement of the commercially employed mechanical coffee dryer and gain further insights on the cup quality of Robusta coffee. Drying of coffee parchment using rotary dryer resulted in drying time of 16 and 8 hours at 40°C , and 50°C - 60°C , respectively, over 48 hours by sun-drying. Energy consumption was 261 MJ/ton and 134-135 MJ/ton at air temperature of 40°C and (50 - 60°C) respectively. Cup test scores: 79.5 (SD), 78.5 (40°C); 62 (50°C); 50.3 (60°C); maximum score is 100[21]. This means that coffee drying at an air temperature of 50°C can save 50% of energy than that of 40°C , resulting in acceptable coffee characteristics.

3.3.3 Coffee Drying by Using Fluidized Bed Dryer

The drying of parchment was conducted by [22] using a fluidized bed dryer with static bed height and porosity of 15cm and 0.39 respectively, and air flow rate of $1.1 \text{ m}^3\text{min}^{-1}$ ($60 \text{ m}^3\text{min}^{-1}.\text{m}^{-2}$). Drying of parchment was conducted to reduce the moisture content from 52-55% to 10 - 12% w.b. Drying air of temperature and relative humidity 46°C and 21% gives a total 8 hours drying time, with uniform moisture content. Meanwhile, drying with air temperature and relative humidity of 49°C and 19% determine a total drying time of 7 hours. In a fluidized bed drying process, the grains are always in motion, allowing the removal of moisture to be uniform for the entire bed. Since heat and mass transfer in fluidization is quite good, the obtained moisture content gradient is low (0.7% on average). Testing of the coffee organoleptic characteristics was carried out with typical parameters such as aroma, taste, and a score of 3 for the two dryings conditions. This fact indicates that the drying process carried out at temperatures up to 49°C did not change the coffee characteristics. Therefore, it is much more favorable for the process to dry coffee in a fluidized bed with an air temperature of 49°C and relative humidity of 19%. The rating scale is 1

to 5, where 5 is very good sensory characteristics. In general, it is considered that scores above or equal to 3 are acceptable. These results are very important to establish whether the drying process used alters the organoleptic characteristics of the coffee.

Inadequate control of the drying temperature causes the coffee beans to dry out, shrink and even break, causing a loss of 2.4%. A vibro-fluidized bed dryer [23] was used to optimize the coffee bean drying process by modifying the drying parameters. Modelling of the drying process using VFBD was conducted through mass and energy balances, drying kinetics, and hydrodynamics. The equipment is divided into 4 zones, each of which uses an air temperature of 225°C, 185°C, 75°C, and 25 °C. The airflow rate is adjusted to suit the vibration speed. Fed coffee beans have a moisture content of 40% on a dry basis, to be reduced to 12%. The theoretical velocity of minimum fluidization was 11 m/s, while the velocity of vibro-fluidization was 7 m/s due to vibration allowing air passage through the grains more effectively.

The minimum fluidization speed (V_{mf}) was higher according to the minimum vibro-fluidization velocity, this being the effect of the hydrodynamics of the coffee beans inside the dryer. With the modification of process conditions (air temperature and vibration), drying of coffee beans from a moisture content of 40% d.b. to 11.4% can be achieved in a shorter time, namely from 1.3 hours to 0.9 hours, with the appearance of a very clear green grain. Thus, damage such as cracked and overdried beans can be reduced, decreasing weight loss from 2.4% to 1.1%.

Djaeni [24] studied corn drying using a fluidized bed dryer with an air velocity of 9 m/s (twice higher than the minimum velocity). By adding zeolite adsorbent in the fluidization system, corn drying from a moisture content of 26% to 14% obtained a shorter drying time than drying without adsorbent. The drying time was reduced by 47% with corn/adsorbent ratio of 1/2 (from 150 minutes to 70 minutes). This happened because the zeolite played a role in assisting the absorption of water

and generate heat. Then, moisture migrates to the surface where it evaporates to the surrounding air. The disadvantage of microwave fixed-bed drying techniques is that the drying results obtained are not homogeneous [11]. A comparative analysis of the drying of coffee beans was conducted in a continuous flow dryer using an electromagnetic cavity [27][16][28] and a conventional electric oven. The microwave-based drying at 2450 MHz-1080 W allows 17 times faster processing, namely 17h drying time to reach a moisture value below 12% (d.b.) by means of the conventional oven (grains with parchment), meanwhile with microwaves only requires 60 minutes [27]. The temperature of the samples from the electric oven drying stay close to 50°C (which was the temperature set for the oven), but the samples temperature by means of microwave oven vary from 30°C to 100°C, or even reach 120°C. This fact is the disadvantage of microwave oven.

For practical research, equilibrium moisture is being a concern for both continuous and intermittent processes. The intermittent process could reduce energy consumption but extend the drying time. Hence, hybrid drying is one of the strategies to reach optimum coffee bean drying. Target coffee bean drying to the moisture content of 12% (d.b.) is easier to be achieved using a hybrid. The hybrid system could be implemented using microwave in a few seconds and then continued with oven drying. The various hybrid drying and resulted from enhanced efficiency are summarized [29][30][27] [31] in Table 1.

The airflow is required to absorb the moisture and is not to provide latent heat for water evaporation. This reduction in airflow would minimize the dust and other pollutants discharged into the atmosphere.

Table 1. Various Hybrid Drying

Number	Combined Drying Techniques	Temperature	Enhanced Efficiency
1.	Solar Drying – Biomass Burner	60 °C	15.59%
2.	Solar Drying – Tray Dray	40-60 °C	20%
3.	Microwave-Conventional Oven	50 °C	-
4.	Microwave-Fluidized Bed Dryer	50-60 °C	14%
5.	Microwave-Convective	30-50 °C	30%

vapor released from the solid surface [25][26][24].

3.3.4 Coffee Drying by Using Microwave

Microwaves can be successfully adopted for the drying of coffee beans and shorten the drying time. Microwaves penetrate through the moist food into the inner layer of the product, vibrate the water molecules,

4. CONCLUSIONS

Drying of coffee beans is carried out to reduce the water content to 12% w.b. so that facilitate product handling, reduce storage volume and transportation costs, improve appearance, prevent microbial growth, maintain nutritional value, and preserve organoleptic

(flavor and aroma as well as its characteristic). The temperature and relative humidity of the drying air must be selected properly to maintain the taste properties of the coffee brew. The efficiency of energy consumption requires the balance between the rate of water evaporation inside the coffee grain (large temperature difference between the air and the solid) and the rate of water vapor removal from the solid surface by the airflow (high air temperature, low relative humidity, and high flow rate). The most efficient coffee drying is achieved at an air temperature of 50°C, resulting in drying time and energy consumption of 65%, and 50% lower than that of 40°C, with a good quality of the coffee brew. Fluidized bed drying combined with zeolite adsorption is the potential to reduce the drying time due to an enhancement of air capacity to absorb water vapor. Application of microwave for coffee drying resulting in much shorter drying time than conventional thermal drying, but has a drawback of un-uniform grain temperature. A hybrid drying system could be implemented by using microwave and thermal oven.

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