INTERNATIONAL JOURNAL OF APPLIED TECHNOLOGY RESEARCH
2023, VOL. 4, NO. 1, pp. 29-40
https://ijatr.polban.ac.id/

Effect of Process Variables and Zeolite Adsorbent in Coffee Bean Drying

[a]Bambang Soeswanto, [a]Ninik Lintang Edi Wahyuni*, [a]Ghusrina Prihandini, [a]Yusuf Pratama, [a]Taufik Akbar Firmansyah, [a]Dewi Widyabudiningsih

[a]Department of Chemical Engineering, Politeknik Negeri Bandung, Bandung 40559, Indonesia

Received October 11, 2022; Revised January 4, 2023; Accepted January 9, 2023; Published April 1, 2023

ABSTRACT

Green coffee beans to be stored or for transportation must meet storage quality standards, especially the maximum moisture content of 12.5%, so the drying process must be carried out to achieve quality standards, but still economical. The study aims to obtain optimum operating conditions on the drying of Arabica-type coffee beans using a fluidized bed dryer assisted by zeolite adsorption in a separated fluidized bed prior to heating, as well as finding the dominant factor of drying rate by comparing the energy consumption between blowers and air heater. The operating conditions were varied, namely air flow rate of 1.789 – 2.296 m/s, air temperature of 45 o C, 50 o C, and 55 o C, zeolite adsorbent mass of 150 g, 175 g, and 200 g. The coffee beans quality tests carried out were the moisture, carbohydrates, protein content, and the visual appearance of the beans. The results show that the optimum drying process of coffee beans resulting in a moisture content of 12,5% as well as a minimum protein and carbohydrate damage are the air velocity of 2.1 m/s, air temperature of 55°C, drying time of 240 minutes, and zeolite adsorbent mass of 150 grams, with total energy consumption of 5.02 KWH. The drying rate of coffee beans is mainly influenced by air temperature (more predominantly) than the adsorption of air humidity by zeolite.

KEYWORDS

Coffee bean drying
Fluidized bed dryer
Zeolite adsorbent

INTRODUCTION

Coffee is one of the most important export commodities for Indonesia. In addition to being exported, coffee is also consumed by the Indonesian people in the form of ground coffee and instant coffee with a consumption level of 0.52 kg / capita / year in 2019 [1]. In general, there are two main varieties of coffee that are popular in the world, namely Arabica coffee and Robusta/Canephora coffee. Arabica coffee has characteristics of color, higher acidity, lower caffeine content, more fragrant and richer, not too thick brewing result. While the second variety, namely Robusta coffee, has more caffeine content and a sweet aroma with a delicate taste. Green coffee beans to be stored must meet storage quality standards, which are mainly a maximum moisture content of 12.5% [2].

*Corresponding Author: ninik.lintang@polban.ac.id

The content of several chemical compounds of Arabica coffee beans includes polysaccharides of 34.44%, sucrose of 6.0 – 9.0%; protein of 10.0 – 11.0%, Caffeine of 0.9 – 1.3%; and chlorogenic acid of 4.1 – 7.9%[3][4] The moisture content of coffee beans affects the characteristics such as physical condition, quality, texture, taste, and shelf life. At ambient relative humidity of 70-73%, the equilibrium moisture content of coffee beans is 12.5% [5]. The moisture content of more than 12.5% results in coffee beans being easily attacked by Aspergillus fungus which produce ochratoxine A (OTA) that shorten the shelf life, while a too low the moisture content (< 8%) will make the coffee taste woody [6].

The carbohydrate present in the coffee drink do not affect its flavor, but monosaccharides (glucose and fructose) and disaccharides such as sucrose (glucose monomer and fructose monomer), are associated with the infusion flavor. Consequently, the higher the sucrose content in the coffee beans, the more intense their flavor will be. Monosaccharides content in coffee will react with protein in the roasting process (at a temperature of 190°C - known as the Maillard's reaction) and produce a certain color, aroma and taste for brewed coffee [7]. Therefore, the levels of carbohydrates and protein in coffee beans during the post-harvest process must be maintained, while the drying process with high temperatures and long duration will cause damage to carbohydrates and proteins in coffee beans. Drying of coffee beans at a temperature of 50°C for 180 minutes causes a greater decrease in protein content than drying at a temperature of 60°C for 130 minutes [8]. The development of equipment used to dry coffee is of fundamental importance to obtain theoretical information about the behavior of coffee beans.

The objectives of the work were:

1. to study the effect of air drying temperature, air velocity, and zeolite mass on quality of the arabica coffee by minimum damage of protein and carbohydrate content,
2. to determine the dominant factor of drying rate by comparing of energy consumption of blower and heater for drying process.

LITERATURE REVIEW

Drying of coffee grain can be carried out using two methods, namely the traditional method by drying the coffee grain in the sun, and mechanical drying using a dryer such as the Fluidized Bed Dryer. The process of drying coffee grains in the sun takes 5-7 days to reduce the water content from 45-50% to 18-20%. In the rainy season, the time required is longer, i.e. 1-2 weeks and produces coffee grain with poor quality with indications of unpleasant aroma and the growth of fungi.

In mechanical drying method, the coffee bean is being pre-dried in the sun for 1-2 days, then further drying is carried out to obtain a moisture content of 11-12.5% [9] . The mechanical drying process is carried out in batches or continuously and involves heating air to evaporate the moisture content, by exposing grain to ambient air with low relative humidity or to heated air. This will evaporate the moisture from the grain and then the drying air will remove the moisture from the grain bulk. The mass transfer of water that occurs during drying includes the transfer of water from the inner tissue of the coffee grain to the surface and mass transfer of water vapor to the drying air stream. The mass transfer of water or the evaporation process will stop when the equilibrium moisture content of the solid material is reached, which is influenced by the relative humidity of the air.

The drying rate zones that occurs during the drying process is divided into two, namely constant rate and falling rate drying. Critical moisture content occurs when the surface water content of the material (free water) starts to run out, and the drying process is carried out to evaporate the bound water content, the drying rate after critical moisture content will tend to decrease. The rate of coffee grain drying is strongly influenced by grain temperature, water content in grain, drying air temperature, air velocity and relative humidity, as well as the surface area of the coffee grain.

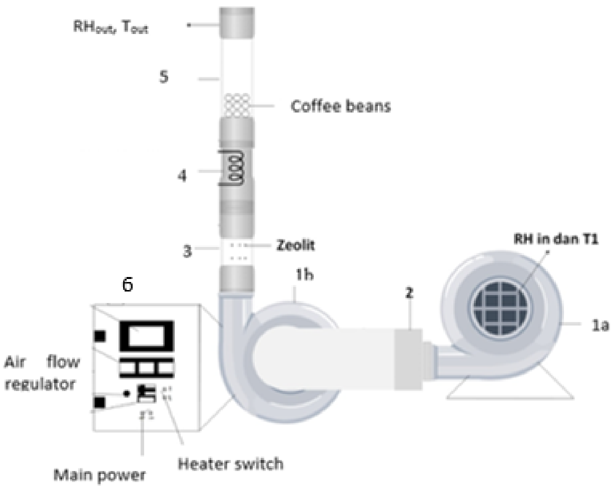
The drying air flow rate determines the length of contact time between the material and the drying air, the heat transfer coefficient, and the velocity of the water vapor leaving the grain bulk. Water vapor on the surface of the grain will quickly be removed at high airflows, thereby preventing the water vapor from becoming saturated on the surface of the grain. Drying of coffee beans from the initial moisture content of 42% to 12% using a forced convection system at a velocity of 4.03 m/s takes about 3 hours [10].

The greater the temperature difference between the heating medium and the coffee bean tissue, the greater the heat transfer rate into the solid material for evaporation of water. Thus, the higher the heating air temperature, the shorter the drying time. The optimum conditions for coffee beans drying using a fluidized bed dryer - based on energy consumption and drying time - were obtained at a temperature of 50°C [8]. An increased airflow (0.4–2 m/s) for pulped coffee provided reductions of 5% (10.65 and 10.15 hours) for temperatures of 40 and 45 °C, respectively [11]. Meanwhile, Sandeep et.al. (2020) [12] found that coffee grain drying at a temperature of 50°C and 60°C require almost the same energy, namely 134-135 MJ/T. Coffee drying should be carried out in a temperature range of 50-55°C. The higher drying rates caused by air temperatures of 60°C deteriorate coffee quality due to damage to cell membranes [13].

Relative humidity indicates the ability of the air to catch water vapor from the surface of the material. The lower the value of the drying air relative humidity, the greater the capacity of the air to absorb moisture from the surface of the grain. Drying of coffee beans in a fluidized bed dryer with zeolite as an adsorbent will increase the capacity of the air to absorb water vapor, thereby reducing drying time [14]. At an air velocity of 3.6 m/s, zeolite has an absorption capacity of 0.130 grams of water vapor/gram of adsorbent [15]. The use of natural zeolite with a ratio of 2:3 to corn kernels in fluidized bed dryer was able to shorten the drying time to 64.8 minutes compared to drying without zeolite which took 86 minutes to reach a moisture content of 13.5% [16]. Drying of coffee beans using a fluidized bed dryer equipped with a baffle-shaped fix-bed of zeolite in the air inlet, at a temperature of 50°C is able to reduce the drying time from 180 minutes to 153 minutes [8].

RESEARCH METHOD

The current research was carried out in the Fluidized Bed Dryer unit which is presented in Figure 1 with specifications: glass columns with diameter of 8.7 cm, fluidization column height of 22.8 cm, zeolite column height of 13.5 cm, two electric blowers of 660 watts and an electric heater of 1,000 watts. This equipment is completed with measuring instruments for operating conditions such as; air temperature, air relative humidity, drying air velocity, voltage and electric current indicator for blowers and heater.



Description:
1a & 1b = Electric blowers
2 = Connection between blowers
3 = zeolite column
4 = electric heater
5 = coffee bean fluidization column
6 = Control Panel, indicating drying air temperature, air relative humidity, electric current of heater and blowers

Figure 1. Fluidized Bed Dryer

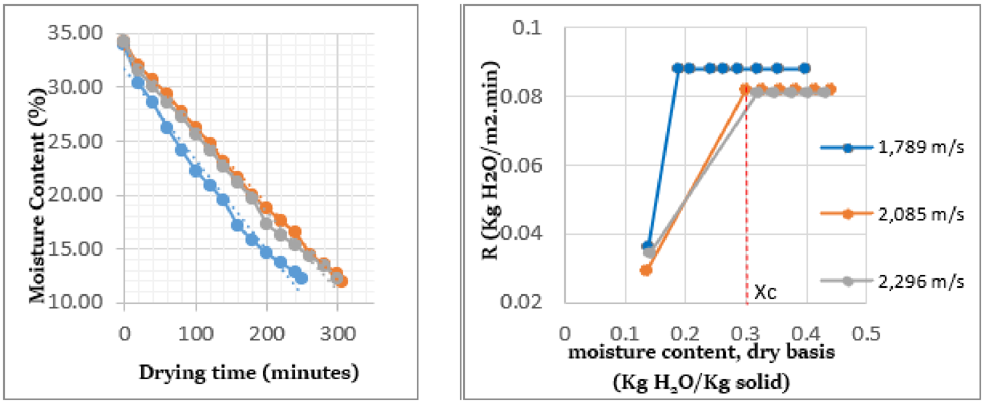
The material used in this study was Arabica coffee beans harvested during the 2022 crop year in the eastern part of Bandung, Indonesia (6.93 °S, 107.72° E, 706 m altitude). Each batch consists of 100 grams of coffee bean with an initial moisture content of 34% after pre-drying. The natural zeolite used has a size range of 8-16 mesh as much as 150-200 grams. Drying air velocity is 1.789 – 2.296 m/s (which is measured using a digital anemometer), with a temperature between 45 – 55°C. Drying air is flowed by two blowers into the first column containing natural zeolite bed for the adsorption process, in order to reduce the air relative humidity, then the air is heated using an electric heater, and afterword the hot air is introduced into the fluidization column for drying of coffee beans. The temperature and relative humidity of the drying air were measured using a portable digital thermo-hygrometer, the sensor of which was inserted inside the plenum. The drying process is terminated when the bean moisture content reach 12,5% (w.b.).

The water content of coffee beans is measured by means of gravimetric method. The energy consumed for the drying process is calculated based on the measurement of the electric current and voltage used for the blower and heater. Determination of protein content is carried out by the Kjeldahl's method, while the carbohydrate content is determined by the Luff-Schoort's method.

CONCLUSION

Effect of Drying Air Velocity

The drying process with drying air temperature of 50°C, air velocity of 1,789 m/s - 2,296 m/s, and the addition of 150 grams of zeolite as an adsorbent are presented in Figure 2. Figure 2.a shows that the air velocities of 2.296 m/s and 2.085 m/s result in a relatively the same drying time, which is 300 minutes. Meanwhile, at a velocity of 1.789 m/s the drying time is reduced by 50 minutes. This phenomenon occurred due to overheating of air at low velocity which resulting in an increased air temperature to 51.5-54.3°C (desired operating condition is 50°C).



(a) (b)

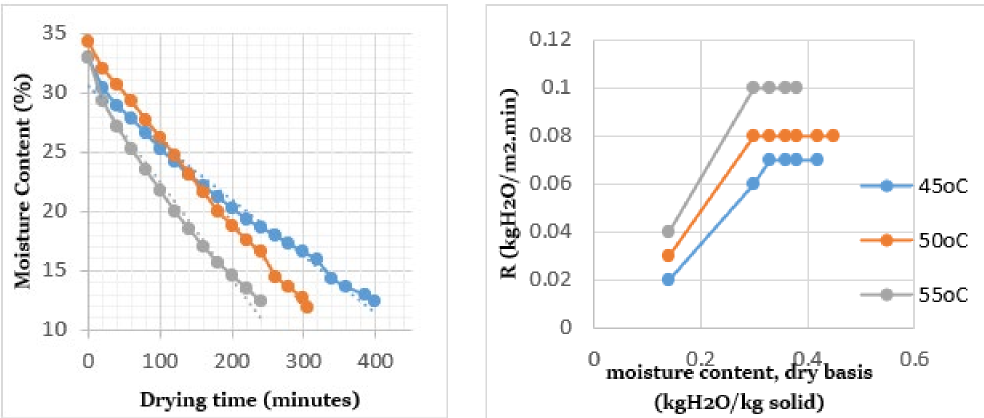
Figure 2.a. The Effect of Air Velocity on Drying Time; 2.b. Drying Rate at Varied air velocity

Processing of drying data at various air velocities obtains the drying rate curve shown in Figure 2.b. This figure shows the two drying zones, namely constant rate drying zone and falling rate drying zone. At the beginning of the process when the moisture content is high, a constant drying rate was occurred, until most of the unbound water was eliminated, which is known as a critical point (X_c). After critical moisture content is reached, more energy is needed to remove the remaining bound water and therefore, the drying rate decreases and the curve deflects. The process changes to falling rate drying (at X lower than X_c). The drying rate constants (R_c) at air velocities of 2.085 m/s and 2.296 m/s are almost the same, namely 0.080 kg/m^2.min, while drying rate constant at air velocity of 1.789 m/s. is 0.088 kg/m^2.min (10% higher than the drying rate at air velocity of 2.085 m/s). The increasing drying rate proves the occurrence of overheating of the air in the heater and results in a higher temperature difference between the drying air and the grains (which acts as a driving force for the movement of water vapor from the grain to the air). This means that the drying rate is enhanced by higher air temperature.

Effect of Drying Air Temperature

Drying with an air velocity of 2.085 m/s, temperatures varying from 45, 50, and 55°C and a zeolite mass of 150 grams are presented in Figure 3. Figure 3.a shows that the higher the air temperature, the shorter the drying time. For air temperatures of 45, 50 and 55°C, drying times are 400, 300, and 240 minutes respectively. This phenomenon happens due to increasing partial pressure of the moisture in the coffee beans tissue at higher air temperature, which in turn causes increasing the mass transfer rate of water vapour from the coffee beans to the air stream, thereby decreasing the drying time. In addition, an increase in the drying air temperature will decrease the relative humidity (H_R), resulting in a higher air capacity in capturing moisture vapour from the coffee beans.

The effect of air temperature on the drying rate is presented in figure 3.b. This figure shows the occurrence of two drying rate zones, which are constant rate and falling rate, when the critical moisture content is reached. It also shows that the higher the air temperature, the higher the drying rate constant (Rc), which is 0.070; 0.082 and 0.100 kg/m².min at air temperatures of 45, 50, and 55°C respectively. However, drying at a temperature of 55°C results in 34.53% amount of coffee beans burnt on the horn skin, while at temperatures of 50°C and 45°C there is no burnt coffee beans.

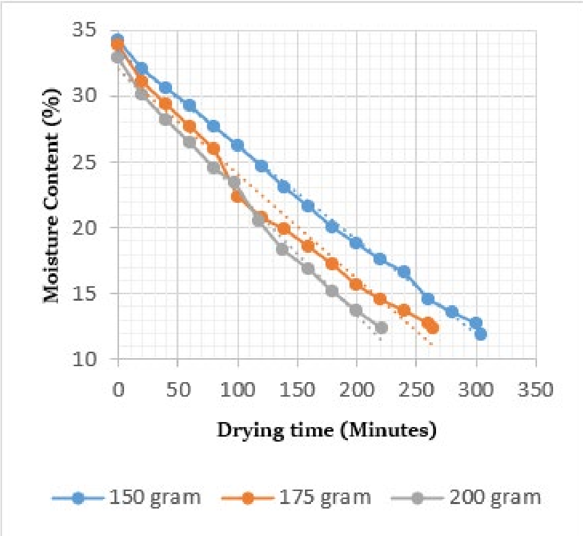


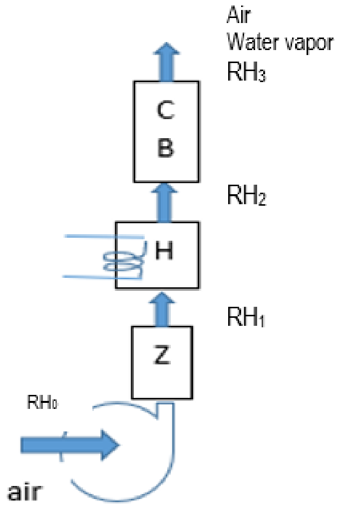
(a) (b)

Figure 3.a. Effect of Air Temperature on Drying Time
3.b. Drying Rate Curve at Varying Air Temperatures

Effect of Zeolite Adsorbent

Adsorption of air humidity by zeolite with a mass of 150, 175, and 200 g, indicates that the greater the mass of zeolite, the greater the air moisture content reduction, namely by 0,018 to 0,020 g/kg dry air. Air heating after zeolite adsorption resulted in a further decrease in relative humidity - R_H, to 20.24, 19.10, and 18.38% which meet the requirement of relative humidity for drying (RH < 20%). Coffee bean drying with an air temperature of 50°C, air velocity of 1.97 to 2.09 m/s and zeolite adsorbent varied at 150, 175, and 200 grams is presented in Figure 4.





(a) (b)

Figure 4.a. Effect of Zeolite mass on Drying Time
4.b. Sketch of air flow

Figure 4.a shows that the greater the mass of zeolite, the shorter the drying time. This is because an increase in the mass of zeolite will increase the adsorption of moisture from the air and produce a drier air, which in turn increases the driving force against the mass transfer of water vapour from the surface of solid materials, that resulting in a shorter drying process. An increase in the mass of zeolite from 150 grams to 200 grams is able to reduce the drying time by 26.91 %. The results of this study are in accordance with the research of [17][18] on drying of rice grain by means of a fluidized bed dryer assisted with zeolite adsorbent, which resulting in a shorter the drying time at a greater mass ratio of zeolite to grain.

However, too large a mass of zeolite results in a significant pressure drop in the column (Figure 4.b) that reduces the air velocity to be used for coffee beans fluidization to 1.97 m/s. The decrease in fluidization air velocity causes a lower fluidization process and results in higher fraction of burnt bean, which means poor quality of coffee beans. Drying with a zeolite mass of 175 grams resulting in 20.85% burnt coffee beans, while in zeolite mass of 200 grams burnt coffee beans increase to 33.46%. Too large a pressure drop in the zeolite column will lead to a waste of energy consumption on the blower.

Changes of Air Relative Humidity by Adsorption and By Heating System

The changing of air relative humidity (RH) resulted from 150 grams of zeolite Adsorption and by air heating of 50°C, as well as after the drying process at air velocity of 4.64, 5.52, and 6.03 m/s is presented in figure 5.

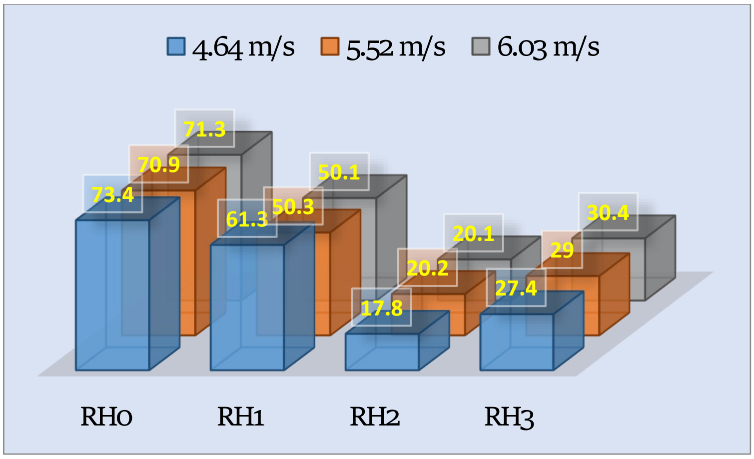


Figure 5. Changes of air relative humidity by adsorption and heating at various air velocity

Adsorption of air moisture using 150 grams of zeolite at air velocity of 4.64, 5.52, and 6.03 m/s is able to reduce air relative humidity by 12.1-21.2% (from RH0 to RH1), meanwhile air heating to 50°C is able to reduce the RH (from RH1 to RH2) by 43.5-30%, which reach an RH2 of about 20%. It means that air heating gives more relative humidity reduction than that of zeolite adsorption. When the drying process is accomplished the RH3 increase to 27,4 – 30,4%.

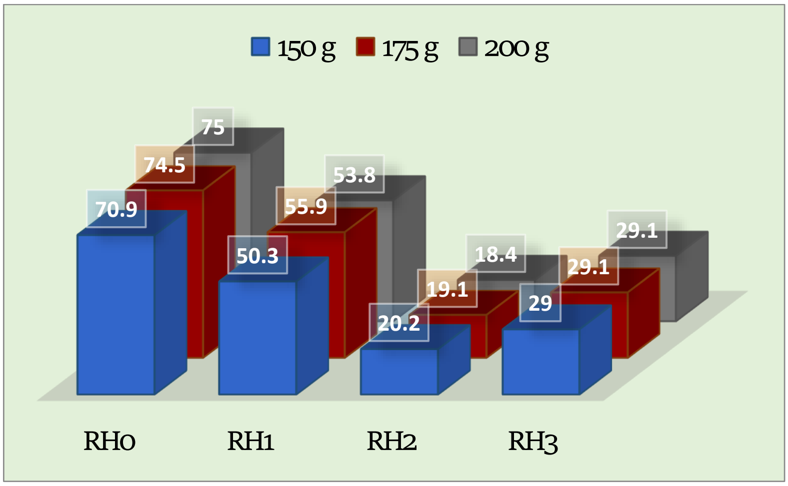


Figure 6. Changes of air relative humidity by adsorption and heat at various zeolite weight

Figure 6 shows that air moisture adsorption using zeolite of 150-200 g with air velocity of 5.52 m/s is able to decrease air RH (from RH_0 to RH_1) by 20.6-21.8%; more zeolite weight gives insignificant RH reduction. Air heating to 50°C reduce RH (from RH_1 to RH_2) by 30.1-35,4%. Again, air heating contributes more reduction of relative humidity than zeolite adsorption.

Protein and Carbohydrate Levels of Product

In the most researches, the quality of dried coffee beans is tested by brewed coffee by means organoleptic method and involving the coffee tasting experts. In such method the green beans need to be roasted, ground, and brewed. The taste of coffee brew can be predicted by carbohydrate and protein content of the beans which undergo reaction during the roasting process. Green coffee sugars and amino acids are the main substrates of Maillard and Strecker [17]

Therefore, in this study we measure the level of those components in the product instead of using organoleptic test of brew. The protein and carbohydrate content of coffee beans before and after the drying process with an air temperature of 50° and 55°C is shown in Figure 7.

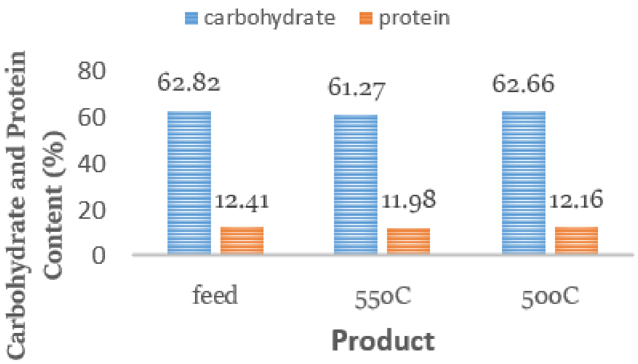
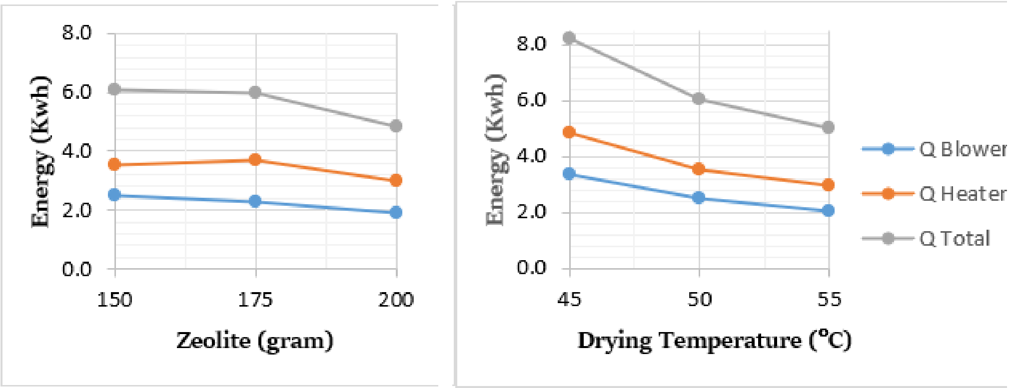


Figure 7. Carbohydrate and Protein Levels in Coffee Beans Before and After Drying Process

Based on Figure 7, drying of coffee beans at an air temperature of 50°C (300 minutes of time) leads to a decrease in protein levels of 3.46% and carbohydrate levels of 2.48%. Meanwhile, at an air temperature of 55°C (240 minutes of time) a decrease in protein levels is 2.01% and carbohydrate levels is 0.25%. The decrease in protein and carbohydrate levels after drying at an air temperature of 50°C and of 300 minutes of time is higher than that of air temperature of 55°C and 240 minutes of time. The drying time resulted from air temperature of 50°C is longer than at 55°C, resulting in more carbohydrates and proteins denaturation. This protein value is relevant to Rodrigues' research [18], that the protein content of coffee beans from any country is in the range of 11.1 – 15.0%, and that of Indonesian indigenous coffee is between 12.5 – 14.4%. Meanwhile, coffee carbohydrate levels vary from 55 -65.5% [19][20].

Energy Consumption in the Coffee Drying Process

In coffee beans drying with a Fluidized Bed Dryer, there are two kinds of energy needed, namely energy for electric blower and energy for electric heater operations. The energy requirement for drying at a temperature of 50°C, and the mass of zeolite varying from 150 – 200 grams (air velocity of 2.085 -1.97m/s) is presented in Figure 8.



(a) (b)

Figure 8.a. Energy Requirements for Various Zeolite Mass, air temperature of 500C
b. Energy Requirements at Various Temperature, zeolite mass of 150 gram

Figure 8.a shows that energy consumption for blower and heater decreases along with the increase in the mass of zeolite, with the lowest value of 4.87 kWh for a zeolite mass of 200 grams. Meanwhile, for zeolite mass of 150 and 175 gram resulting in almost the same energy consumption, of about 6.00 kWh. Drying process assisted by zeolite adsorbent results in a shorter drying time, so the total energy consumption becomes lower, since energy consumption is proportional to the duration of drying.

Drying at a temperature of 45-55°C, with an air velocity of 2.085 m/s and a zeolite mass of 150 grams (Figure 8.b) shows that energy consumption decreases as the air temperature increases, and the lowest energy consumption is obtained at a drying temperature of 55°C, which is 5.02 kWh. This occurs because at a temperature of 55°C the drying process take place at the fastest speed, that give the lowest total energy consumption.

Energy consumed by heater is about 40 to 50% higher than energy consumed by blower, but when it is viewed from the decrease in RH, heating energy has a greater impact on drying process. In terms of energy consumption, temperature enhancement is more dominant in increasing the drying rate with good product quality results.

CONCLUSION

The optimum conditions of coffee beans drying process, indicated by a minimum protein and carbohydrate damage obtained at the drying air velocity of 2.1 m/s, air temperature of 55°C, drying time of 240 minutes, zeolite adsorbent mass of 150 grams, with energy consumption of 5.02 kWh. The drying rate of coffee beans is mainly influenced by air temperature (more dominant) than the adsorption of air humidity by zeolite.

ACKNOWLEDGEMENTS

The authors very thankful and appreciate to Pusat Penelitian dan Pengabdian kepada Masyarakat, Politeknik Negeri Bandung for financial support with number contracts 8167.1s/PL1.R7,PG.00.03/2022 in laboratory capacity building and development scheme.

ACKNOWLEDGEMENTS

Research should be carried out with a blower size that matches to the coffee beans mass in order to create optimal fluidization conditions. The air heating device should be selected for long operation durability and equipped with a temperature controller (thermostat) to prevent air overheating. The fluidization unit should be equipped with air flow rate measurement at the output of the adsorption column.

REFERENCES

[1] K. Pertanian, "Kementerian pertanian. (2020). Buku Outlook Komoditas Perkebunan Kopihttp://epublikasi.pertanian.go.id/download/file/564-outlook-kopi-2020," 2020.

[2] Badan Standardisasi Nasional, "Biji Kopi," *Sni 01-2907-2008*, vol. ICS 67.140, pp. 1–12, 2008.

[3] L. Zhong *et al.*, "Enhanced enzymatic performance of immobilized lipase on metal organic frameworks with superhydrophobic coating for biodiesel production," *J. Colloid Interface Sci.*, vol. 602, pp. 426–436, 2021, doi: 10.1016/j.jcis.2021.06.017.

[4] Y. F. Chu, "Coffee: Emerging Health Effects and Disease Prevention," *Coffee Emerg. Heal. Eff. Dis. Prev.*, 2012, doi: 10.1002/9781119949893.

[5] E. Novita, R. Syarief, E. Noor, and D. S. Mulato, "PENINGKATAN MUTU BIJI KOPI RAKYAT DENGAN PENGOLAHAN SEMI BASAH BERBASIS PRODUKSI BERSIH (Smallholder Coffee Bean Quality Improvement with Semi Wet Processing Based On Clean Production)," *J. Agroteknologi*, vol. 4, no. 01, pp. 76–90, 2010.

[6] S. . Menon, "Quality, value, perceived price.," *Tea Coffee Asia*, vol. 34, no. 82–88, 2021.

[7] M. de S. G. Barbosa, M. B. dos S. Scholz, C. S. G. Kitzberger, and M. de T. Benassi, "Correlation between the composition of green Arabica coffee beans and the sensory quality of coffee brews," *Food Chem.*, vol. 292, no. April, pp. 275–280, 2019, doi: 10.1016/j.foodchem.2019.04.072.

[8] R. dan M. F. R. Q. Rahmawati, "Laporan Tugas Akhir: Pengaruh Suhu Udara Pada Pengeringan Biji Kopi dengan Menggunakan Fluidized Bed Dryer," Politeknik Negeri Bandung, 2021.

[9] R. Silaban, K. Panjaitan, B. Maruli, T. Pakpahan, and B. Siregar, "Efektivitas Pengeringan Biji Kopi Menggunakan Oven Pengering Terkontrol," *Virtual Semin. Nas. Has. Pengabdi. Kpd. Masy. LPPM UNIMED*, no. November, pp. 39–44, 2020.

[10] R. Sary, "Kaji eksperimental pengeringan biji kopi dengan menggunakan sistem konveksi paksa," *J. POLIMESIN*, vol. 14, no. 2, p. 13, 2017, doi: 10.30811/jpl.v14i2.337.

[11] G. E. Alves, F. M. Borém, E. T. Andrade, É. P. Isquierdo, V. C. Siqueira, and C. A. Dias, "Influence of different temperatures and airflows on drying of natural and pulped coffee," *Eng. Agric.*, vol. 40, no. 2, pp. 192–200, 2020, doi: 10.1590/1809-4430-ENG.AGRIC.V40N2P192-200/2020.

[12] S. R. M. R. K. Sandeepa, V.V. Basava Rao, "Studies on Drying of Sorghum Seeds in a Fluidized

Bed Dryer.”

[13] A. Kopi, S. Barat, S. Barat, S. Barat, and S. Barat, “KECEPATAN ALIRAN UDARA PADA SOLAR DRYER Endri Yani * & Suryadi Fajrin Jurusan Teknik Mesin Fakultas Teknik Universitas Andalas Kampus Limau Manis Padang TeknikA,” vol. 20, no. 1, pp. 17–22, 2013.

[14] B. Soeswanto, N. L. E. Wahyuni, and G. Prihandini, “The Development of Coffee Bean Drying Process Technology – A Review,” *Proc. 2nd Int. Semin. Sci. Appl. Technol. (ISSAT 2021)*, vol. 207, no. Issat, pp. 164–170, 2021, doi: 10.2991/aer.k.211106.026.

[15] R. Hasibuan, I. Dian, and S. Marbun, “Effectiveness of Various Desiccants and Air Velocity on Adsorption of Water Vapor From Air,” *J. Tek. Kim. USU*, vol. 7, no. 1, 2018.

[16] Nurcahyati, “Pengaruh Penambahan Zeolit Alam terhadap waktu pengeringan biji jagung pada alat pengering tipe fluidized bed drier”.

[17] C. Yeretzian, A. Jordan, R. Badoud, and W. Lindinger, “From the green bean to the cup of coffee: Investigating coffee roasting by on-line monitoring of volatiles,” *Eur. Food Res. Technol.*, vol. 214, no. 2, pp. 92–104, 2002, doi: 10.1007/s00217-001-0424-7.

[18] C. I. Rodrigues, R. Maia, and C. Máguas, “Comparing total nitrogen and crude protein content of green coffee beans (Coffea spp.) from different geographical origins,” *Coffee Sci.*, vol. 5, no. 3, pp. 197–205, 2010.

[19] L. Poisson, I. Blank, A. Dunkel, and T. Hofmann, *The Chemistry of Roasting-Decoding Flavor Formation*. Elsevier Inc., 2017. doi: 10.1016/B978-0-12-803520-7.00012-8.

[20] E. R. M. Paulo Carteri Coradi2, Flávio Meira Borém3, Reni Saath4, “EFFECT OF DRYING AND STORAGE CONDITIONS ON THE QUALITY OF NATURAL AND WASHED COFFEE1,” *Coffee Sci. Lavras, v. 2, n. 1, p. 38-47, jan./jun. 2007*, vol. 2, no. 1, pp. 38–47, 2007.