Design and performance test of a batch system rotary vacuum dryer with a 50-liter capacity to dry basidiomycota class mushrooms

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Abstract. The community’s most common drying process is drying under the sun for at least two to three days, depending on the weather. Research aimed to resolve the weather dependency of this drying process by drying mushroom in the oven at 40-degrees Celsius and drying process using tray dryer under a vacuum condition and obtained optimum cap and stalk drying results at 60-degrees Celsius under 20 kPa vacuum pressure. However, the shelf drying process resulted in differences in the moisture content. To resolve this problem, a dryer that can operate at a low temperature by vacuuming. The objectives of this research were to design and test the performance of a rotary vacuum dryer with a batch system for drying mushrooms from the Basidiomycota class. The results of functional test and performance tests using 1000 g of mushrooms were obtained: vacuum pressure 16 cmHg, temperature of drying chamber (60 ± 1) °C, drying time 16 hours, rpm drying cylinder 6-8 rpm, and final mushroom moisture content: 13% wb.

1. Introduction

The mushroom has easy damaged characteristics if it is stored in open air for 2-3 days because the high moisture content in it. Therefore, the growth and microbial activity and polyphenol oxidase enzyme activities continue (Agrocendawan Persada, 2011). The activity of these enzymes causes chemical changes, such as the appearance, taste, texture, and quality of the mushroom. To inhibit the activity of these enzymes can be done by reducing the moisture content through the drying process.

Drying process is one way to reduce the moisture content of the material. Therefore, it becomes durable because microbial growth and unwanted reactions become inhibited. Also, drying process makes the added value of mushrooms increases. This is shown by the selling price of dried oyster mushroom is Rp. 90,000/kg, yet the fresh oyster mushroom is only Rp. 18,000/kg (Robin, 2011)

The most used drying technique in the community is drying in the sun. The advantage is that, besides not requiring expensive fees and special expertise, also the drying capacity is unlimited. However, this method is less effective because it relies heavily on weather conditions and takes a 2 days long (Sulistyowati, 2004) and produces less hygienic products because the product is contaminated with dust or contaminants in the air (Raharjo, 2010).
Some researchers have tried to overcome the dependence of weather on drying natural ways such as Widyastuti (2015) has done drying oyster mushrooms using an oven at 40 oC for 48 hours resulted dried mushrooms with the best color that is pure white. Izan (2012) has conducted ear mushrooms studies on tray dryers but there is still a lack of mushrooms which are placed on tray 1 dried faster than those placed in tray 2, 3 and 4. As the result, it makes the final moisture content gradation occurs. Oyster mushrooms besides having high moisture content are also resistant to heat. For drying process Asgar (2013) used a rack dryer with a vacuum at 20 kPa of 60 oC produces the most optimal drying with drying rate of 0.11 gr / min.

Because there are some weaknesses in drying process that has been studied, it is necessary to design rotary vacuum dryer machine batch system with the aim to produce dried mushrooms with uniform moisture content and browning. Also, the damage to nutritional content due to high temperature can be suppressed and drying time can be accelerated.

2. Materials and methods

2.1. Material and tool

The material that is used in the construction of the prototype Rotary Vacuum Dryer Batch System: 2 mm stainlees plate, the stainless steel plate has a hole size of 5 mm, 1 mm stainless plate, diameter copper pipe ¼", dried mushroom material.

The tools used include: welding machine welding, plate roll, hand drill, grinding, vacuum pressure gauge, temperature gauge and thermocouple

2.2. Design and build a rotary vacuum dryer with a batch system

Design analysis includes functional design and structural design that is equipped with engineering designs. Functional design is used to determine the components that is needed to make a Rotary Vacuum Dryer Batch System. While the structural design is used to determine the size of the components in accordance with the needs and strength of the material that is used.

Functional design analysis:

a. The vacuum dryer tube functions to produce the room conditions according to the set pressure
b. The drying cylinder that is equipped with flight functions to storage the material that will be dried and rotate during the drying process with certain interval time.
c. The condenser functions to condense the water vapor that is released during drying process
d. The water jet vacuum pump functions to suck air in the drying chamber so that the pressure becomes low and also to suck water vapor from the dried material
e. The operating control unit functions to activate the vacuum device and heating unit
f. The heating source of the bulb serves as a heating source
g. The electric motor serves to rotate the drying cylinder during the drying process
h. Reducer functions to change the rpm of the electric motor to the drying cylinder

Structural Design Analysis:

a. The drying chamber is designed in a cylindrical shape so that the drying cylinder can be rotated and the use of plate material is thinner. The dimensions of the drying chamber are 46 cm in diameter, 80 cm long and able to work at a vacuum pressure of 10 cmHg.
b. The drying chamber door is made of glass so that it can monitor the drying process.
c. The drying chamber heater uses 100 watts of 10 bulb to produce a low temperature <100 oC
d. The temperature that is used for drying is 60 oC
e. Drying chamber pressure during drying process is 60 Pa

2.3. Performance test

After the Rotary Vacuum Dryer Batch System Prototype is designed and constructed, then a performance test is performed to verify whether the criteria that is required in the dryer system can be qualified or not. The best criteria of drying system are determined by its ability to reach a drying temperature of 60 oC, vacuum pressure of 60 Pa and the moisture content of dried mushrooms are reaching 13% wb.
3. Results and discussion
3.1. Rotary vacuum dryer with a batch system

The Rotary Vacuum Dryer Batch system is made to work in a vacuum condition and there is a process of reversing the material that is dried automatically, so that the drying component consists of: dryer chamber, drying cylinder equipped with flight, heating system, water vapor cooling system, water jet vacuum pump, electric motor, temperature control panel and reduction system. The dryer arrangement can be seen in figure 1, resulting the design can be seen in figure 2.

![Figure 1. Design of prototype of a rotary vacuum dryer with a batch system](image1)

![Figure 2. The rotary vacuum dryer with a batch system](image2)

3.1.1. Dryer chamber

The drying chamber is cylindrical so that the drying cylinder can rotate and the material that is used not too thick. Therefore it is necessary to be accounted the thickness of the stainless steel plate that is needed to be able to withstand the vacuum power of the pump. Pressure on the wall of chamber occurs because of the difference between the pressure inside the drying chamber and the pressure outside the drying chamber is $P_{atm}$. The pressure in the drying chamber is very small compared to the pressure outside the drying chamber. So that, there is an inward pressure loading. The drying chamber material is chosen from the stainless steel that is not easily corrosive, the tension stress of the stainless steel material $\sigma_y$ is 370 MPa and the safety factor $n$ is used 1.67 (Gere et al., 1987), with the strength data can be found of stress $\sigma_i$.

$$\sigma_i = \frac{\sigma_y}{n} = 221.56 \text{MPa}$$  \hspace{1cm} (1)

If the vacuum pressure is made $p_v = 10 \text{cmHg}$ or $13.3 \text{kPa}$ and atmospheric pressure $P_{atm} = 101.3 \text{kPa}$, then the drying chamber wall pressure $\Delta p = P_{atm} + p_v = 114.3 \text{kPa}$

The diameter of the drying chamber is 46 cm and the length is 80 cm, so the thickness of the wall can be searched by considering several types of loading.

Radial load:

$$\sigma_{r} = \frac{F}{A} = \frac{\Delta p \pi d l}{2 x_{dp} l}$$ \hspace{1cm} (2)
\[ x_{dp} = \frac{\Delta p \pi d}{2\sigma} = 0.22 \text{ mm} \quad (3) \]

Axial Load:
\[ \sigma_i = \frac{F}{A} = \frac{\Delta p 0.25 \pi d}{2x_{dp}d} \quad (4) \]
\[ x_{dp} = \frac{0.25 \Delta p \pi d}{\sigma_i} = 0.035 \text{ mm} \quad (5) \]

From the results of calculating the required radial plate thickness is 0.22 mm and the required thick axial loading is 0.035 mm, because the thickness of the plate that is used is greater (2 mm) than the thickness of the calculation, the plate of the drying chamber is qualified to withstand external loads.

3.1.2. Dryer chamber door
The drying chamber door is made of glass. The glass value \( \sigma_{ult} \) is known to be 10 x 10² Mpa. Garmo et al. (1984) said that if the stress used is \( \sigma_{ult} \) then the safety factor that used is 2.8 with these data then it can be searched \( \sigma_i \) (Gere et al., 1987):
\[ \sigma_i = \sigma_{ult} = 3.57 \times 10^2 \text{ Mpa} \quad (6) \]

The thickness of the door is determined by using equation 4 by changing the variable \( x_{dp} \) to \( S_{pp} \).
\[ S_{pp} = \frac{0.25 \Delta p d}{\sigma_i} = 0.321 \text{ mm} \quad (7) \]

Because the calculation of the strength of the material result shows the required glass door thickness is 0.321 mm while the thickness of the glass used is 10 mm, it can be concluded that the drying door adequates to the material strength requirements.

3.1.3. Vacuum pressure
To make the vacuum condition of the drying chamber, water jet pump is used that works with the Bernoulli principle, where the water jets of pump that is through the pipe produces a venture effect or vacuum. By using 7 or 8 nozzles, a special suction pipe the air until the pressure in the drying chamber drops to 7.52 cmHg which causes the boiling point of the dried material to drop

3.1.4. Heating source
Considering the volume and temperature of the drying chamber 60 oC, that 100 watts of 10 bulbs are used, it is resulting in an energy of 1000 w.

3.1.5. Temperature control
The temperature of the drying chamber is maintained by 60 oC by using a closed loop control system by controlling the load on off control so that the accuracy of the control is more guaranteed and costs less.

3.2. Performance of rotary vacuum dryer with a batch system
The pressure drop in the early minutes can take place quickly because pumping air from the drying chamber to free air is easier because the pressure difference inside and outside is not too large. The vacuum pressure that able to be produced from a water jet pump is less than the maximum, which still shows 16 cmHg.

The temperature of the drying chamber is set at a temperature of 60 oC and it is controled automatically uses relay connector to maintain the set temperature. To reach the temperature according to the setpoint, it takes 40 minutes and changes in temperature after reaching set point ± 1 oC (figure 3).
The magnitude of the decrease in the moisture content of the mushroom during drying process as shown in figure 4. It can be seen that the tool is able to reduce the moisture content from 96% to 13% wet basis (wb) within 16 hours, then the drying rate is 63.65 gH2O / hour (figure 5).

![Figure 3. Reaching the temperature 60 oC at 40 minutes](image1)

![Figure 4. Drying rate](image2)

4. Conclusion
Technical characteristics of functional test results and performance tests using 1,000 g of oyster mushroom obtained: Vacuum pressure (16 cmHg), temperature of drying chamber (60 ± 1) °C, drying Time Process (16 hours), rpm drying cylinder (6-8 rpm), final mushroom moisture content (13% wb). It is necessary to test engine performance to see the actual capacity and characteristics of the Rotary Vacuum Drying with a Batch System.
Acknowledgment
The authors acknowledge the financial support from PNBP Politeknik Negeri Jember, Indonesia.

References
[1] Asgar, A., Zain, S., Widyasanti, A., dan Wulan, A., 2013, Kajian Karakteristik Proses Pengeringan Jamur Tiram (Pleurotus sp.) Menggunakan Mesin Pengering Vakum (Characteristics Study of Drying Process of Oyster Mushrooms (Pleurotus sp.) Using Vacuum Dryer), J. Hort. Vol. 23 No. 4, 2013
[2] Agroendawan Persada. 2011, Pengaruh Kadar Air Pada Kualitas Jamur Tiram, diunduh tanggal 17 Oktober 2011, <http://Jamuraceda.Com/Tips-Memilih-Jamur-Kadar-Air.Html>.
[3] De Garmo, E.P. Black, J.T., Kohser, R.A., 1984, Material and Processes in Manufacturing, six edition, Mc. Millan Pub Co, New York, USA
[4] Gere, J. M., Timoshenko, S. 1987, Mechanic of material, second edition, Van Nostrand reinhold, Hongkong
[5] Kutovoy, V, Nikolaichuk, L & Slyesov, V., 2004, The Theory of Vacuum Drying, International Drying Symposium, vol. A, pp. 26627.
[6] Muhammadiah, M.S. Budi I.S., Erizal, Leopold O.N, Naesworo, N., 2012, RekayasaMesin Pengering Vakum dengan Tekanan Terkendali, Jurnal :Teknologi, Volume 15, No. 1, April 2012.
[7] Perumal, R., 2007, Comparative Performance of Solar Cabinet, Vacuum Assisted Solar And Oven Drying Method’, Thesis, Natural Resources Technology Depostment, University Montreal, Kanada.
[8] Pinedo, A, Fernanda, E, Abraham, D & Zilda, D., 2004, Vacuum Drying Carrot : Effect of Pretreatments and Parameters Process, Int. Drying Symposium, vol. C, pp. 2012-26
[9] Raharjo, S., 2010, Uji Kinerja Cabinet Dryer dengan Sistem Tray Dengan Pengurangan Kadar Air Pada Jamur Tiram, Thesis, Teknik Kimia, Universitas Diponegoro, Semarang