Scale up and performance test of the rotary vacuum dryer type batch for drying oyster mushrooms

S Djamila 1*, Iswahyono 1, A Bahariawan1
1Department of Agricultural Technology, Politeknik Negeri Jember

*E-mail: umi.djamilasy@gmail.com

Abstract. Rotary Vacuum Dryer Type Batch (RVDTB) is designed to reduce the moisture content of oyster mushrooms from ± 92% to ± 10%, at 60 °C with vacuum pressure 76 cm Hg and 8 hours drying time by capacity of 2 kg/process. Grinded dry oyster mushrooms produce flour used as a raw material due to its flexibility. This is in accordance with the Indonesian National Standard (SNI), therefore, there is a need to increase the dimensions (scale-up) of RVDTB capacity. The study aims to scale up and to test the RVDTB performance by increasing the drying capacity and suction power of the water jet pump. The methodology was used to redesign the RVDTB scale up, manufacture component, assemble, and test performance. The redesigning results shows on 36 cm diameter of cylindrical drying chamber with a length of 50 cm, and 2 HP suction pump power with the flight sets horizontally on 30°. The performance test results before and after the RVDTB scale-up were a) capacity of 2 kg and 3 kg, b) drying rate of 0.227 kg/hour, and 0.250 kg/hour, c) efficiency of 6.74 % and 7.42 %.

1. Introduction
In 2014, Indonesia's mushroom production reached 37,410 tons from 586 hectares of land [1]. Oyster mushroom is the kind which is in demand by the public because of its attractive appearance, delicious taste, rich in nutrients, and low in fat which make it superior for consumption. Oyster mushroom can be consumed fresh and processed mixed with meat, fish, or other vegetables. Also, it can be consumed in the form of sausages, chips, nuggets, shredded, meatballs, and processed into natural flavorings to replace MSG.

The very high moisture content of 86.6 - 90% while it is being harvested causes the mushroom to be easily flawed. The higher the free moisture content is contained in food, the faster it will get damaged due to the activity of microorganisms. It will shift its appearance, taste, texture, and quality of the food. Therefore it is compulsory to take action to extend the shelf life of oyster mushrooms after being harvested. Increasing the shelf life of mushroom and oyster mushroom can be completed by drying it in form of flour. One of the important steps in the process of making mushroom flour is drying. The most conventional way of drying is by exposing it to the sun. This method is less effective because it is very reliant on weather conditions and takes a long time, most likely 3 days [2] and the resulting product is less hygienic because it probably is contaminated with dust or other contaminants from the air. Therefore, it requires a more effective drying technique, by utilizing a dryer.

Previous research designed a Rotary Vacuum Dryer Type Batch (RVDTB) to dry oyster mushrooms [3]. The Rotary Vacuum Dryer works in a vacuum condition and the reversal process of the material during drying occurs automatically because the drying drum rotation is equipped with a material flight carrier which lifts the material up and pours it down while rotating. Dried oyster mushrooms resulted from the Rotary Vacuum Dryer Type Batch after being ground into flour and tested for their physico-
chemical properties produces oyster mushroom flour in accordance to SNI (Indonesian National Standard)[4].

The existing batch type rotary vacuum dryer has not been able to dry large amounts of oyster mushrooms, which is why it needs to be increased in size, vacuum pump suction capacity, drying capacity and flight modification so that the capacity rises from 2 kg per process to 4 kg per process.

This study aims to increase the capacity of the rotary vacuum dryer batch type to 4 kg per process and to assess the performance of the scaled up rotary vacuum dryer batch type.

2. Materials and methods

2.1. Material and tool

The research was conducted at Sinar Alam workshop and agricultural machine tool laboratory of Jember State Polytechnics, from May to August 2020. The tools utilized in this study were: welding machines, grinders, thermometers, saws, pliers, plate rollers and ovens. While the materials used in this study include: heating element, water jet vacuum pump, pressure gauge, condenser, operation control unit, electric motor, reducer, 100 watt bulb, and oyster mushroom.

2.2. Methodology

This research consisted of two stages, namely scale up and the performance test of the rotary vacuum dryer. Structurally, the part to be scaled up is the rotary cylinder part and the vacuum pump power, while the performance test parameters include drying temperature, drying chamber pressure drop, drying rate, and drying efficiency.

The scale-up procedure in this study was carried out by collecting data on the specifications of the existing rotary vacuum dryer, determining which parts to scale up, calculating the level of enlargement and manufacturing the equipment. The performance test procedure began with the preparation stage of the rotary vacuum dryer, the preparation of fresh oyster mushrooms, and measurement of the initial moisture content. Then, 4 kg of oyster mushrooms were put into the drying room and the drying process was carried out. During the drying process, changes in temperature and vacuum pressure of the drying chamber were measured as a function of time. The technical construction of the rotary vacuum dryer is shown in figure 1.

![Figure 1. Plan of scale up rotary vacuum dryer](image)

2.2.1 Defining scale up parameters. The calculated scale up parameters are the volume of the rotary cylinder, the capacity of the drying chamber, the power of the vacuum pump, based on equations 1, 2, and 3.

a. Volume silinder rotary

\[ V = \frac{1}{4} \pi d^2 L 1000 \]  

(1)
Which:
\[ V = \text{Volume of rotary cylinders (liter)} \]
\[ d = \text{Rotary cylinder diameter (m)} \]
\[ L = \text{Rotary cylinder length (m)} \]

b. Drying chamber capacity

\[ Kp = \rho V \]  (2)

Which:
\[ Kp = \text{capacity of drying chamber (kg)} \]
\[ \rho = \text{density of oyster mushroom (kg / liter)} \]

c. Vacuum Pump

Water-jet is a component to produce vacuum pressure by utilizing a pressurized fluid flow. The main components of a water-jet pump include the input canal (primary), the suction canal (secondary), the suction chamber, the nozzle, the diffuser and the mixing chamber.

The working principle of the water-jet pump is to flow the fluid through the primary channel and then exit through the nozzle tip with a greater current speed, so that the pressure of the flow and the suction space will decrease (forming a vacuum), this condition which then becomes the source of vacuum. When the fluid passes through the diffuser, the flow promptness decreases so that the flow pressure rises to approach the pressure in the tip of the diffuser [5].

The sum of power of the vacuum pump to be based on the jet pump theory from Bernoulli’s theory

\[ \frac{p_1}{\gamma_1} + \frac{v_1^2}{2g} = \frac{p_s}{\gamma_1} + \frac{v_n^2}{2g} \]  (3)

Which :
\[ P_1 = \text{Pressure in the primary channel} \ (\text{Pa}) \]
\[ P_s = \text{Pressure on the secondary channel} \ (\text{Pa}) \]
\[ \gamma_1 = \text{Viscosity of primary channel} \ (\text{poise}) \]
\[ V_1 = \text{Primary channel speed} \ (\text{m/s}) \]
\[ V_n = \text{Primary channel flow} \ (\text{m/s}) \]
\[ g = \text{Acceleration of gravity} \ (\text{m/s}^2) \]

2.2.2 Performance test of rotary vacuum dryer. The performance test of the batch type rotary vacuum dryer consist of calculating the drying rate and drying efficiency, using equations 4, 5, and 6.

a. Drying rate

The drying rate is the amount of water evaporated per time, calculated using the equation 4.

\[ LP = \frac{m_v}{t} \]  (4)

Which:
\[ LP = \text{Drying rate (kg/hr)} \]
\[ m_v = \text{weight of water evaporated (kg)} \]
\[ t = \text{drying time (hours)} \]

b. Drying efficiency

Drying efficiency is the percentage of the total of energy used in drying divided by the energy required for drying, calculated by equation 5.

\[ EP = \frac{(m \times c_p \times \Delta T) + (m_v \times \lambda)}{P \times T} \]  (5)
The drying input energy (P) is the sum of the vacuum pump energy (P_v), heating energy (P_h), and electric motor energy (P_m). The drying energy is calculated using equation 6.

\[ P = P_v + P_h + P_m \]  

3. Results and discussion.

3.1. Scale up type batch rotary vacuum dryer
Batch type rotary vacuum dryer is designed to dry the material working in vacuum, accompanied by an automatic reversing process for the dried material. Under vacuum conditions, it is supposed that water can evaporate at a lower temperature than drying under normal pressure conditions so that the dried material does not experience much damage due to high temperatures. Automatic reversal of the material will end in more even moisture content of the final dried material.

The amount of material that can be dried using the Batch Type Rotary Vacuum Dryer dryer is very reliant on the size of the dryer both geometrically and dynamically. Increasing the dimensions of the Batch Type Rotary Vacuum Dryer can increase the drying material capacity.

3.2. Specification of batch type rotary vacuum dryer
The specifications of the batch type rotary vacuum dryer before and after scale up are listed in Table 1. The scale up batch type rotary vacuum dryer can be seen in figure 2.

![Figure 2. Scaled up batch system rotary vacuum dryer](image)

Increasing the dimensions of the rotary cylinder focuses on increasing the drying capacity of the material to be two times more than the amount of material that can be dried in the previous batch type rotary vacuum dryer. Determining the dimensions of the rotary cylinder is to be based on the specifications of the previous batch type rotary vacuum dryer. Rotary cylinders are made of perforated stainless plate with diameter of 0.5 cm and a plate thickness of 0.2 cm. The rotary cylinder is 36 cm in diameter with a length of 50 cm so that the volume of the rotary cylinder is 50.9 liters. The kamba density of the oyster mushroom is 0.1 kg per liter, so theoretically the rotary cylinder can be filled with 5 kg of oyster mushrooms. In order to create an automatic reversal of the material through the rotation of the rotary cylinder and the flight on the rotary cylinder wall during the drying process so that the volume is not completely filled with material, an empty space should be left between 20-40%, so that...
once drying process can be filled 3-4 kg of oyster mushrooms. Selecting the material of stainless should be the weightless one, which makes it easier for the operator to lift the drying room when removing the dried material.

In addition to the dimensions of the rotary cylinder, the pumping power of the water jet pump has also been augmented from 1 HP to 2 HP. By improving pumping power of the water jet pump it is assumed that vacuuming to be faster and can extent to the maximum vacuum pressure. The structure of previous rotary cylinder and after being scaled up is shown in Table 1.

|                      | Before scale up | After scale up |
|----------------------|----------------|---------------|
| **Material**         | Stainless steel | Stainless steel |
| **Shape**            | Cylinder        | Cylinder      |
| **Length (cm)**      | 50             | 50            |
| **Diameter (cm)**    | 25             | 36            |
| **Radius (cm)**      | 12.5           | 18            |
| **Thickness (cm)**   | 0.2            | 0.2           |
| **Volume (liter)**   | 24.5           | 50.9          |
| **Capacity (kg)**    | 2.4            | 5             |
| **Water jet pumping power (HP)** | 1          | 2             |

Besides, the inside chamber of rotary cylinder is equipped with flight functioning to lift the material up and to pour it down while it rotates down again. Before being scaled up, the flight is positioned parallel in horizontal and after being scaled up it is changed by forming an angel of 30° in order that the material can flow along the cylinder.

3.3. Performance test of rotary vacuum dryer

3.3.1. Temperature.

One of the factors that influences drying process is temperature, RVDTB works in vacuum with the drying room temperature in range of 60-100 oC using the Thermo Autonics control type TC4s. Thermo autonics control type TC4s works with a closed loop control system with on and off load controlling system so that the control accuracy is more precise and the cost is cheap. Drying agricultural product using a good drying air flow is between 45 oC to 75 oC [1]. In response to that, the selection of the drying temperature is 60 oC. The drying temperature of 60 oC provides the best quality which is why the drying process of oyster mushrooms using RVDTB is carried out at a temperature of 60 oC.

The results of measuring the temperature of the drying room between RVDTB before and after being scaled can be seen in Figure 3. From the graph in Figure 3 it can be explained that the drying room temperature of 60 oC is achieved first in RVDTB after being scaled up. It can be explained because RVDTB after being scaled up can reduce the vacuum pressure of the drying chamber faster and greater than RVDTB before it is scaled up in consequence of an increase in water jet pumping power by 2 HP compared to 1 HP before being scaled up. The temperature of drying room during the next process is more stable in the range of 60 ± 1 oC. The relationship between time and temperature of the RVDTB drying chamber is shown in figure 3.
3.3.2 Vacuum pressure.

The batch type rotary vacuum dryer operates in a vacuum by purpose to drop the boiling point of the water so that water can evaporate below 100 °C. By decreasing the boiling point temperature, the risk of material damage can be lessened. The vacuum condition of the drying chamber is led from the performance of the water jet pump. The water-jet pump is a component to create vacuum pressure by utilizing a pressurized fluid flow. The main components of a water-jet pump include the input canal (primary), the suction canal (secondary), the suction chamber, the nozzle, the diffuser and the mixing chamber.

The working principle of the water-jet pump is to flow the fluid through the primary channel and then exit through the nozzle tip with a greater current speed. So that the pressure in the current and the suction chamber will drop (forming a vacuum), this condition is then utilized as a source of vacuum. When the fluid passes through the diffuser the flow promptness decreases so that the flow pressure rises approaching the pressure in the diffuser tip channel [5].

The results of the measurement of the drying room vacuum pressure can be seen in Figure 4. From the graph of the relationship between time and drying room pressure, it is supposed that there is an increase in the vacuum condition from 70 cmHg before it is scaled up to 76 cmHg in response to an increase in the water jet pump power from 1 HP before being scaled up becomes 2 HP after being scaled up. In addition to an increase in vacuum pressure in the drying chamber, there is also an acceleration of time to produce a vacuum pressure under constant conditions. Before the scale up, the drying room comes across a constant vacuum of -70 cmHg for almost 2 hours drying process, while after the scale up, the vacuum drying room will be constant at -76 cmHg for only 0.11 hours drying process. Acceleration and an increase in the vacuum level after being scaled up occur. This is due to an increase in the power of the water jet pump using a greater power rather than a small one, so that the fluid passing through the primary channel and then out through the nozzle tip has a greater current promptness. The relationshipship between time and vacuum pressure of the rvd drying chamber can be seen in figure 4.
3.3.3 Drying Rate.
The drying rate is the sum of water evaporated per unit of time. Based on the characteristics of the dryer with the movement of the material, the volume that can be filled with the material is about 60-80% of the dryer cylinder or 3-4 kg of oyster mushroom material. After drying tests based on the weight of 3 and 4 kg of oyster mushrooms, it is managed that 3 kg oyster mushrooms can be dried until the moisture content is below 14%, while the oyster mushrooms weighing 4 kg cannot be dried even it crumples forming like dough. This is because the materials are pressing against each other due to the limited cylinder space.

Based on the data in table 2, the drying rate after being scaled up of 3 kg of material is higher than before it is scaled up, it is caused by the vacuum pressure of the drying chamber after being scaled up which is greater than before it is scale up. A higher vacuum pressure causes the moisture rate of the material even higher.

| Weight (kg) | Initial moisture (%) | Final moisture (%) | Drying time (h) | Drying rate (kg/h) |
|------------|----------------------|--------------------|----------------|-------------------|
| Before scale up | 2 | 92 | 11.1 | 8 | 0.227 |
| After scale up | 3 | 93 | 13.5 | 11 | 0.250 |

3.3.4 Drying efficiency.
The drying energy efficiency is the percentage of the total of energy used in drying divided by the input energy required for drying. The value of drying energy efficiency can be seen in table 3.

| | Drying energy (J) | Energy input (J) | Drying efficiency (%) |
|-----------------|------------------|-----------------|-----------------------|
| Before scale up | 4,113,509        | 61,014,240      | 6.74                  |
| After scale up  | 6,231,685        | 87,707,970      | 7.42                  |

The difference of drying energy efficiency of before and after scale up is not much significant, the energy efficiency values of both are classified very low. This low efficiency is probably because the input energy is mostly used to drive the batch type rotary vacuum dryer component and the heat energy from the light bulb which is used to dry oyster mushrooms is also stored in the drying chamber. The energy is maintained not to dry the material but to sustain the drying room temperature in the targeted range so that the drying room temperature does not experience a drastic drop in temperature.

4. Conclusion
Increasing the cylinder dimensions of the batch type rotary vacuum dryer with a diameter of 36 cm, a length of 50 cm, end up in a total volume of a rotary cylinder of 50.9 m³ or the equivalent of 5 kg of oyster mushrooms. The capacity of the material that can be dried is targeted to reach 4 kg but actually it is only 3 kg. The drying room temperature before and after scale up can be reached and can be controlled at 60°C. The vacuum pressure of the drying chamber after being scaled up can reach a vacuum pressure of -76 cmHg while before being scaled up it is 70 cmHg. Drying rates before and after scale up were 0.227 kg/hour and 0.250 kg/hour, respectively. Energy efficiency of drying before and after scale, respectively 6.74% and 7.42%.
Acknowledgment
The research was conducted with funding from DIPA Politeknik Negeri Jember for PNBP research activity 2020 with contract number SP DIPA - 023.18.2.677607/2020.

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