Design of recirculated column dryer type for corn (*Zea mays* Linnaeus) drying

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Abstract. Corn (*Zea mays* L.) is usually consumed as food and feed. In post harvest handling, drying process is the most critical step that affect on the quality of corn. One method of drying corn is mechanically using a recirculated batch dryer. However, these dryers has not been widely found in Indonesia. Therefore, research on the design of this type of dryer is needed. The purpose of this research was to design a recirculated batch dryer machine and test its performance. The recirculated batch dryer machine was designed with a capacity of 2000 kg of corn shelled to dry from moisture content 25% to 14% for 8 hours. Feeding system into the drying chamber used a screw feeder. Corn were recirculated in the drying chamber using a vertical screw conveyor. Air heating system was directly using LPG gas fuel. Furthermore, the design results were tested for the performance of drying, feeding and circulation. The design results show that the designed machine has a capacity of 2,000-2,300 kg. The screw feeder capacity was 1,857 kg/hr and the vertical screw conveyor capacity was 2,216 kg/hr. The airflow supplied blower was 4,358 m³/hr. The results of the machine performance test showed a drying rate of 1.55%/hr. The efficiency of air heating was 92.03% and the the efficiency of drying was 88.96%.

1. Introduction
Corn (*Zea mays* L.) is one of the largest types of food crops in the world besides rice and wheat. Beside from being a high source of wheat, corn is also grown as animal feed, cornstarch making, as well as raw materials for certain products. In some regions, corn is the main food ingredient, mostly in several places in Indonesia.

Indonesia is one of the largest producers of corn in the world, this is because Indonesia is a tropical country which is very suitable for all types of agricultural communities. Based on data from the Food and Agriculture Organization (FAO), Indonesia was 7 of the largest corn producers in the world. Able to produce corn around 20.4 million tons per year in 2017 [1]. The post harvest process of corn will greatly affect the yield and quality of corn. For this reason, special attention needs to be paid to the post-harvest corn process [2]. Corn that is ready for harvest is old and has corn seed moisture content of around 30-35% that at that moisture level the corn is still wet [3]. If corn is stored without drying for 24 hours after the drying process, the corn has the chance to grow aflatoxin fungi or fungi [4].

Drying is the process of decreasing water content until it reaches a certain value so that it is ready for further processing and safe to store [5,6]. Besides that the purpose of drying is to meet the quality...
requirements to be marketed, the moisture content of corn that meets the trade quality standards is 14%, while the corn moisture content that is safe to store is 13% [2].

In Indonesia, the corn drying method that is very often used is drying by conventional method, i.e. corn is spread over the ground on a tarpaulin, there is directly on the concrete. This method is relatively cheaper because of the heat obtained directly from sunlight radiation. However, this method has many disadvantages, including the drying process depends on the weather. If the weather is bad, then corn drying cannot be done so delay the drying process of corn. This would cause the growth of fungi if the corn were still wet. In addition this method requires a large place as a place to dry corn, a lot of labor, high losses and requires a long time for drying, which is about three days [7].

One common mechanical dryer in the society is a flat bed dryer, which is by placed corn in a large stack to a certain height, and then hot air is blown from under the drying area. However, the weakness of this method is the distribution of uneven temperatures at different heights, caused a level of moisture content that is not uniform at various points [8]. For this reason, there is a need for periodic turning. The mechanical dryer that has recently been present in Indonesia is a corn dryer type vertical dryer. This dryer can accommodate larger materials and used bucket elevator for loading and unloading of materials. However, this dryer requires stronger and more complex construction, and the use of bucket conveyors requires high maintenance costs [9].

The expected mechanical dryer is to have a simpler construction, lower manufacturing costs, and have sufficient capacity for the productivity of household scale in corn farming in Indonesia. The components used to feed and circulate materials using screw conveyors. The screw conveyor replace the bucket elevator function. The use of a screw conveyor for a recirculated batch dryer type is a new thing so there is a need for further research. The hypothesis of this study is that the corn dryer type recirculated batch dryer has a good performance so that this machine could be applied in the community.

The purpose of this study was to design a recirculated column batch dryer for corn drying. The specific objective of this research is to engineer the construction of 2000 kg recirculated batch dryer machine and test the engineering results of the construction of a recirculated batch dryer machine with corn.

2. Materials and Methods

2.1. Material

The material namely shelled corn variety NK 6328, Plosoharjo Village, Toro District, Grobogan Regency, Province of Central Java was carried out to test the performance of this dryer. The corn has initial moisture content of 25% (w.b.). Each running test required about 2 tons of shelled corn.

2.2. Research procedures

This study focused on the construction engineering of the recirculated batch dryer type corn dryer. The corn dryer type recirculated batch dryer will be made and then tested how well the performance of the machine to dry the corn. The research procedure begins with the determination of the frame of mind, designing tools, making tools, testing tools and retrieving data, and ending with data analysis. At the stage of the mindset, it includes information related to the material to be dried and the components to be be used to dry the material. The next step is to make the components, test, then analyze the performance data from the drying machine.

2.2.1. Conceptual Framework . For design of the dryer required an orientation about the material that would be dried. The main factor that determines the drying system and dryer design is the physical properties of the corn itself. The physical properties of corn that affect the design of recirculated batch dryer designs are bulk density, moisture content, abrasiveness, flow ability [10]. In addition, information is required about the maximum temperature of hot air used for drying corn so that corn is not damaged due to high temperatures of hot air.
It is intended that the selection of components used is in accordance with their functions and performance. The dryer component generally has several main parts for the drying process. The main parts include; corn dryer room, air heating unit, blower and heat source. Additional sections namely; feed section, unloading, frame and corn stirrer or circulating section so that the corn receives heat and has a uniform decrease in moisture content.

2.2.2. Machine design. The recirculated column batch dryer is designed to dry corn with a capacity of 2 tons of corn per 8 hours. For this purpose, there are several parameters that need to be considered, namely;

a. Dryer column
The dimensions of the drying chamber depend on the volume of drying capacity, and the bulk density of the material to be dried. The desired volume for corn capacity can be analyzed using equation 1.

\[ V_j = \frac{M_j}{\rho_j} \]  

Where:

- \( M \) = mass (kg)
- \( \rho_j \) = Bulk density (kg/m\(^3\))
- \( V_j \) = volume (m\(^3\))

b. Screw conveyor
Determination of screw conveyor design depends on the type of material to be delivered. The type of material used is corn seed, therefore the corn load delivered is 45%, bulk density is 45 lb / ft\(^3\), besides that the corn material can be delivered by vertical vertical screw [11].

c. Frame
The design of the dryer is concerned with the mass of the material and the mass of the drying chamber. The tool feet are designed to be able to withstand the total load received [12]. For analyzing force distribution, the total load received by the skeleton is the load of the corn mass and the mass of the body. The burden borne on one leg is one quarter of the total load. Each one leg holds the load at two different points. For structural analysis, the dryer feet are considered as rigid objects. The equilibrium of rigid bodies occurs if the algebraic number of components of the vertical and horizontal forces and the number of algebraic moments of the force to a point are zero. For the analysis of the strength of the material, the force acting on each stem of the drying chamber should not exceed the maximum compressive force and maximum tensile force.

d. Design of drying process
The design of a corn drying system with a mass of 2000 kg uses hot air temperatures of 50°C. The analysis of the drying system takes into account the parameters needed for drying. The parameters that must be determined for the drying process are determining the total evaporated of moisture mass, drying air requirements, heat requirements, and fuel requirements during the drying process.

3. Results and discussion
3.1. Design of recirculated column dryer
Figure 1 shows the design of recirculated column batch dryer. The total lengths was 5,380 mm, and the height is 3,533 mm. The drying chamber was made using diameter of 2 mm perforated plate of stainless steel with thickness of 2 mm. The inner tubes function as source of heat, and the outer tube as outlet of moistured air. The moisture loose from the grain mainly through from this perforated plate, and it was also exhausted through the top layer.
3.2. Screw feeder

The dried corn was delivered by screw feeder from the hopper to the drying chamber. Screw feeders are mounted horizontally. This feeders consist of a flight screw, shaft, screw pipe, cover plate, bearing, and support leg. All materials except bearings are made of iron steel. The screw feeder dimension is determined by the desired screw feeder capacity. The feeding capacity of 2000 kg is carried out by the screw feeder and is expected to be completed in about 90 minutes, which is equivalent to 1,333 kg/hr.

The bulk density value of corn is 720.83 kg/m$^3$ [11]. The screw feeder capacity required in m$^3$ per hour is obtained at 1.85 m$^3$ per hour, equivalent to 65.3 ft$^3$ per hour. This capacity value in ft$^3$ per hour is used to determine the diameter of the screw feeder to be selected. Considered the relationship between screw diameter, percent load (%), and screw capacity, the screw feeder diameter was decided [11]. Selection of screw feeder diameter by taking the closest data to the required capacity. It was found, the diameter length which has the closest screw capacity is a screw with a diameter of 6 in (152.4mm) with a load of 45% and a capacity of 368 ft$^3$ per hour. The screw feeder designed has a 154 mm screw diameter, 58.7 mm pitch, 42 mm shaft diameter, and 1,410 mm screw length. The result of the screw feeder design is shown in Figure 2.

The outside of the screw feeder is a metal pipe that functions as a housing screw that supports the process of transferring material by the screw feeder. The pipe is made of iron pipes with a pipe diameter of 6 in and a pipe length of 1,193 mm. In one end of the pipe there is a hole for the input channel and it was installed with pipe cap that has bearing for the screw shaft.
3.3. Vertical screw
In this dryer, the vertical screw conveyor serves to circulate the dried material and for the un-loading process. The vertical screw working principle is same as the screw feeder, the difference is that the use of vertical screw must have a higher rotational speed than the screw feeder. The results of vertical screw design is shown in Figure 3.

![Figure 3. Design of vertical screw](image)

3.4. Frame
In order to stand upright, the dryer need to be supported by the tool frame. The tool framework is divided into two parts. The first part is the frame that holds the drying chamber called the drying chamber foot. The number of feet of the drying chamber has 4 pieces. Foot dryer is made of hollow iron with a size of 60 × 40 mm and has a thickness of 2.8 mm and hollow iron with a size of 40 × 40mm with a thickness of 1.6 mm.

3.5. Drying system unit
The corn drying system using a dryer is design to dried corn with a capacity of 2000 kg. The moisture content of corn before the drying process is 25%. The corn was dried to reach 14% moisture content for 8 hours. The drying rate designed is 1,38%/hr. Hot air requirements per hour are determined by the amount of evaporated water mass and air condition. The mass of water evaporated from 2000 kg of corn is 255.8 kg. The ambient air condition used is 30°C with RH 70%, and the air temperature for heating needed is 50°C. The assumed moisture coming out of the dryer is 85%. In the room condition, the air used for drying is 36,544.9 kg/kg. dry air. The heat needed to heat the environmental air 30°C to 50°C requires energy of 796,678 kJ. The total heat used to heat the corn material 2000 kg and evaporate water 255.8 kg is 653,829 kJ. It is assumed that the efficiency of the drying system is 75% [13], therefore the heat requirement for drying the actual corn is 871,771.8 kJ

3.6. Energy consumption
The energy needed in the recirculated batch dryer is in the form of energy needed to drive the driving motor used, fuel and labor during the drying process. The screw feeder drive motor has a power of 1 HP which is operated only when feeding corn which is for 1.5 hours. Vertical screw has a power of 2 HP to operate starting from feeding for 1.5 hours, drying for 8 hours, until spending for 0.5 hours, so the total use of the motor 2 HP is for 10 hours. The blower drive motor is 5 HP which operates during 8 hours of drying and 1 hour of cooling, so the total use of the 5 HP motor is for 9 hours.
3.7. Performance test
The drying process in testing is done by heating the environment air to an average of 47.5 °C. Water content of corn before drying is 24.1%. Water content of corn after drying reaches 13.23%. The time for the corn drying process is 6.5 hours. The drying rate produced during the test is 1.55% per hour. The drying rate at the time of testing is higher than the desired drying rate of 1.38%.

The energy used for heating air is 700854 kJ. The mass of fuel used during testing is less than the mass of fuel needed when designing a drying system, which is 16.16 kg. The heat of the fuel produced is 761,523.8 kJ. The heating efficiency produced by heating units is 92.03%. The heating efficiency based on minimum SNI is 90% [13].

The energy used to dry 2025 kg of corn is 623,494 kJ. The heat supplied from the heating unit is 700,854 kJ. The drying efficiency produced in the drying unit is 88.96%. The minimum drying efficiency based on SNI is 75% [13]. The value of the drying system efficiency is 81.87%. This shows that the drying system on the recirculated batch dryer machine works very well.

4. Conclusion
Based on the results of this study, it can generally be concluded that the results of the design of the recirculated batch dryer machine used to dry shelled corn from the moisture content of 25% to 14% is to have a corn load capacity of 2000 - 2300 kg, Feed capacity by screw feeders of 1316 kg / hour, lifting capacity by vertical screw of 3250 kg / hour, driving power of 1 HP screw feeder, 2 HP vertical screw drive, and 5 HP blower drive. The results of the design of the recirculated batch dryer machine are machine feed capacity by a screw feeder of 1.857 kg/hr, the lifting capacity by vertical screw is 2216 kg/hr, drying rate is 1.55%/hr for 7 hr, heating efficiency 92%, drying efficiency 88.96%, and the efficiency of the drying system is 81.87%. Based on the performance tests that have been carried out, the performance of the recirculated batch dryer machine is close to the design for the drying process, feed capacity, and lifting capacity, but for the value of lifting capacity by vertical screw is still below the designed value.

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