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Characteristics of temperature uniformity system in multi-tier drying equipment with sharp turning technology

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Abstract

Drying is a process of heat and mass transfer that occurs on the surface and within the material to be dried. It helps reduce the internal moisture of the material, inhibiting the growth, damage, and chemical changes of microorganisms during storage, thus extending the shelf life of dry materials and improving the quality of raw materials. This study aims to test multi-level drying equipment using combustion heat with a square shape and racks inside it used as the drying space for the material. The raw material was placed on racks made of perforated metal. This research started from designing the drying equipment system, fabricating and testing system. The drying system was tested using fish and cocoa beans as sample materials. The tested equipment system included temperature distribution in the combustion chamber, distribution system of hot combustion gases through sharp turning technology, uniform temperature distribution in the drying chamber with 8 levels of racks, each capable of holding a load of 10 kg, and testing of the chimney system. The research findings concluded that to maintain a drying chamber temperature of 90ºC, an average combustion chamber temperature of 339ºC was required. The average combustion chamber temperature needed to maintain a drying chamber temperature of 80ºC was 290ºC. For a drying chamber temperature of 70ºC, an average combustion chamber temperature of 314ºC was required. The temperature distribution inside the drying chamber moves horizontally, indicating that the temperature distribution in the drying chamber was uniform for each drying rack.

Keywords:
Multi-level dryer, uniform temperature, sharp turning channel.

1 Introduction

Drying is a process of heat and mass transfer that occurs on the surface and inside the material to be dried. This helps reduce the internal moisture of the material, inhibits the growth, damage, and chemical changes of microorganisms during storage, extends the shelf life of dry materials, improves the quality of raw materials, and reduces production, storage, and transportation costs [1]. The drying process is usually carried out by two methods of water transfer: first, water transfer from inside to the surface of the material through pores within the material; second is the diffusion of water from the material surface to the environment through evaporation [2].

Currently, there are three types of material drying methods: natural drying, traditional energy drying, and clean energy drying. Natural drying involves exposing fresh agricultural materials to direct sunlight, with the materials typically placed on the ground with good ventilation [3].

Drying with clean energy is done by harnessing solar energy, such as solar-assisted drying systems. The advantages are energy saving, emission reduction, and improved drying quality [4]. Solar energy holds promise for application in drying fields such as solar tunnel drying, greenhouse drying using solar energy, heat pump drying combined with solar energy [5], solar fluidized bed drying [6], drying using solar energy storage [7], and solar photovoltaic (PV) greenhouse drying [8].

The optimal drying temperature ranges between 60℃-80℃. To enhance the drying temperature using solar heat energy, solar collector drying systems have been developed. The air temperature exiting the collector can currently reach up to 80℃ by employing absorber and other technologies [9]–[11]. The drawback of drying technology utilizing collectors is its limited drying capacity and inability to be utilized during cloudy and rainy seasons for drying purposes [12], [13].

To address the limitations of solar energy utilization, much development has been made in drying using heat energy from fuel combustion. By harnessing the heat energy from fuel combustion, the drying temperature can be adjusted according to needs, and the heat can be continuous. Typically, drying systems utilizing combustion energy are conducted through forced convection using fans, resulting in uneven drying [14]. To achieve uniform drying results, natural convection systems can be employed. Drying equipment using fuel energy has been implemented, utilizing a seven-tiered drying system where the temperature variation between tiers reaches 3℃-4℃ [15].

Another drying method that can be used is by using an oven. The heat generated in the furnace is obtained from electricity and fuel energy. Drying with an oven is typically faster compared to air drying under sunlight [16].

Several recent studies have been conducted to optimize the temperature uniformity system in multi-tier drying equipment. For instance, research by Zhang et al. [17] indicates that the use of sharp turning technology and precise airflow settings can enhance temperature uniformity within drying equipment. Another study by Zhang et al. [18] demonstrates that the utilization of drying systems with a combination of sharp turning technology and proper air humidity control can also improve temperature uniformity within drying equipment.

This study examines multi-tier drying equipment utilizing combustion heat with square-shaped forms containing shelves used as places for the materials to be dried. The materials are placed on trays made of metal with perforated bottoms. The purpose of these perforations is to facilitate the flow of hot gas and steam from the materials. The size of the shelves and the diameter of the perforations used vary depending on the type of material to be dried.

The sharp turning technology is a technique and channel form designed to alter the desired flow to transform laminar flow into turbulence. Turbulent flow is required to enhance the heat transfer coefficient from the flow to the channel walls. Flow passing through sharp turns not only increases heat transfer but also serves to change the flow direction and distribute the flow as a temperature uniformizer in multi-tier drying chambers [19]–[23].

In this study, the activities include the planning of the drying equipment system, fabrication of the drying equipment, and testing of the drying system. The drying sample materials in the system are fish and cocoa beans. The tested equipment system includes: temperature distribution in the combustion chamber, distribution of hot gas resulting from combustion through sharp turning technology, temperature uniformity distribution within the drying chamber with the 7-tier rack, where each rack can accommodate a load of up to 10 kg, and testing of the chimney exhaust system.

2 Methods

The drying system was operated by utilizing hot air generated from the combustion process in the combustion chamber. The hot air entered the drying chamber through the hot air duct, and then the direction of the hot air flow abruptly changes, partly due to sharp turns leading into the drying chamber. The temperature of the hot air entering the drying chamber was between 60°C and 80°C as required. Thus, the hot air generated in the combustion chamber enters the hot air duct with a temperature ranging from 100°C to 150°C.

This drying equipment featured a drying chamber which its planning encompasses the main dimensions of the drying equipment. The drying equipment comprised a drying chamber consisting of racks for placing the materials to be dried. The purpose was to minimize heat loss throughout the drying chamber. The design of the drying chamber along with the description of each component is depicted in Fig. 1.

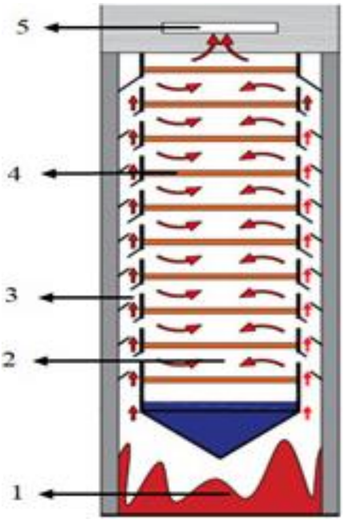

Fig. 1. Drying equipment design.

Fig. 1description:
1. Combustion chamber as the heat source generator;
2. Drying chamber;
3. Hot gas distribution channel;
4. Rack for placing drying objects; and
5. Chimney for exhaust gas release.

The hot gas separation channels were formed by sharply angled channels as shown in Fig. 2 and Fig. 3. These sharp-angled bends were created in a quantity of 18 each on every level of racks on the right and left inner and outer walls of the drying chamber using 0.3 mm thick zinc plates at a 45° angle to vary the heat flow. This layer exited from the combustion chamber towards the drying chamber, thus creating uniform heat distribution within the drying chamber and achieving nearly uniform temperatures to expedite the drying process and produce the desired dry product. Measurement points conducted on the drying equipment are indicated in Fig. 4.

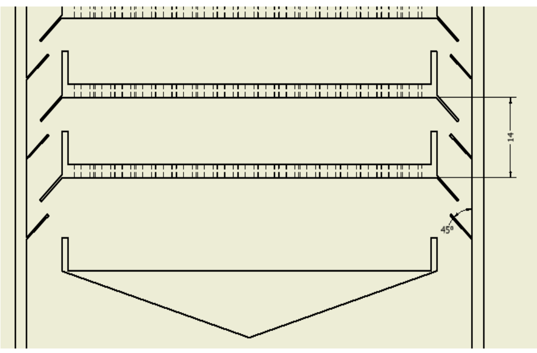
Fig. 2. Hot gas distributor channel.

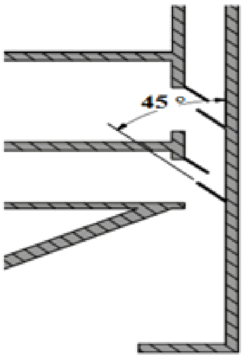

Fig. 3. Sharp-turn hot gas duct.

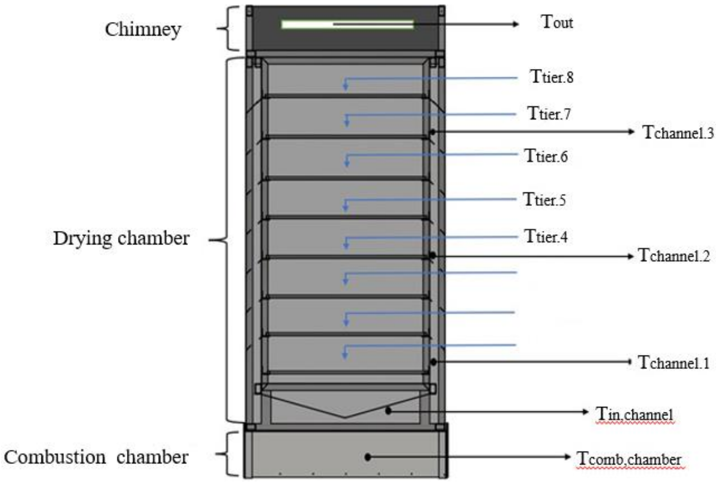

Fig. 4. Measurement points on the drying equipment.

3 Results and Discussion

3.1 The Temperature Distribution in the Drying Equipment

Fig. 5 shows the temperature distribution in the drying equipment, where the drying chamber temperature was maintained at 90°C. From the graph, it show that to maintain a uniform drying chamber temperature at 90°C, an average combustion chamber temperature of 339°C was required. The graph also indicates the average temperature in the directing channels, which was 228°C. Furthermore, the average temperature in channel 1 was obtained at 187°C. The average temperature in channel 2 was found to be 164°C, while in channel 3, the average temperature was 133°C. Channel 4 exhibited an average temperature of 107°C. Conversely, the average temperature in the chimney was measured at 79°C

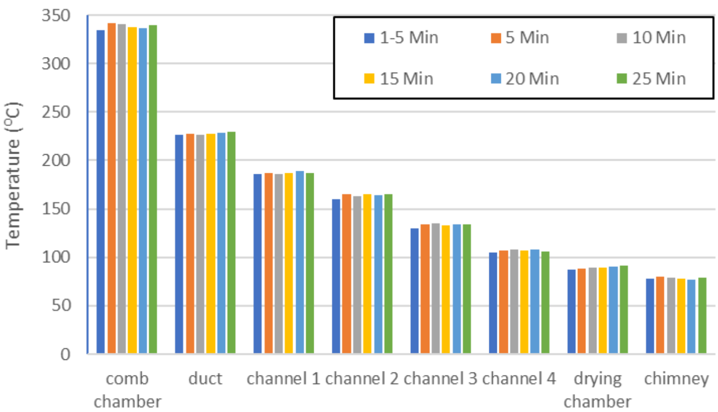

Fig. 5. The temperature distribution in the dryer with a drying chamber temperature Tr = 90°C.

From Fig. 5, it can be observed that the temperature distribution in the drying equipment decreases progressively from the combustion chamber to each section. There is a temperature decrease of 33% from the combustion chamber to the directing channels. Subsequently, from the directing channels to channel 1, there is an 18% temperature decrease.

Furthermore, from channel 1 to channel 2, there is a 12% temperature decrease. The temperature decreases by 19% from channel 2 to channel 3, and by 20% from channel 3 to channel 4. Conversely, the temperature decreases by 17% from channel 4 to the drying chamber. In the chimney, there is a temperature decrease of 12% from the drying chamber temperature.

From the test results at a temperature of 80°C, the temperature distribution in the drying equipment is shown, where the drying chamber temperature was maintained at 80°C. From these results, it shows that to maintain a uniform drying chamber temperature at 80°C, an average combustion chamber temperature of 290°C was required. The average temperature in the directing channels was found to be 201°C. Furthermore, the average temperature in channel 1 was obtained at 162°C. The average temperature in channel 2 was measured at 138°C, while in channel 3, the average temperature was 110°C. Channel 4 exhibited an average temperature of 86°C. Conversely, the average temperature in the chimney was measured at 73°C.From these results, it can be inferred that the temperature distribution in the drying equipment experiences a decrease in each section of the combustion chamber. There is a temperature decrease of 31% from the combustion chamber to the directing channels. Subsequently, from the directing channels to channel 1, there is a 19% temperature decrease. Furthermore, from channel 1 to channel 2, there is a 15% temperature decrease. The temperature decreases by 21% from channel 2 to channel 3, and by 21% from channel 3 to channel 4. Conversely, the temperature decreases by 8% from channel 4 to the drying chamber. In the chimney, there is a temperature decrease of 9% from the drying chamber temperature.

Further testing at a drying chamber temperature of 70°C revealed temperature distribution within the drying equipment, where the drying chamber temperature is maintained at 70°C. From these results, it can be concluded that to maintain a uniform drying chamber temperature at 70°C, an average combustion chamber temperature of 314°C is required. This is also evident in the average temperature in the directing channels, which is 215°C. Furthermore, the average temperature in the directing channels is found to be 174°C. The average temperature in channel 2 is measured at 151°C, while in channel 3, the average temperature is 122°C. Channel 4 exhibits an average temperature of 97°C. Conversely, the average temperature in the chimney is measured at 67°C.

From the measurements, it can be observed that the temperature distribution in the drying equipment experiences a decrease in each section of the combustion chamber. There is a temperature decrease of 31% from the combustion chamber to the directing channels. Subsequently, from the directing channels to channel 1, there is a 19% temperature decrease. Furthermore, from channel 1 to channel 2, there is a 13% temperature decrease. The temperature decreases by 19% from channel 2 to channel 3, and by 20% from channel 3 to channel 4. Conversely, the temperature decreases by 28% from channel 4 to the drying chamber. In the chimney, there is a temperature decrease of 4% from the drying chamber temperature.

3.2 Temperature Distribution in the Drying Chamber

This research aims to standardize the temperature between levels or shelves in the drying chamber. The measurement results of temperature distribution on each shelf as shown in Fig. 6.

Fig. 6 shows the distribution of average temperature on each shelf inside the drying chamber. From the graph, it is evident that the distribution of average temperature on each shelf moves horizontally, indicating uniform temperature distribution inside the drying chamber. When the average temperature of the drying chamber was 90°C, the average temperature on shelf 1 was obtained as 90.2°C. Then, the average temperature on shelf 2 was found to be 88.7°C. On-shelf 3, the average temperature was 88.6°C, while on shelf 4, it was 89.3°C. Shelf 5 had an average temperature of 88.6°C, and shelf 6 had an average temperature of 88.7°C. Meanwhile, shelf 7 had an average temperature of 89.3°C.

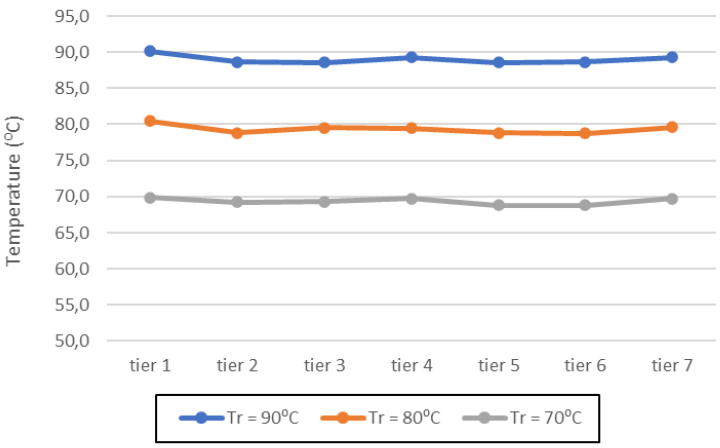

Fig. 6. The temperature distribution in the drying chamber.

In the dryer with an average chamber temperature of 80°C, the average temperature on shelf 1 was found to be 80.5°C. Then, the average temperature on shelf 2 was determined to be 78.8°C. Shelf 3 had an average temperature of 79.5°C, while shelf 4 had an average temperature of 79.4°C. Shelf 5 recorded an average temperature of 78.8°C, and shelf 6 had an average temperature of 78.8°C as well. Meanwhile, shelf 7 registered an average temperature of 79.6°C.

The testing of the dryer with an average chamber temperature of 70°C resulted in an average temperature on shelf 1 of 69.9°C. Subsequently, the average temperature on shelf 2 was found to be 69.2°C. Shelf 3 had an average temperature of 69.3°C, while shelf 4 recorded an average temperature of 69.7°C. Shelf 5 had an average temperature of 68.8°C, and shelf 6 also recorded an average temperature of 68.8°C. Meanwhile, shelf 7 registered an average temperature of 69.7°C.

From the results of measuring the distribution in the multi-tiered drying chamber from level 1 to level 7, a nearly uniform temperature distribution inside the drying chamber was obtained. The temperature difference at the operating temperature of 90°C reached 1.9°C, while the temperature difference at the operating temperature of 70°C was 1.7°C. A temperature difference of 1.1°C was obtained at the operating temperature of 70°C. The temperature uniformity in this study is better compared to previous studies [19, 20, 21, and 23].

4 Conclusion

The research results indicated a nearly uniform temperature distribution inside the multi-tiered drying chamber from level 1 to level 7. To maintain a drying chamber temperature of 90°C, an average burner room temperature of 339°C was required. The average burner room temperature required to maintain a drying chamber temperature of 80°C was 290°C. At a drying chamber temperature of 70°C, an average burner room temperature of 314°C was required. The temperature distribution inside the drying chamber moves horizontally, indicating uniform temperature distribution within each drying rack.

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