ANALYZING THE HOMOGENEITY IN THE REDUCTION OF WATER CONTENT DURING THE DRYING PROCESS OF GRAINS USING A FLATBED DRYER MACHINE EQUIPPED WITH A STIRRING MECHANIZATION SYSTEM
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PEMBUKTIAN HOMOGENITAS PENURUNAN KADAR AIR DI PROSES PENGERINGAN BIJI-BIJIAN MENGGUNAKAN MESIN FLATBED DRYER YANG DILENGKAPI SISTEM MEKANISASI PENGADUKAN

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DOI: https://doi.org/10.35633/inmateh-68-20

Keywords: *Flatbed Dryer; Auto stirring; Stirring; Water Content; homogeneity; Uniform*

ABSTRACT
Uneven drying is a prominent problem in the performance of Flatbed type grain dryer. An effort to move around the materials during the drying process is needed in order to get a uniformed drying rate. This paper investigates the conditions of an evenly distributed reduction of materials' water content during drying, using a flatbed dryer and a stirring mechanization system. It is found that ≥ 4rpm stirring rotation produces a relatively even drying result after 1 hour, and that there exists a second airflow that leaked due to the stirring process moving around with the motion of the stirrer.

ABSTRAK
Hasil pengeringan yang tidak rata merupakan masalah utama dalam kinerja mesin pengering biji-bijian tipe Flatbed. Diperlukan upaya pengadukan komoditas bahan yang dikeringkan agar laju pengeringannya seragam. Pada penelitian ini akan khusus menginvestigasi kondisi kerataan distribusi penurunan kadar air dari komoditas bahan yang dikeringkan tersebut dengan menggunakan pengering type Flatbed yang dilengkapi sistem pengaduk otomatis. Hasil pengujian menunjukkan di putaran pengadukan ≥ 4rpm, setelah 1 jam pertama pengeringan, kerataan pengeringan yang relatif seragam antar lapisannya. Dibuktikan pula pada hasil pengujian bahwa terdapat aliran udara kedua yang bocor akibat proses pengadukan yang berpindah-pindah mengikuti pergerakan pengaduk.

INTRODUCTION
In order to properly store grains and further process them in methods such as the cracked shells and polishing process, as well as other efforts such as the one concerning the prevention of fungus during long-term storage or shipment (*Muller & Heindl, 2006; Madamba, et al., 1996*), it is necessary for harvested grains to be dried from a 28% - 18% water content *(Chen, et al., 2019*) to a 14% - 13% water content *(Karbassi & Mehdizadeh, 2008*). The drying process is considered very integral, and the bare minimum amount of energy needed to do it is quite large (*Motevali & Chayjan, 2017*), thus constantly making it a subject of concern and sensitivity. Other than the material commodity's starting water content, the drying process itself is dominated by 3 main variables, which consist of Hot Air Velocity, Drying Temperature (*Motevali & Chayjan, 2017*)) (*Dorneles, et al., 2019*) (*Paziuk, et al., 2019*) (*Snezhkin, et al., 2020*) and Ambient Air Humidity *(Chanpet, et al., 2020; Namkanisorn & Murathathunyaluk, 2020; Lira, et al., 2009*). The higher temperature used in drying, the faster the drying rate would be (*Muller & Heindl, 2006)*. However on the other hand, a drying rate this rapid could negatively affect the dried result due to hasty dehydration (the thermal quenching phenomenon)) (*Paziuk, et al., 2019*), especially in the case of seeds (*Snezhkin, et al., 2020*) (*Rogovskii, et al., 2019*). In Indonesia, there has been a restriction on a Flatbed Dryer's maximum limit of the average drying temperature (Indonesia, 2015) to 43^{o} C for grains and soybeans, and 65^{o}C for corn. On the other hand, the higher the air flow rate and the lower the humidity level, the more rapid the drying process is *(Muller & Heindl, 2006)*. Considering that factors of weather, climate, geographical location, as well as day and night conditions are difficult to control, in consequence they greatly affect the humidity of the air around the environment.

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The emphasis of control variables here will be more dominant on aspects regarding drying air temperature and hot air velocity.

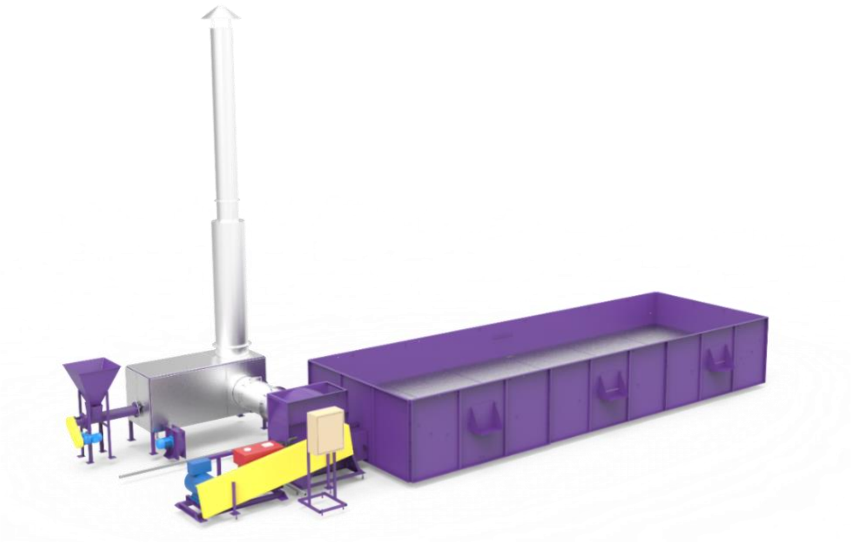


Fig. 1 - Flatbed / Fixed Bed Dryer

Flatbed Dryer or Fixed Bed Dryer is a type of grain / fruit dryer that has simple properties due to its physical form, uncomplicated working principle, sturdy and convenient construction, as well as easy maintenance, (*Teodorov, et al., 2012*) as well as a considerably affordable investment of its manufacture that allows for small to medium batch size applications and for it to be developed directly by farmers *(Noetzel, 2006*). It is constructed as a rectangular chamber separated into two sides horizontally aligned through a perforated dividing screen, with the top part being a reservoir for commodity materials to be dried, and the bottom (plenum space) being a part where the air sourced from the burner is accommodated and distributed. The heat generated by the burner is exhaled by the blower, then directed towards the plenum space, and afterwards flowed out through the dividing perforate screen, penetrating the layer of the material that requires drying while carrying the existing water content.

This type of dryer has generated several flaws. Some of the prominent ones are the uneven and non-uniform result of drying, as well as the heat loss that occurred from unequal distribution of air stream *(Brooker, et al., 1992*) (*Jayas & Muir, 2002*) *(Mellmann & Fürll, 2008*) (*Nagle, et al., 2008*) (*Nagle, et al., 2010*) *(Noetzel, 2006*) (*Ramsey & Fortis, 1984)*, labor intensive, and the lack of process control, instrumentation (Mellmann & Fürll, 2008) and automation function. There is a lot of research that has analyzed the homogeneity of airflow in the plenum space with a scale model testing experiment validated by Computer Fluid Dynamics (CFD). The first method of testing was done by directing the airflow coming from the blower in order to maintain it being linear. Examples of this are through making modifications with chambers/baffles in the plenum area, to get a steady airflow (*Nhi, et al., 2003*) (*Teodorov, et al., 2012*), and through modifying by creating multiple inlet locations that are evenly distributed on all sides (*Roman, et al., 2012*). The second method is done by placing in the plenum area a barrier configuration/screen (*Teodorov, et al., 2012*), a reflector configuration, as well as other varying configurations (*Nagle, et al., 2010*) before the air blows out to the drying chamber, which in consequence will cause the velocity of the air coming out from the plenum space to the commodity material to be more evenly distributed. All tests in this research are done in the effort of producing a uniform airflow coming out from the plenum space. However, all tests except Nagle's research have a drawback where the focus of the research is in the plenum area, instead of the drying chamber where the commodity material itself is being dried. Nevertheless the grain itself is the final subject that must be uniformly dried, and not a homogeneous airflow velocity that comes out of the plenary room.

In contrast to the research discussed above, Nagle's (*Nagle, et al., 2008*) previous research has analyzed a drying process with a Flatbed dryer, which focused on the causative factors in the uneven drying of longan fruits in Thailand. The research did so by dividing the areas in the drying basin into 3 layers resembling large nets, whose position would afterward be moved and horizontally rotated 180° with a big crane. In each respective net, 5 porous sacks which were each written with a number would be filled with longans and combined in one layer with other longans.

This experiment was done by doing various drying trial experiments with inter-layer displacement patterns and horizontal rotation, as well as the positional displacement to the 5 sacks in each layer. The resulting conclusion was that a Flatbed dryer produces uneven drying results with a tendency for the bottom layer, middle layer, and areas near the air intake's base to be even drier than the rest of the commodity's pile.

It was a research that combined both the drying chamber's internal aspect as well as the aspect of plenum space (*Nagle, et al., 2010*), and then was validated with CFD (*Prukwarun, et al., 2013*) with the conclusion that the evenness of the air in the plenary room does not solve the problem of uncontrolled drying rates. It concluded that there is still a need to undergo the process of displacing the materials that are already dry (bottom layer) with the ones that are still relatively undried (upper layer). This process can be done by rotating/stirring the material commodities of the bottom layer, moving them, and afterward replacing them with the ones whose water content is relatively still higher (*Yahya, et al., 2018*).

The concept of this research is in line with other previously-done research in continuously stirring using a stirrer (*Sjechlad, et al., 2019*) which is attached on the drying chamber and operated automatically. This will be a reference used in this paper to test the evenness of reducing water content during the drying process.

MATERIALS AND METHODS

As it was previously discussed in the paper (Sjechlad, et al., 2019), the concept of stirring in this mechanization system was designed to guarantee that the stirring process would happen without having to rely on human resources as stirring labor, which is a factor that naturally increases operational costs. With the exception of one human operator who oversees the overall drying process, the role of human labor is significantly minimized during the drying process except the process of loading/unloading the materials. In addition to being more efficient with a lower production cost rate (due to it having only to rely on a 3phase 2HP electric motor as its driving source) the system was designed to make as little skin contact as possible for the operator involved with the grain. The skin of grains contain very high silica content (Fernandes, et al., 2016) which will cause itching and irritation because of the scratches occurring between human skin with grain skin. Another thing to overcome is minimizing human interaction with dust produced from the drying process.

The solution is designed to utilize the rotational and translational motion of the stirring shaft. The stirring shaft itself continuously rotates at about 4 rpm and is directed following the motion of the translational movement of the shaft at about 0.94 m/min along the long span of the Flatbed dryer (Fig. 2). The shaft diameter is 110 mm. It has a length of 2810 mm, and it has 22 stirring blades of 500 mm length. This stirring mechanism is designed as an attachment to conventional flatbed dryers. This design makes it easy to apply the machine to already widely distributed dryers. In order to be able to thoroughly stir and mix the material to the very depth of its pile, a combination of rotational and translational motion must reach the span of the drying basin's effective length, while the blades must be able to rake until the very bottom of the plenum. Furthermore, stirring is done from the top to minimize resistance. The electric motor drives the stirring shaft in a rotational and translational motion by utilizing a chain along the rail as a medium that is pulled by the gears of the electric motor driving it. Furthermore, as shown in Fig. 3, the dead corner spaces, or in other words areas where the blades cannot reach, must be closed to ensure all grain is touched with the stirrer.

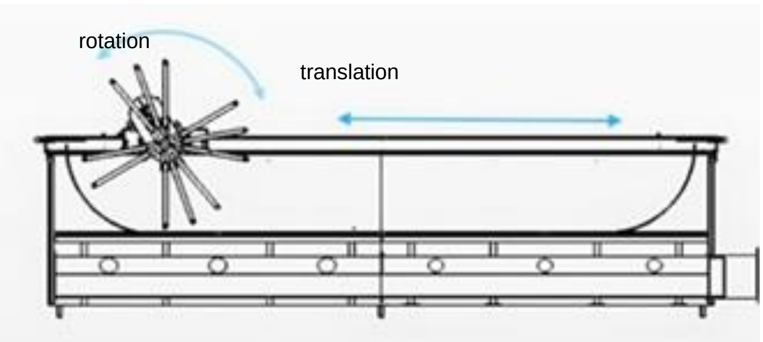


Fig. 2 - Translational and rotational movements in the stirring system

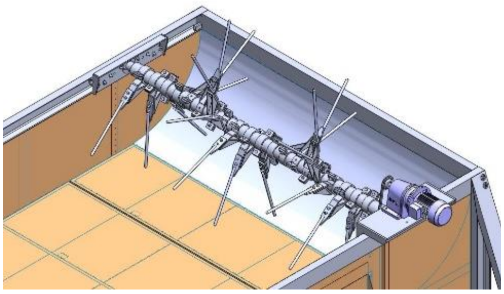


Fig. 3 - Curved wall divider in the Dryer

In this study, it has not been proven that the dried material commodities experience a uniform rate of reduction in water content in each layer and in every part in the drying chamber.

This research has just proven that the drying cost rate is lower than the one belonging to a conventional system that utilized human labor power and answer the problem of labor intensity, lack of process control, instrumentations, and automation functions. The design solution has not been proven able to overcome the main weakness of the Flatbed dryer as has been widely reviewed in previous studies.

The purpose of this paper is to study the evenness of material commodities' drying rate that happen due to stirring. This paper aimed to do this with the above mechanization system where it is expected that the bottom, middle and upper layers will experience drying rates that are relatively the same, so that a uniformed drying rate will be achieved. If this is proven, then this automatic stirring system solution approach may be an answer to the weaknesses of the Flatbed Dryer, which have been widely reviewed in previous studies as being non-uniform in its drying process, and as being prone to heat loss due to uneven flow distribution.

A flatbed dyer of a 7280 mm x 2600 mm x 1100 mm measurement was used as the testing tool. It was equipped with a drying chamber's storage volume of 4.28 m^3. The dried material was grain, and its initial moisture content was in the range of 22.3% - 19.1%, depending on their condition in each test batch. The burner used was of the Husk / Biomass Burner type, and hot air was supplied by a blower. The stirring mechanism was rotated by a 2Hp 3 phase electric motor.

Two types of tests were carried out in a series form. The first tests were carried out 3 times with the aim of observing the homogeneity rate of drying of wet grain with varying rotational speeds. The fourth test was carried out only once with the aim of proving the occurrence of air velocity leaking due to the exposure of the commodity material pile by the movement of the stirring, proving the descent of height in the surface of grain piles due to the stirring, as well as seeing the effect that occurs when the blower speed and/or stirring speed are changed. These are deemed necessary to prove, because without an air breakthrough, the regular air passing through the commodity pile will work harder to bind water in the upper layers (Sarker, et al., 2014). It is necessary then to prove that the drying occurring during the stirring process is a combination of both the movement of commodity materials, and the breakthrough of fresh air that continuously moves according to the movement of the stirrer.

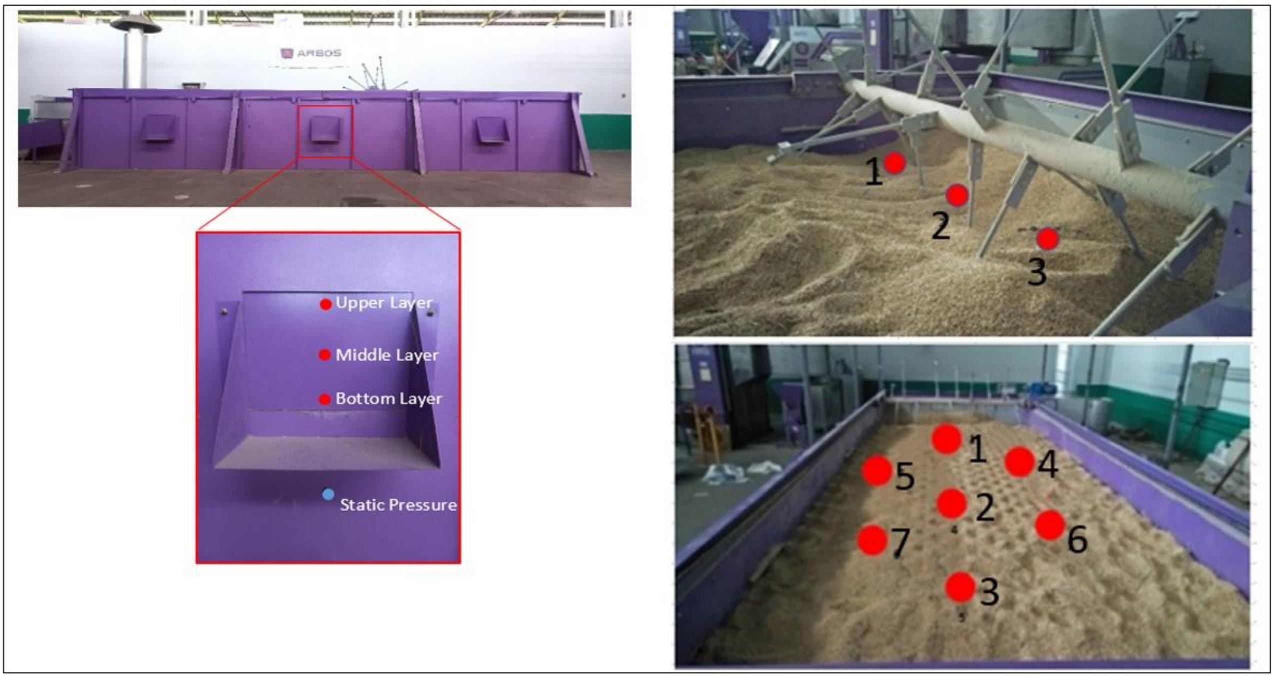


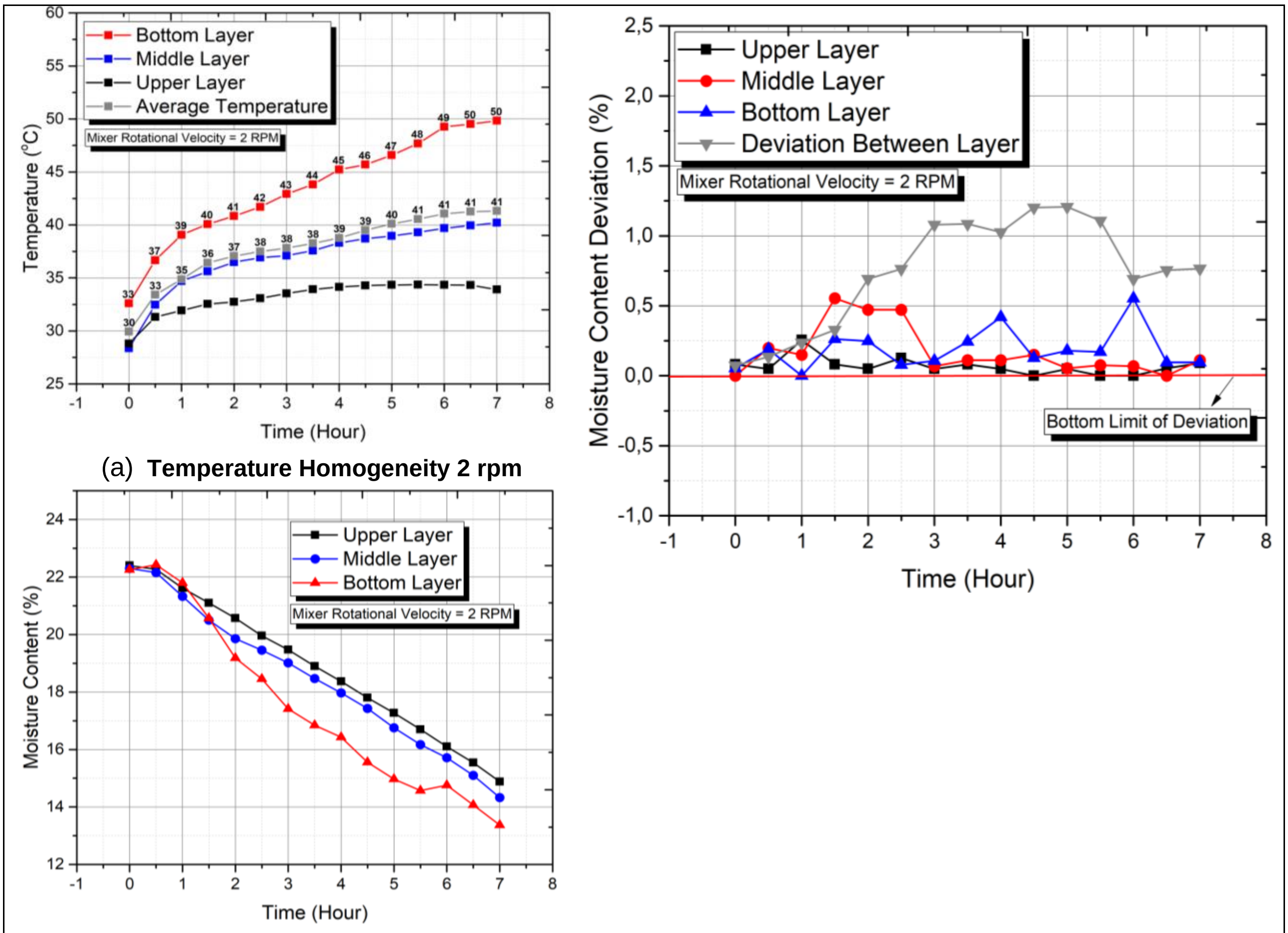
Fig. 4 - Location points for taking specimens and data

The measurement sampling points are shown in Fig. 4 that shows how the temperature was taken at 9 points on the side wall of the drying chamber where each layer is represented by 3 sample points. Moisture test samples were taken at 7 points where the top layer was measured at a depth of 5 cm from the surface of the material, whereas the bottom one was measured at a depth of 5 cm above the bottom of the perforated partition. These measurements were done on the upper, middle and lower layers. Whereas for the duration, the data collection was carried out every 30 minutes, counted starting from the beginning of the test, until the desired moisture content was reached.

RESULTS

The first, second and third tests were carried out using approximately 3.5 tons of wet grain. Each with an initial moisture content of 22.3%, 21.9% and 19.1%. The drying process was carried out using standardized heat of approximately 1549 kJ/Kg, at a static pressure of 10.8 mmH20 and an average blower speed of 4.53 m/s at 1500 rpm rotation. The first test was done with a stirring rotation speed of 2 rpm and with a translational speed of 0.47 m/min, the second test with a rotation 4 rpm/translation 0.94 m/min, and the third test with a rotation 6 rpm/translation of 1.41 m/min (fixed drive gear ratio). Keeping in mind that the purpose of these three tests were to observe the effect of stirring on the evenness of the drying rate, the blower speed was then kept constant according to the manufacturer's settings.

The first test was conducted from 08.00 to 15.00 with an average RH of 55.31% and an average temperature of 32.96^{0}C. In Fig. 5(a) it can be seen that the 2 rpm rotation had not been able to even out the temperature. In fact, over time the difference between the bottom, middle and top layers was getting higher. However, up to 7 hours in the drying process, the maximum average temperature was still below the maximum reference standard, which is a maximum of 43^{0}C (Indonesia, 2015).



(a) **Temperature Homogeneity 2 rpm**

(b) Water Content Reduction Homogeneity 2 rpm

(c) Std. Deviation of Water Content Reduction 2 rpm

Fig. 5 - The results of the drying test at a stirring rotation of 2 rpm

This 2 rpm stirring rotation itself was also not able to even out the rate of the reduction in water content. In Fig. 5(b), we can see a relative uniformity only in the middle and upper layers. In Fig. 5(c) it can be seen that the std. deviation in the same layer was relatively low (uniform), but the std. deviation of the combined layers (top, bottom and middle average water content) was very high. This means that there was a distance between the layers.

The second test was conducted from 09.00 to 16.00 hours with an average RH of 54.53% at an average temperature of 33.17^{o}C. The test results are shown in Fig.6(a) which shows that with a stirrer rotation of 4 rpm, the temperature could only be evened out in the middle and top layers, the same as in the 2 rpm rotation. Until the end of the drying process, the maximum average temperature was still safely below the maximum reference standard.

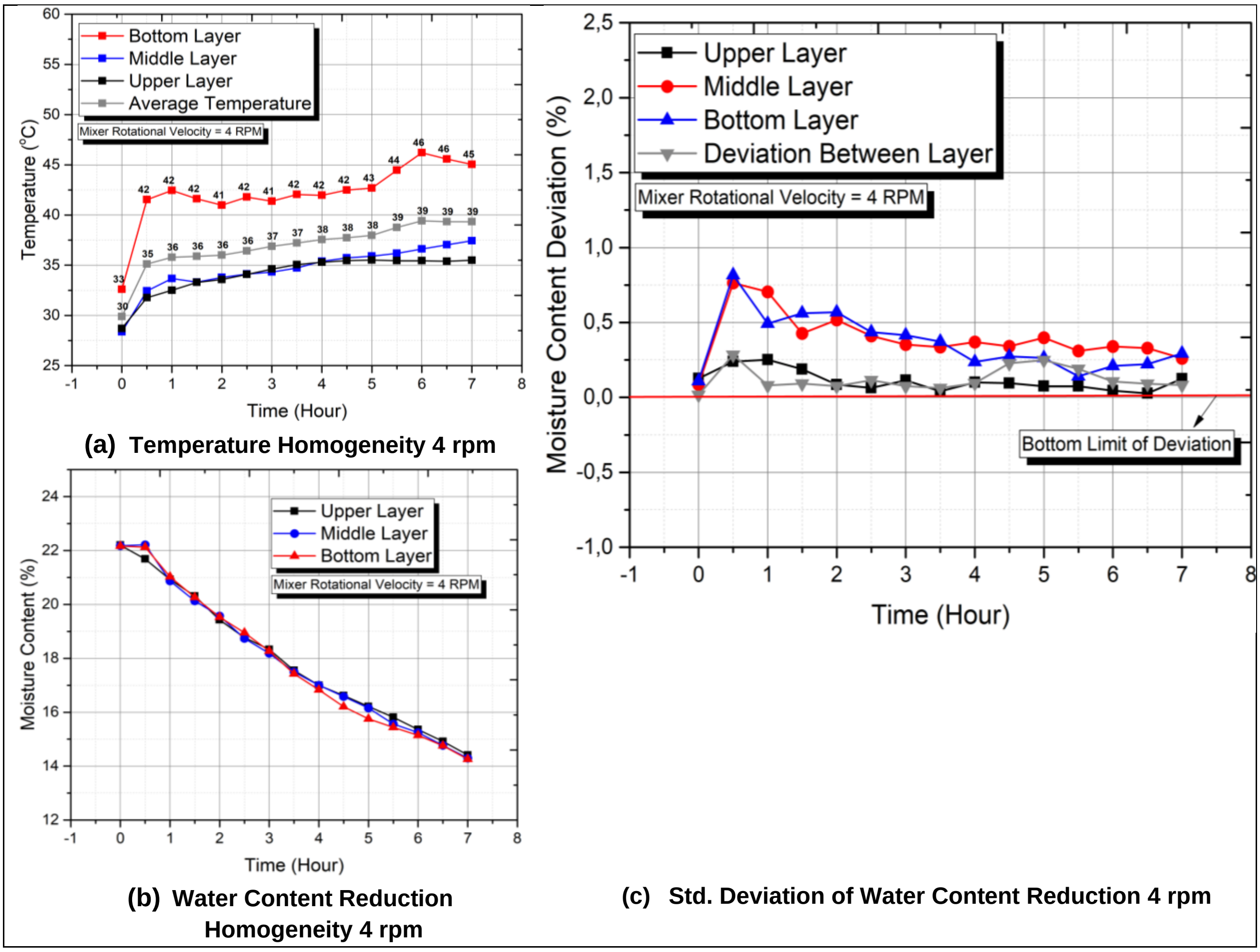
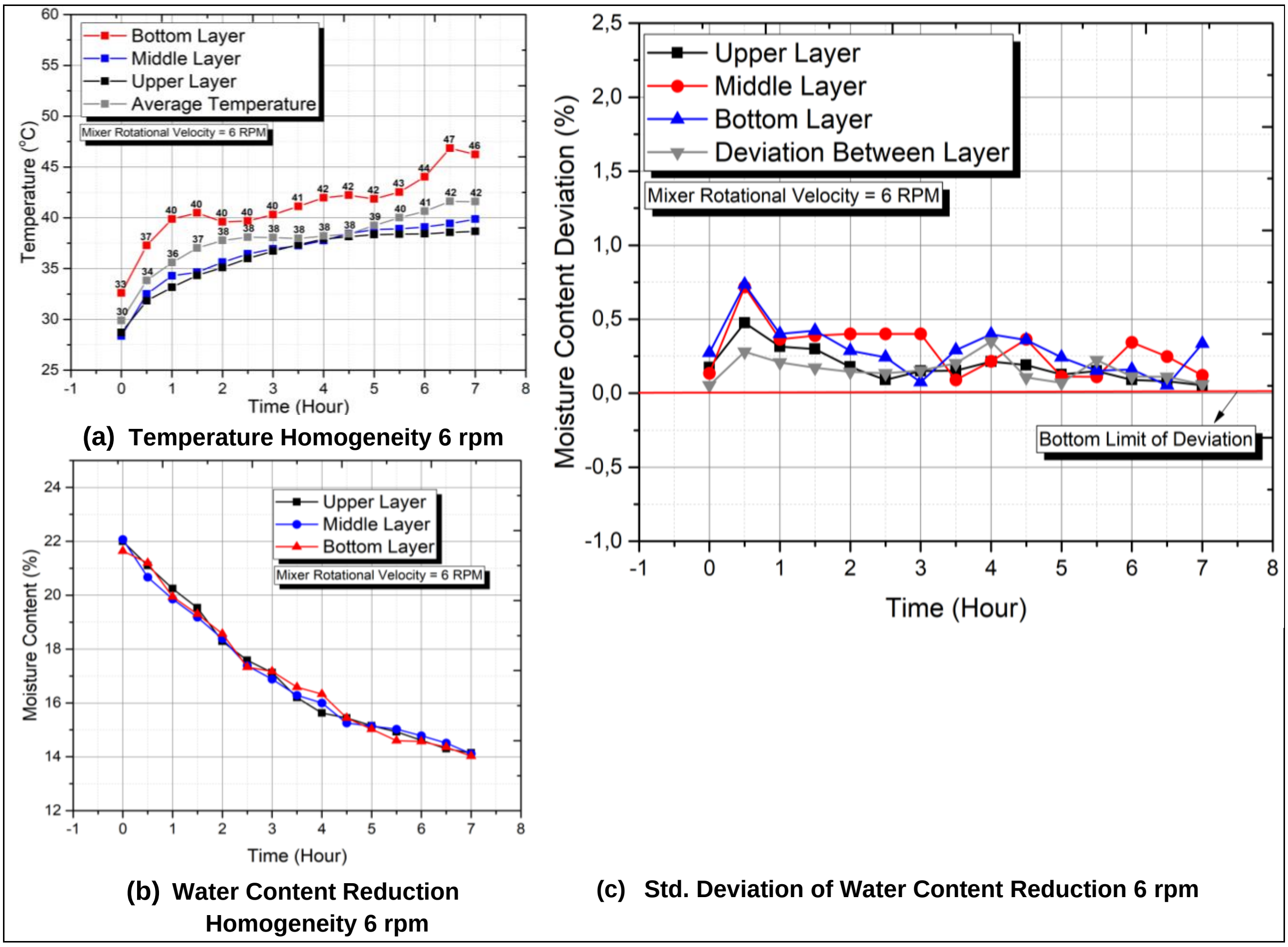


Fig. 6 - The results of the drying test at a stirring rotation of 4 rpm

After 1 hour of processing at 4rpm stirring rotation, one can see a uniform effect of evenness in the reduction of water content. In Fig. 6(c) it can also be seen that the std. deviation of combined layers value was much smaller than the three already relatively small std. deviations of each layer. This can be used as an indicator of the formation of homogeneity in water content reduction throughout the layer as a whole. The oversaturation in airflow was a phenomenon that occurred at the beginning of the process in the lower and middle layers. This could be seen at both the speeds of 2 and 4 RPM in the first 30 minutes. Hot air was not able to bind steam anymore. Instead, it was now only able to heat the layer above, and that condensation-caused steam migrated by diffusion to the layer above it (*Sarker, et al., 2014*) (*Nagle, et al., 2008*).

The third test conducted from 08.30 to 15.30 with an average RH of 55.31% at an average temperature of 32.99°C. At this 6 rpm rotation, a very good effect of a uniform reduction in water content was seen from the start of the process (Fig. 7(b)). It was better than 4 rpm, in Fig. 7(c) is shown that the std. deviation of each layer several times has a very low value, following std. deviation of the combined layers that was already very low. This indicates a better homogeneity process in all layers. In Fig. 7 it can be seen that until the stirring rotation was at 6 rpm, the stirring test had not been able to even out the temperature of all layers. However, this is still considered safe due to the maximum average temperature being still below the maximum reference standard.

The fourth test was carried out using the dry grain from the third test result. The test was to examine if there is a resulting second airflow that is fresh and drier from the outcropping of the stirring effect. The test also verified whether the airflow, as depicted in Fig. 8, was affected by the rotation speed of the stirrer and/or the blower. The test was carried out by measuring 3 points below the stirring shaft and 7 points above the commodity pile. Considering the safety concerns as well as the difficulty of measurement, the collection of the speed data under the stirrer is done by pausing the stirring system for a moment. However, the collection of 7 speed data above the commodity pile was carried out while the stirring process was ongoing.



(a) Temperature Homogeneity 6 rpm

(b) Water Content Reduction Homogeneity 6 rpm

(c) Std. Deviation of Water Content Reduction 6 rpm

Fig. 7 - The results of the drying test at a stirring rotation of 6rpm

From Fig. 9, one can see that the stirrer's motion is proven to leak air at an amount of almost twice the normal speed of air that penetrates the commodity layer with a difference of about 0.2 m/s.

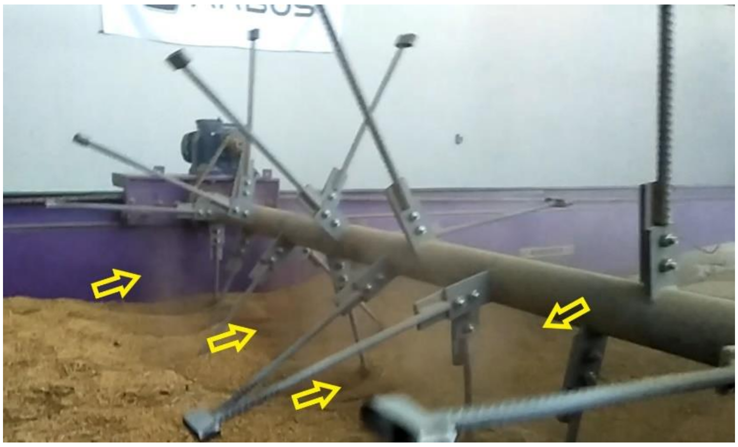


Fig. 8 – Air Velocity experiment

It can also be seen that as the speed of the blower increases, the speed of these two air velocities also increases, although the difference was around 0.2 m/s, it was still visible. This phenomenon appeared similar at the rotational stirring of 2, 4, and 6 rpm.

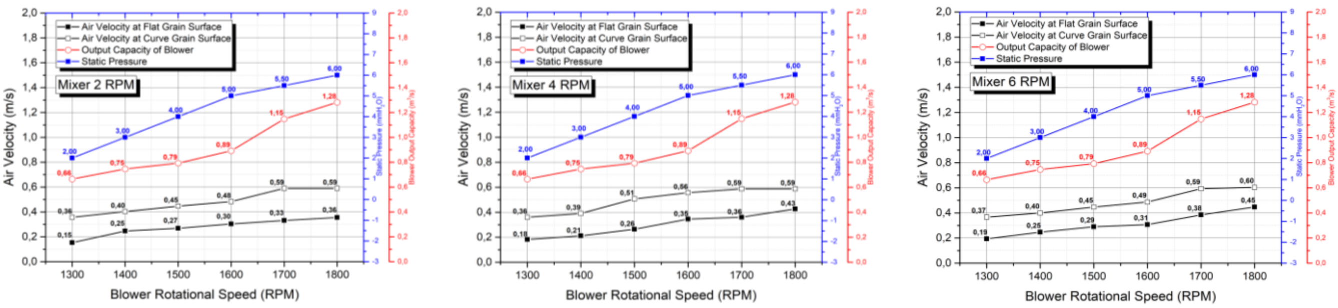
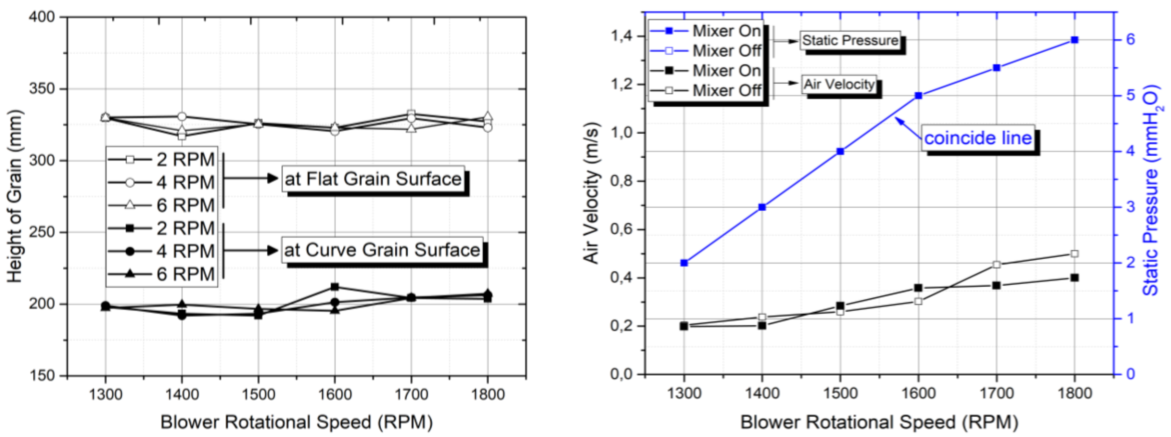


Fig. 9 - The air velocity performances

It can be seen that although the normal air velocity was affected by the blower air velocity, it was not affected by the stirring speed. It can also be seen that the air velocity of the outcrop was affected by the blower's speed and agitation. Meanwhile, normal air velocity, static pressure in the plenum chamber, as well as blower air velocity were not affected by the stirring rotation, and instead by the blower rotation. As can be seen in Fig. 8, with the blower set fixed, the air velocity was normal. The blower's air velocity and static pressure were also relatively constant, while the outcrop air velocity was affected by the stirring cycle.

The fourth test also saw the phenomenon of a decrease in the surface height of the pile due to stirring. Fig. 10(a) shows a descent in the grain's surface flatness face to about 200 mm during the stirring movement, lower than the average surface of the other grains of 325 mm. This lowering in the material's surface appears not to be influenced by the stirring speed, and instead by the configuration of the shape of the stirrer. It can also be seen in Fig. 10(b) that the process of stirring has relatively no influence on changes of either the static pressure in the plenum space, or the speed of airflow penetrating the grain pile's layers.



(a) Surface Drop under Stirrer **(b) Distribution of Airflow & Static Pressure due to Stirring**

Fig. 10 - The phenomenon of stirring effect

CONCLUSIONS

Through the tests performed with grains, one can see that a stirring mechanism was proven to be able to maintain the evenness of the reduction of water content in all parts of the drying chamber, in order to produce a drying end result with uniformed quality. It has also proven the way these translation and rotational motions were able to replace the role of stirrers to evenly turn over and mix the commodity. The stirring that was done on various rotational speeds up to 6 rpm in this testing was not yet able to even out the grains' drying temperature, particularly in the bottom layer near the perforated dividing screen. However, the acceleration in stirring speed was proven as able to narrow down the temperature difference between the layers, starting from the layer positioned furthest from the source of hot air.

The evenness of stirring can be seen from the std. deviation graphic of interlayer water content reduction. The smaller the value, the more even and uniformed the reduction of water content between the layers. The higher the stirring rotation, the smaller the resulting std. deviation between the layers. During the 2 rpm rotation, one can see the top and middle layer receiving uniformed rate of drying.

However, the drying rate in the furthest bottom layer became faster especially after the 90 minutes' mark. This shows that the rotational speed was not yet optimal due to the evenness between the layers having not yet occurred. This phenomenon is further clarified by the std. deviation between the layers, which became bigger in size after that minute. During the ≥ 4 rpm rotation, one can begin to see the drying rate becoming more uniformed in all layers, particularly after the 1-hour mark since the drying process started. The higher the stirring rate, the quicker the homogenization process of the water content reduction rate started. This was further clarified by the std. deviation graphic, in which one can see that the std. deviation of 4 rpm and 6 rpm stirring rotations between layers where the value was very small and lower than the std. deviation of each layers. However, during the initial drying process under the 4 rpm rotational speed at the middle and a relatively lower layers, we can see a phenomenon of oversaturation happening in the hot airflow, in which hot air was not able to bind steam anymore. Instead, it was now only able to heat the layer above, and that condensation-caused steam migrated by diffusion to the layer above it.

Due to the stirring motion, a second continuous airflow was caused. This airflow occurred because of the outcrop and moved according to the motions of the stirrer, where there was a difference with the even air flow that had penetrated the grain pile, because it could be seen that the air velocity is greater by about 0.2 m/s. This difference was relatively constant, even though the rotations of stirring and/or blower were changed. Due to the displacement of the continuous movement, this second airflow also contributed to evenly aid the drying rate, because the normal air flow that penetrated the grain pile tend to have a higher moisture content than the material commodities in the middle/upper layers, especially in the early stages of drying time.

In the fourth test, one can see that the movement of the stirring rotation had no effect on the static pressure in the plenum chamber, the air velocity that penetrated the grain pile, as well as the air velocity under the stirrer. Instead it can be seen that the blower's rotational speed was the one that had an effect on the increase. The higher the blower speed rotation, the more increased the value. In this test, it was also proven that the stirring process has an effect on the decrease in the surface of the grain pile under the stirring shaft which moved along with the stirring movement. The difference in height was constant even though the stirring speed was variously changed. This shows that the grain pile's height difference was not due to the rotational speed, but the configuration of the shape of the stirrer blades. It was then also proven that the static pressure and the speed of air flow that penetrated the grain pile did not change according to the changes in stirring conditions.

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