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ANALYSIS OF GRAIN MASS FLOW EXPERIMENTS IN A MIXED-FLOW DRYER

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In Central Europe approximately 30% of the grain must be dried after harvest. The most popular continuous crop dryers are mixed-flow dryers. Although this type of dryer is widely used it is still necessary to optimize many segment processes during the drying. For example there are big differences in the vertical grain particle velocity causing differences in the residence time. The aim of the work was to carry out experiments for the grain mass flow measurements in a semi technical dryer. Based on the results a mathematical and 3D computer model for the grain mass flow will be developed in the future enabling improvements in the prediction of the drying process which does not form part of present study.

Keywords: Modeling and control of agriculture, Crop processes, Crop modeling, Drying, Food quality, Image analysis in agriculture

1. INTRODUCTION

Mixed-flow dryers often work in a quasi-stationary mode of operation. In this case, the grain is at rest during almost the whole drying time. The standing time between two discharges may reach several minutes whereas the discharge time – the period of time while the discharge device is open – takes a few seconds. In these dryers the air and the grain are guided through the dryer shaft in co-current, counter-current, and cross flow modes at the same time (Pabis, *et al.*, 1998). The grain is transported step-by-step downwards the dryer shaft. At each discharge it is assumed that the grain bed moves in plug flow pattern. The bed material is assumed to be a connection of single grain layers' series the drying behavior of which is described by means of a single grain model (Farkas and Rendik, 1996).

The influence of different forms of air ducts on the grain and air flows through a mixed-flow dryer has already been studied, see (Klinger, 1977). The dryer was modeled as a series of co-current and counter-current elements. The same modelling concept was successfully employed to predict the general behavior of the dryer and the influence of operating variables on drying performance, see (Bruce, 1984). In a dynamic form it has also been used in the 5development of an automatic dryer controller (McFarlane and Bruce, 1991). Cenkowski et al. (1990) experimentally investigated the air-flow patterns in a mixed-flow dryer. They revealed that about 30 % of the dryer shaft volume operates in a cross-flow configuration. Giner et al. (1998a,b) developed a two-dimensional model of the mixed-flow dryer including cross-flow elements. To calculate the grain drying process in each co-current, counter-current, and cross-flow element first of all it

is necessary to know the proceeding of mass- and air-flow processes. Recent publications on the modelling of hot-air grain dryers are concerned with cross-flow, deep-bed and single kernel drying, for example Rumsey and Rovedo (2001), Jia et al. (2002), Sitompul et al. (2003) and Wu et al. (2004).
The present publication deals with the analysis of mass flow measurements in a mixed-flow grain dryer using wheat as test material. In parallel also the air-flow patterns have been investigated. This work submits first results of the grain flow experiments.

2. EXPERIMENTAL SETUP

The mass flow experiments which were carried out at the mixed-flow dryer test station at ATB in Potsdam have illustrated how the bed material moves through the experiment dryer and the mixed-flow dryer. Dried wheat samples with a moisture content of 12-14 % w.b. were used as bed material. For the bulk material experiments the left shaft (with transparent Plexiglas® wall, see Fig. 1) was used. The experiment was recorded using a video camera and evaluated by special video and picture software. The video camera was placed on a stand and directed towards the lowest air duct (on a middle level, thereby no distortions developed). The videos were recorded with a rate of 50 pictures per second. Quick-motion video sequences offer a better view over the fast bed material transport processes. The picture resolution was also sufficiently high, so that the individual seeds could be well recognized.

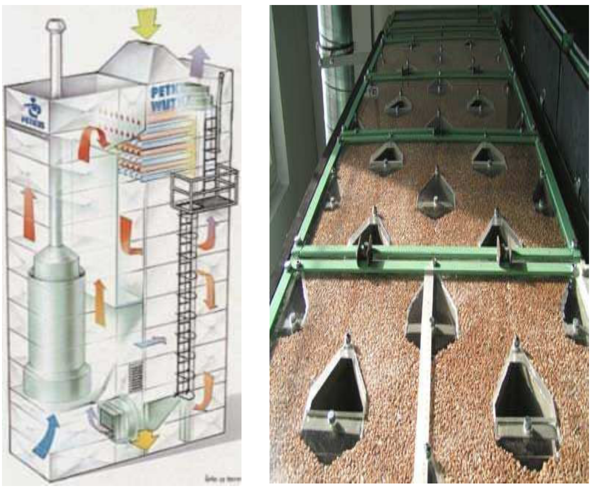


Fig 1. Layout of an industrial dryer and ATB test dryer with Plexiglas® wall

3. GRAIN MASS FLOW EXPERIMENTS

The experiments were accomplished with both a shorter (300 ms) and a longer (1000 ms) discharge time to compare the different grain quantities delivered. Also experiments with colored particles and colored wheat layers were accomplished (see in Fig. 2). The courses of the colored particles were recorded and analyzed by a video software. Combined with the time capture a detailed observation of the grain flow processes is possible for the same videos. The video records were taken in a 50 pictures per second quality, which offers detailed view for shorter time intervals.

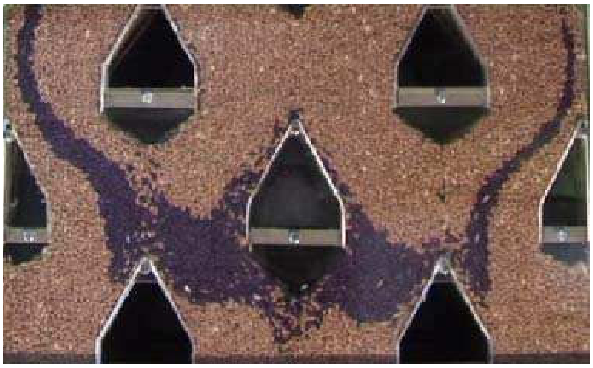


Fig 2. Colored grain layer in the test dryer during discharge

For the bulk material transport experiments only the lowest part of the Plexiglas® wall was filmed by the digital camera, so that the processes could be pursued more exactly, see scaled Fig. 3. The evaluation of the video and picture information collected demonstrates where the wall friction had a large effect over the bulk material movement. In Fig. 2 this can be well recognized. The wheat pouring into the dryer centre trickles clearly faster than the layers at the side walls, where the wall friction is retarding the flow. Thus a grain column in the dryer shaft centre is clearly faster delivered than the remaining part in the shaft. In this way the grain mass remains for different time periods in the dryer and as a final result will have uneven moisture distribution. This big difference in the grain flow must be reduced by certain methods.

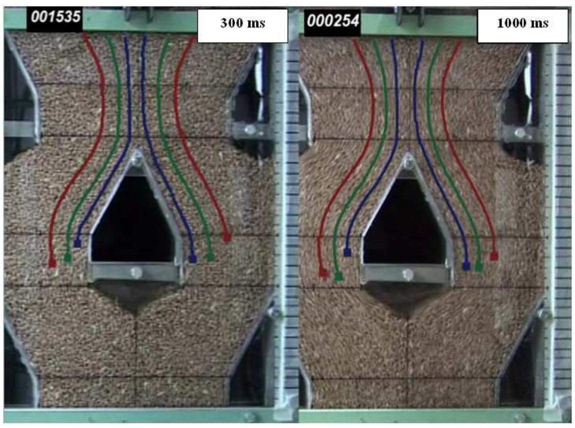


Fig. 3. Cut-out comparison experiment video where the courses of the colored grain were pursued by special software.

The cut-out comparison experiment video was analyzed frame by frame. 25 pictures per second were provided from the videos of the lower flow rate, for the higher flow rate 50 pictures per second. The videos were evaluated by a picture analyzer program as slow memo-motion studies. The Plexiglas® front wall was equipped with a scale (Fig. 3), so that the real mean particle velocities could be measured. The gaps between the air ducts were divided into units of 1 cm. After several pictures the grain pin-pointed a certain distance on the picture sequence which was measured by each section. According to that number of pictures was the time determined. Only after this it was possible to determine the average velocity of the grain flow. The results are shown in Figs. 4 and 5. In Fig. 4 the air ducts (dark triangles) can be seen in the background with measured ranges (gray rectangles). In Fig. 5 the results are overlapped on a picture about the dryer (only for illustration). The measured ranges are marked here with red. It must be considered that these test results represent mean velocities of one experiment.

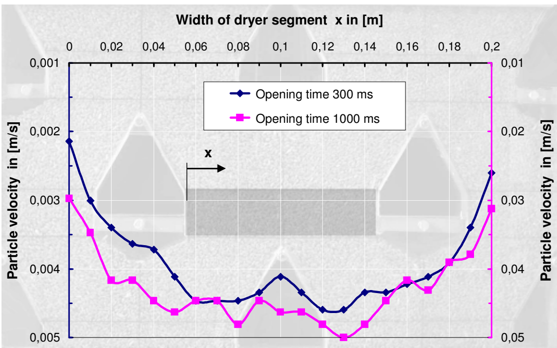
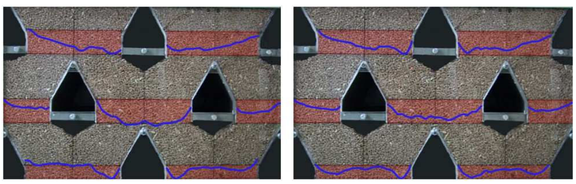


Fig. 4. Vertical particle velocities measured at the front wall between two air ducts at 300 ms and 1000 ms opening time

In Fig. 4 the measured range in the center section of the dryer is represented graphically. The other measured ranges can be seen in Fig. 5. The average grain velocities determined for the experiments at 300 ms and 1000 ms are overlapped. The diagram is individual with two y axes (grain velocities in m/s), for each attempt. Only by doing such a diagram lap the grain flow is comparable at the two flow velocities. It can be seen very well that at larger flow rate the velocity differences are smaller than at smaller flow rate. That phenomenon is because at larger flow rates the grain has a higher impulse and the wall friction effect is smaller.



a) b)

Fig. 5. Qualitative particle velocity distribution over the vertical cross-section in the lower part of the dryer: a) at 300 ms opening time; b) at 1000 ms opening time

In Fig. 5 the wall friction influence is very well recognizable. Over the roof points grain dipping develops strongly breaking the grain flow in this area. The diagonal roof walls affect a smaller upsetting. There is also a grain dipping with vertical roof walls by which the thinning is caused on this dryer level. Under each roof the trickling grain seeds accelerate themselves mutually to the upsetting area over the next roof point where some of them are strongly brake. The grain seeds trickling through under each half roof are brake by the wall friction under the half roof. Directly beside the wall a thin grain layer is formed where the grain seeds move downwards clearly more slowly than the layers lying closer to center. The upsetting area over the lower half roof point causes still another additional upsetting braking.

These experiments were accomplished on the three lowest roof levels. The discharge device is placed 26 cm under the last two air duct. The missing air ducts and the close-lying discharge device cause a diagram change to the measured grain velocity between the lowest roofs. Under the last roofs there are no more disturbing thinning and upsetting causers like following roof points and roof walls. This area directly over the discharge works like a balance memory, before the grain leaves the dryer. At the different delivering velocities no salient differences are to be observed in the grain flow relationship. The bulk property mixing is hardly affected by the delivering velocities. The bulk material transportation experiments have shown a large effect of the wall friction. It remains open to model and simulate this complex bulk material moving process in the future also with the DEM-calculation method.

On the diagrams it can be very well recognized that in the centre more grain mass is delivered than at the walls. To the corners hardly any is delivered. That is to be due to the complicated shaft flow conditions. There are clearly larger friction forces at the walls than in the shaft center.

This wall friction causes a lower grain flow velocity. In addition mutually the grain seeds in the shaft center accelerate themselves, Fig. 2. The bulk material movement in the dryer is to be happened as evenly as possible, so that all grain layers have the same drying time. It was tried to suppress this inevitable edge effect by special split form (the sliding plate), see in Fig. 6.

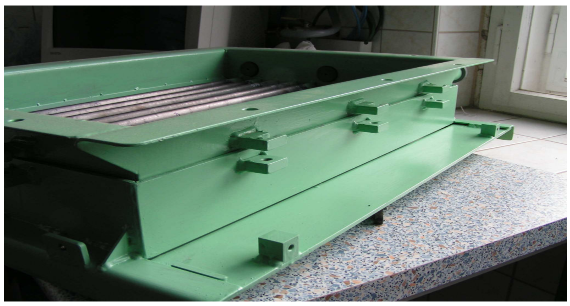


Fig. 6. Discharge device of the dryer

With this measure the slots of the sliding plate in the center are arranged clearly narrower, because largest grain transport is experienced accordingly in the center. These works on the discharge cause almost an even delivering, because the grain flow behavior is very little dependent on the discharge system. This grain flow behavior develops itself in the whole dryer shaft height. A more complex, but also more effective method to suppress this inadvertent edge effect can be used. Into the whole dryer shaft partition plates are built in over the roof points. So the grain flows through many equivalent pits. A purposeful additional wall friction is caused over the whole shaft volumes. These shafts are symmetric, only one roof gap broad, and those offer even flow conditions in the whole dryer. In addition, the wall friction causes a large grain dipping and turbulence under each roof. In this way a certain grain quantity remains clearly longer time in the dryer and is strongly over-dried. Because of many auxiliary walls this turbulence effect is strengthened several times in a dryer shaft with partition plates over the roof. This measure makes the delivery even, but because of the upsetting and turbulence effect under each roof the effectiveness of the dryer does not become higher.
There is a possibility to minimize the edge effect with half roofs placed to the wall. By doing so the wall friction is smaller because of the missing cater-cornered placed sheet metals (the roof surface). This method causes a smaller drying effect at the wall because of missing roofs. This method must be effective despite its simplicity against the inadvertent edge effect.

4. MEASUREMENT OF THE GRAIN MASS FLOW DISTRIBUTION

The regulation of the delivering uniformity was measured with a 24 cells paper grid (with dimensions of L 100mm; B 100mm; H 200mm) under the discharge positions, Fig. 7. After each discharge the property of the mass of each individual cell is individually determined with a digital scale (measuring error 0,005kg).

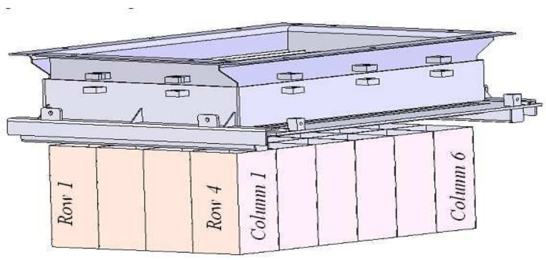


Fig. 7. Set-up for measuring the mass flow distribution at discharge

From the average values of 5 measurements each provided the following three-dimensional diagrams. In the Fig 8 the direct discharged mass measurement at 300ms opening time and in the Fig 9 at 1000ms opening time can be seen.

5. EVALUATION OF MASS FLOW MEASUREMENTS

During the mass flow experiments the discharged masses and the mass flow rate were measured in the test dryer.

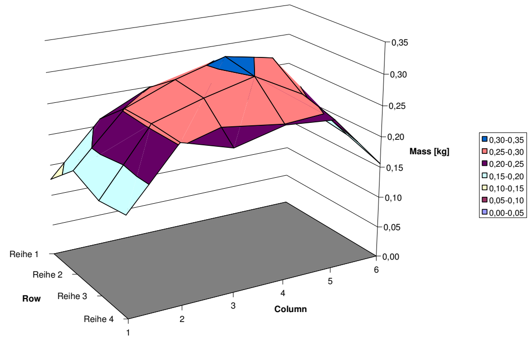


Fig. 8. Distribution of grain masses measured at 300ms opening time

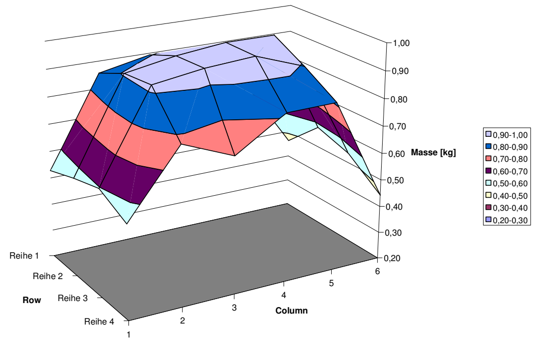


Fig. 9. Distribution of grain masses measured at 1000ms opening time

To evaluate the mass flow measurements a simple grain mass flow model was applied as follows. The mass flow rate is defined to be

$$\dot{m} = \rho_b v A \ , \qquad (1)$$

where ρ_b is the bulk density of the grain, v is the vertical particle velocity, and A corresponds to the cross section of flow. From this basic equation it is possible to write a more precise equation as follows

$$\dot{m} = \sum_{i=1}^{n} \rho_b v h \Delta x_i \ . \qquad (2)$$

From the vertical particle velocity distribution measured at 1000 ms opening time in a dryer section between two air ducts (see Fig. 4) the mass flow distribution was calculated for a thin layer behind the Plexiglas® front wall. The layer thickness h was assumed to be one particle diameter (h = 2 mm). The cross section of flow was divided into small units by $dA = hdx$ with $\Delta x = 10$ mm.

For the more accurate calculation the following integral equation was used

$$d\dot{m} = \int_0^x \rho v(x) h dx . \qquad (3)$$

The calculated results are depicted in Fig. 10.

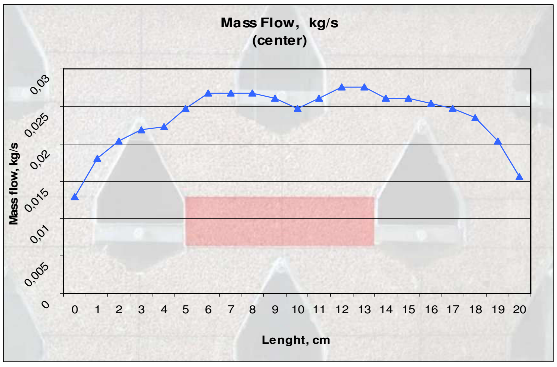


Fig. 10. Calculated mass flow distribution at the center of the test dryer

As can be seen from the diagram the shape of the mass flow distribution is very similar compared to that of the mass distribution directly at the front wall obtained from the measuring at the dryer discharge according to Fig. 9. For smaller opening times, however, the agreement between the two different measuring methods was not as good. This is because not the whole opening time is effective for discharge in that case.

6. CONCLUSION

With the aim to develop a mathematical model for the grain mass flow in mixed-flow dryers first experiments on particle velocity and grain mass flow distributions were conducted. The measurements were carried out at the pilot dryer of ATB Potsdam using wheat as test material. The dryer shaft was equipped with a transparent Plexiglas® front. A high-speed video camera with up to 50 pictures per second was used to measure the vertical particle velocity distribution at the wall. The camera was also applied to visualize the segregation of the grain flow due to effect of the wall friction both of the sidewalls and the air ducts. For this purpose, single colored particles as well as colored particle layers were inserted at top of the dryer and followed through the dryer shaft. In addition, the mass flow distribution at the dryer discharge was measured.
The grain mass flow experiments could demonstrate that there is a strong effect of the sidewalls on the grain flow causing segregation. As a result, big differences in the residence time of single grain portions and, hence, uneven drying occur in the mixed-flow dryer. The objective of future work is therefore to develop a mathematical model for the grain flow. This model will be applied to optimize the dryer apparatus, the discharge system as well as shape and adjustment of the air ducts.

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