Investigation of moisture content fluctuation in mixed-flow dryer

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Abstract: In the mixed-flow dryers 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 a series of single grain layers the drying behaviour of which is described by means of a single grain model. Although mixed-flow dryers are widely used it is still necessary to optimize many segment processes. For example there are big differences in vertical grain particle velocity causing differences in residence time. As a result, uneven drying occurs and, hence, under-drying or over-drying of single grain portions. To investigate the influences of the dryer walls and the air ducts on particle velocity distribution experiments were carried out.

This paper presents experimental results for the fluctuation of wheat moisture content at the discharge device of a mixed-flow dryer. This phenomenon is caused by inhomogeneous mass flow during drying. The aim of the investigations was to measure the amplitude of the mass-flow fluctuation under different conditions.

Hereby this work also submits the results of grain-flow computer simulated modelling experiments. In a future work for grain mass flow a mathematical model will be developed enabling improvements in the prediction of the drying process.

Key words: Grain drying, wheat, mass-flow fluctuation, modelling.

INTRODUCTION

This paper is provided to present measured and simulated results of mass-flow in mixed-flow dryers by investigation of few industrial mixed flow dryers. One of the most popular possibilities in Europe for seed drying is the use of a mixed flow dryer. 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 in 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 a series of single grain layers the drying behaviour of which is described by means of a single grain model (Farkas & Rendik, 1996).

The aim of the investigations was to study how the mass-flow develops during the drying while the corn moves through the mixed-flow dryer. The influence of different forms of air ducts on the grain and air flows through a mixed-flow dryer have already been studied by Klinger, 1977. The dryer was modelled as a series of co-current and counter-current elements. The same modelling concept was successfully employed to predict the general behaviour 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 development of an automatic dryer controller (McFarlane & 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. (1998 a, 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 & Rovedo (2001), Jia et al. (2002), Sitompul et al. (2003), and Wu et al. (2004).

The present publication deals with investigations of mass flow measurements in a mixed-flow grain dryer. This time wheat was used as test material. Additionally, PFC 2 Dimensional modelling was carried out and compared with the measurements. This work submits the results of the grain flow experiments which were carried out in industrial and model mixed-flow dryers.

MATERIALS AND METHODS

The mass flow investigations were accomplished with both a shorter (300ms) and a longer (1,000ms) discharge time to compare the different grain quantities delivered. Also experiments with coloured particles and coloured wheat layers were accomplished (see in Fig. 1) in the model dryer. The courses of the coloured particles were recorded and analyzed by video software. Combined with the time capture a detailed observation of the grain flow processes is possible in the same videos. Also based on the measurement 2D simulation were carried out to compare the results. For the simulation the same physical parameters of the particles and dimensions of the dryer were used as those appearing during the experiments by the pilot dryer.

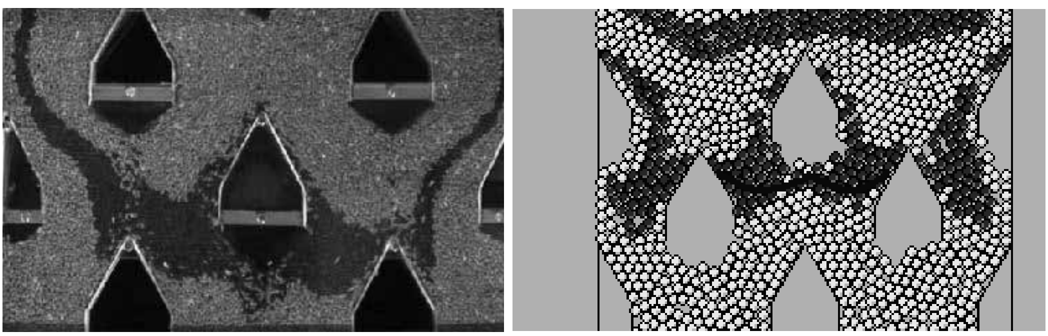


Figure 1. Coloured grain layer in the test dryer during discharge and 2D simulation.

In Fig. 1 it can be well recognized that 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 in the dryer for different time periods and will have uneven moisture distribution as a final result. This big difference in the grain flow must be reduced by certain methods.

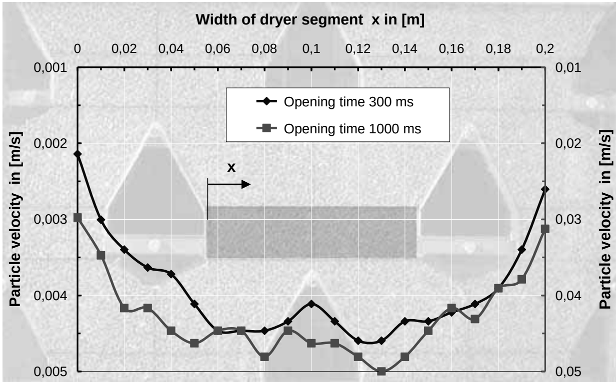
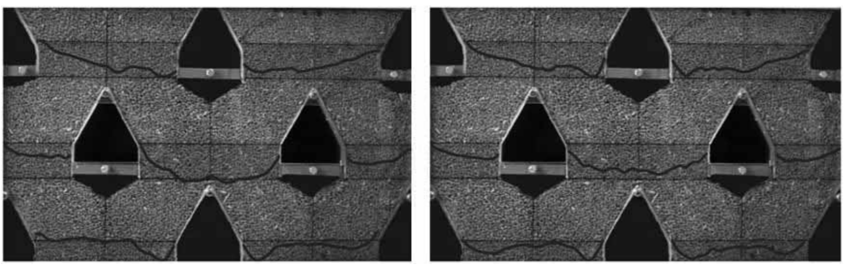


Figure 2. Vertical particle velocities measured at the front wall between two air ducts at 300ms and 1,000ms opening time.

In Fig. 2 the measured range in the central section of the dryer is represented graphically. The diagram is individual with two y axes (grain velocities in m s^{-1}), for each attempt. Only by doing such a diagram lap the grain flow is comparable at two flow velocities. It can be very well seen that at a larger flow rate velocity differences are smaller than at a smaller flow rate. This phenomenon is caused by the fact that the grain has a higher impulse at larger flow rates and the wall friction effect is smaller. The other measured ranges can be seen in Fig. 3. The average grain velocities determined for the experiments at 300ms and 1,000ms overlapped.



a) b)

Figure 3. Qualitative particle velocity distribution over the vertical cross-section in the bottom part of the dryer: a) at 300ms opening time; b) at 1,000ms opening time.

In Fig. 3 the wall friction influence is very well recognizable. Grain dipping develops strongly over the roof points, breaking the grain flow in this area. Diagonal roof walls affect a smaller upsetting. There is also grain dipping with vertical roof a wall by which thinning is caused at 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 braked. The grain seeds trickling through under each half roof are braked 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 the centre. 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 26cm 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, such as the following roof points or roof walls. This area directly over the discharge works like a balancing memory, before the grain leaves the dryer. At different delivering velocities no salient differences can be observed in the grain flow relationship. Bulk property mixing is hardly affected by the delivering velocities. Bulk material transportation experiments have shown a large effect of the wall friction. Based on results of the pilot dryer experiments and the developed 2D model, industrial dryer evaluation investigations were carried out.

RESULTS AND DISCUSSION

The regulation of the delivering uniformity was measured at 300ms and 1,000ms opening times at the pilot dryer the values of which were used during the real drying measurements. For the separation of the discharged mass 40 pcs aluminium profile cells were used as a grid (with dimensions of L 80mm; W 80mm; H 200mm) with sharp edges to reduce the inaccuracy of the mass-flow distribution measurements under the discharge positions. The designed measuring grid was placed very close to the discharge device to measure the most accurate mass-flow distribution as possible. After each discharge thermo images were taken of the temperature distribution in the dried grain (see Fig. 4). As the pilot dryer had no cooling zone these thermo pictures could show immediately after the discharge the temperature distribution and the expected moisture content distribution. After the discharge the property of the mass of each individual cell was individually determined with a digital scale (measuring error 0,005kg) and the moisture content of the samples was also measured and later the results were compared with the temperature distribution too.

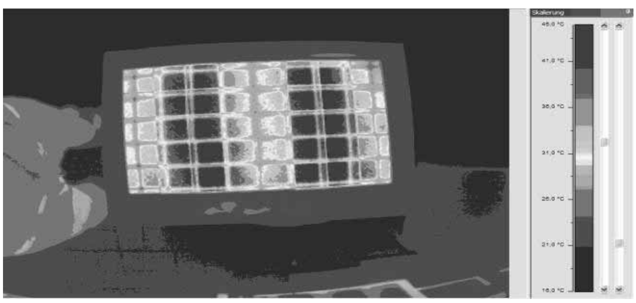


Figure 4. Thermo picture of discharged grain in the measuring cells.

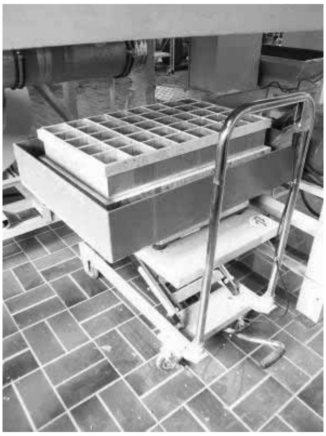


Figure 5. Set-up for measuring mass flow distribution at discharge by pilot dryer.

Figure 6. Sampling from industrial dryer.

During the measurement of the industrial dryer discharging was continuous. The samples were taken from the last air ducts after the cooling zone (Fig. 6). From each air duct 1kg of samples were taken out from the front wall of the dryer. After the sampling the temperature and moisture content of the samples was measured immediately.

EVALUATION OF MASS-FLOW MEASUREMENTS

From the average values of 5 measurements the following diagrams (Fig. 7) were depicted which show the moisture content fluctuation caused by the mass-flow distributions very well after discharging.

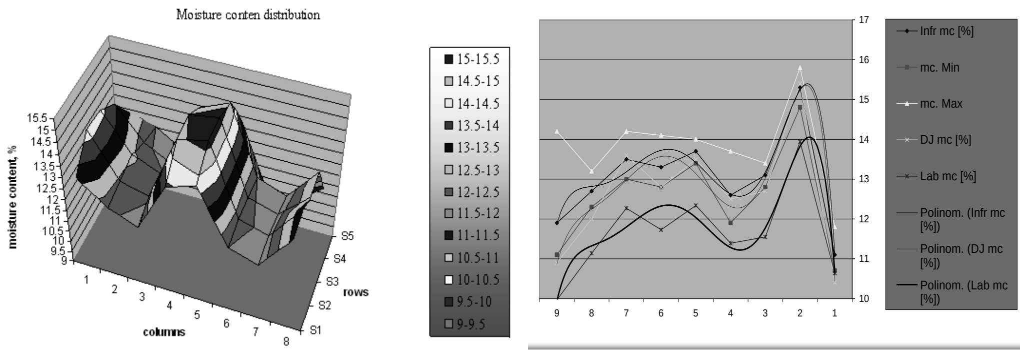


Figure 7. Distribution of grain moisture content in the pilot and in the industrial dryer.

In the diagrams of the measured results it can be seen very well how the plug-flow develops in the dryer during different discharge opening times. Because of this effect the mass-flow is not homogeneous which causes also uneven drying. This effect can also be seen in the diagram of the industrial dryer measurement where uneven charge of the dryer increases inhomogeneous drying.

After analyzing the results of the mass-flow distribution measurement and the thermo pictures the results of the analysis showed an unexpected effect. In view of the previous results of the mass-flow distribution measurements, a similar temperature distribution was expected to the mass-flow distribution. But the results of the mass-flow distribution measurement showed very big differences compared to each other, which means that the temperature distribution just partly depends on the mass-flow distribution.

CONCLUSIONS

The measurements were carried out at the pilot dryer and by one industrial dryer using cereal as test material. In the pilot dryer the 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 the wall friction effect both of the sidewalls and the air ducts. For this purpose single coloured particles as well as coloured particle layers were inserted at top of the dryer and followed through the dryer shaft. In addition mass flow distribution at the dryer discharge was measured. By the industrial dryer the sampling just from the front wall of the dryer was possible, but here significant differences could be recognized when the wheat was measured by the pilot dryer.

Grain mass flow experiments demonstrated that there is a significant effect of the sidewalls on the grain flow causing segregation. As a result, big differences in the residence time of single grain portions cause uneven drying in the mixed-flow dryer. Because of this uneven drying the dried grain will be over or under dried which means that the recent drying process works with relatively high losses and neither is the energy consumption effective. In view of these results of mass-flow and temperature distribution of the pilot dryer the measurements will be extended to measure moisture content distribution of the discharged grain as well. The goals are to discharge homogeneous moisture content and to grant that mass-flow becomes homogeneous during the drying process and at the discharge device too.

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 objective of future work is therefore to continue the 2D modelling and continue the modelling in 3D also to predict the moisture distribution in any industrial dryer. 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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